Optically controlled reconfigurable band-notched UWB antenna for cognitive radio systems

Shou Hui Zheng, Xiongying Liu and Manos M. Tentzeris

A compact optically controlled ultra-wideband (UWB) antenna with reconfigurable band-notched characteristics is investigated for cognitive radio (CR) applications. The rejection mechanism is realised by etching one symmetric folded slot on the U-shaped radiation patch and the essence of the reconfigurable function is achieved by laser controlling photoconductive switches to change the effective length of the folded slot. A prototype with an overall size of $25 \times 25 \times 0.8$ mm^3 is designed and constructed. On the basis of simulated and measured results, the proposed antenna exhibits good radiation behaviour and operates in a wide band with the performance of switchable band rejection of the wireless local area network (WLAN) 2.4 GHz (2.2–2.9 GHz), worldwide interoperability for microwave access (WiMAX) (3.2–4.7 GHz), WLAN 5 GHz (4.8–6.6 GHz) and the ITU 8 GHz (7.5–8.7 GHz).

Introduction: Cognitive radio (CR) was proposed to improve the management and utilisation of the increasingly scarce and crowed radio spectrum. In a CR system, generally an ultra-wideband (UWB) antenna senses spectrum and several narrowband antennas are severed as 'communication' to operate at the selected idle bands without effect on the already licensed wireless systems [1]. On the other hand, a wideband antenna with the ability to leave some notch frequencies based on the surrounding dynamic wireless environment is necessary to avoid interference with authorised narrowband wireless communications. The UWB antennas have been widely used, having the advantages of good omnidirectional radiation, broadband and easy fabrication. Although there still exist several wireless communication systems over the designated wide band, e.g. wireless local area network (WLAN) operating at 2.4–2.483, 5.15–5.35 and 5.725–5.825 GHz, worldwide interoperability for microwave access (WiMAX) (3.3–3.6 GHz), C-band satellite communication systems (3.7–4.2 GHz) and the ITU service (8.025–8.4 GHz). To be coexistent with these conventional wireless systems, the UWB antennas with the rejection of one band, multiband and even reconfigurable bands have been presented [2–6]. In [5], *pin* diodes with a biasing voltage were embedded in the ∏-shaped slot to achieve the reconfigurable band-notched function. However, additional electrical biasing lines may have an effect on the radiation of the antenna. In [6], a stepped motor was used for controlling the different rejecting elements of the antenna to obtain reconfigurable characteristics. Owing to the mechanical devices, the dimension will be increased.

In this Letter, we report the design of a compact optically controlled reconfigurable band-notched UWB antenna. The proposed antenna consists of a U-shaped resonator operating at a wide band (2.1–11 GHz). By inserting a folded slot on the U-shaped patch, a notched band of 2.2–2.9 GHz is obtained for the shielding of WLAN 2.4 GHz. With the advantage of being electromagnetically transparent, hence, a significantly reduced electromagnetic impact on antenna radiation, five laser-controlled photoconductive silicon chips are symmetrically placed in the folded slot. Combining different switch states, the effective lengths of the slot are changed and reconfigurable band-notched characteristics for the protection at WiMAX, WLAN 5 GHz and ITU 8 GHz are subsequently achieved. Moreover, to authors' knowledge, so far the optically controlled technology has not been utilised for the design of reconfigurable band-notched antennas.

Antenna configuration and design: The geometry of the proposed antenna and photographs of the fabricated prototype and backside laser-feeding are shown in Figs. 1*a*–*c*, respectively. The antenna is printed on an FR4 substrate with a relative permittivity of $\varepsilon_r = 4.4$, a loss tangent of $\tan\delta = 0.02$, a thickness of $h = 0.8$ mm and dimensions of 25×25 mm^2. A coplanar waveguide fed U-shaped monopole patch with a tapered ground is chosen as the basic structure of the antenna. A folded slot is cut along the edge of the UWB monopole antenna, which behaves as a half-wavelength resonant unit and disturbs the UWB resonant response to achieve the band-rejection function [7]. For the convenience of fabrication and setup, a piece of photoconductive silicon was cut into five $1 \times 1 \times 0.4$ mm^3 chips, working as switches (i.e. SW1–SW5). They were placed in the slot symmetrically, shown with dark blocks in Fig. 1*a*. When the laser illuminates one of the switches, it turns 'ON' and behaves as a short-circuiting conductor. Otherwise, it will be 'OFF' and act as an insulator, i.e. open circuit. The arrangement of different switch states (namely 'ON' or 'OFF') will make the UWB antenna reconfigurability with the corresponding notched bands. When only SW5 is 'ON' (case 1) and others are 'OFF', the antenna acts as an UWB monopole. Although all switches are 'OFF' (case 2), the notched band performance is at WLAN 2.4 GHz. If SW1 and SW2 are 'ON' (case 3), the notched frequency shifts to the WiMAX band. When SW1 and SW4 are 'ON' (case 4), the band of WLAN 5 GHz is rejected. In case 5, SW3 and SW4 are 'ON', thus the rejection band of ITU 8 GHz is achieved. With the aid of ANSYS high-frequency structure simulator v.13, the following optimised values of the geometrical parameters are selected: $W = 25$, $W1 = 1.5$, $W2 = 11.5$, $W3 = 4.05$, $W4 = 20$, $L = 25$, $Lg = 6$, $L1 = 2$, $L2 = 7$, $L3 = 5$, $L4 = 17$, $S1 = 3.8$, $S2 = 6.3$, $S3 = 5.4$, $S4 = 3$, $S5 = 7$, $g = 1$ and $g1 = 0.25$, where all units are in millimetres.

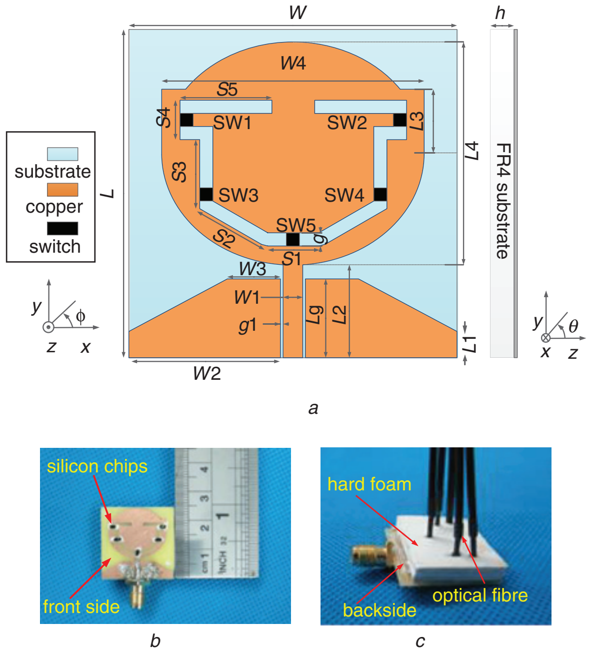

Fig. 1 *Geometry of proposed reconfigurable band-notched UWB antenna*

a Antenna configuration, top view (left) and side view (right)
b Photo of fabricated prototype
c Photo of backside optical feeding

Photoconductive silicon switches: According to the theory of internal photoelectric effects in semiconductors, when the energy of the incident photon exceeds the bandgap energy, the irradiated electrons in the silicon will jump from the valence band to the conduction band, thereby making the silicon behave as a conductor. In this experimental measurement, an *n*-type silicon with high resistivity ($\rho = 2.5 \times 10^3$ Ω·cm) was implemented as the switching element. An 808 nm wavelength laser with an optical splitter, which can equally divide one light beam into four, was used to excite the *n*-type silicon chips. Aligning with the positions of the silicon chips, five holes were drilled on the backside of the FR4 substrate. To reduce optical loss in the air, as shown in Fig. 1*c*, light guided in the optical fibre was fed to the photoconductive silicon switches via the above-mentioned holes. To fix the optical splitter, a piece of hard foam with five holes was attached on the back of the substrate.

Experimental results and discussion: Fig. 2 shows the measured and simulated voltage standing wave ratios (VSWRs) for all cases. The VSWR was measured with an Agilent N5230A vector network analyser. It can be observed that the designed antenna has the ability to reconfigure frequencies, including UWB and four notched bands. The broadband antenna in case 1, covering the entire UWB band of 2.1–11 GHz with a VSWR < 2 (return loss > 10 dB), can be obtained to sense the spectrum. The reconfigurable notched bands from case 2 to case 5 are WLAN 2.4 GHz (2.2–2.9 GHz), WiMAX (3.2–4.7 GHz), WLAN 5 GHz (4.8–6.6 GHz) and ITU 8 GHz (7.5–8.7 GHz), respectively. When the UWB antenna detects one of the mentioned wireless communications working, the corresponding band will be rejected, thereby eliminating conflict with the existing wireless communication systems. The radiation patterns of the proposed antenna in the five reconfigurable cases are depicted in Figs. 3 and 4. They are taken at 5 GHz (case 1–case 3) and 7 GHz (case 4 and case 5). It is observed that the radiation patterns, similar to those of the monopole UWB antenna, are close to omnidirectional in the *XOZ*-plane and approximate '8' shape in the *YOZ*-plane.

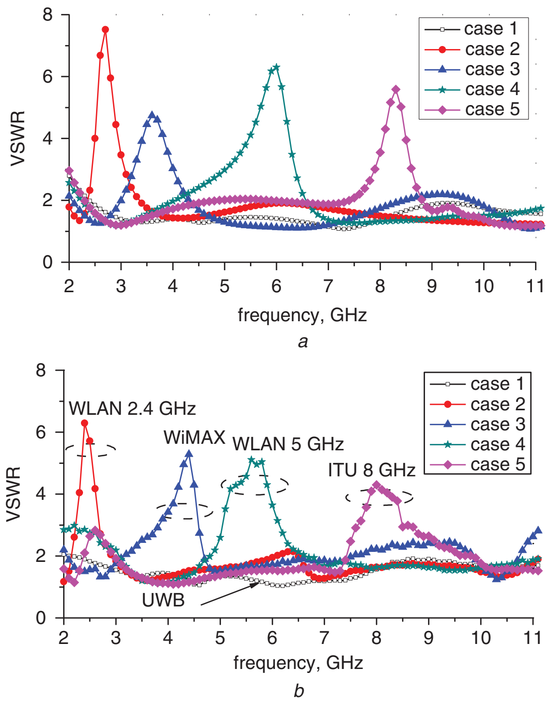

Fig. 2 *Simulated and measured VSWRs for different cases*

a Simulated results
b Measured results

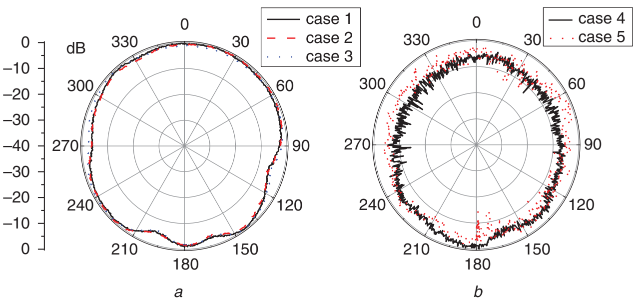

Fig. 3 *Measured XOZ-plane radiation patterns*

a At 5 GHz
b At 7 GHz

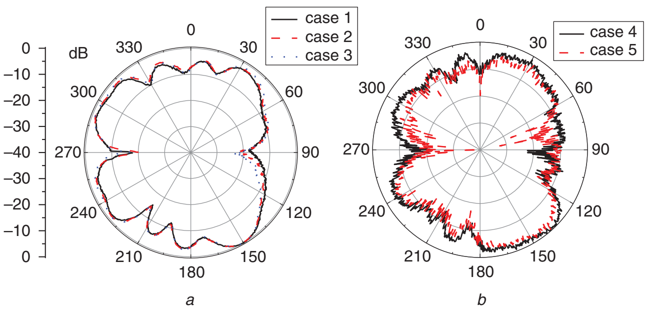

Fig. 4 *Measured YOZ-plane radiation patterns*

a At 5 GHz
b At 7 GHz

Conclusion: A new optically controlled reconfigurable band-notched UWB antenna topology for CR systems has been presented. The rejection characteristics are achieved by inserting a folded slot on the U-shaped UWB antenna with different setup positions and the 'ON' or 'OFF' combination of photoconductive switches. The proposed antenna can operate at a wide band and four wide bands with the reconfigurable band-notched function, shielding the conventional wireless communication systems, such as WLAN 2.4 GHz (2.2–2.9 GHz), WiMAX (3.2–4.7 GHz), WLAN 5 GHz (4.8–6.6 GHz) and ITU 8 GHz (7.5–8.7 GHz). The proposed antenna was simulated, fabricated and measured. Results show its potential for CR communication systems.

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One or more of the Figures in this Letter are available in colour online.

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