A Novel Switchable Double Band-Notch Antenna for Ultra-Wideband Application

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Abstract **─** A novel microstrip-fed planar monopole antenna is proposed that is miniaturised in size and provides reconfigurable band-notch properties. The antenna's impedance bandwidth is 150% for VSWR < 2 across 2.6-18.3 GHz, thus satisfying FCC's frequency requirement for UWB systems defined between 3.1-10.6 GHz. To circumvent interference issues resulting from existing nearby communication systems within the UWB operating frequency, the antenna includes an inverted open-loop triangular slot embedded in the hexagonal shaped radiation patch to realize a band-notch response between 3.1 to 3.9 GHz necessary to reject the WiMax band, and open-end resonator structures at both sides of the patch to create a band-notch response between 5.1 to 5.9 GHz, thus enabling band rejection of WLAN and Hyperlink systems. Furthermore, it is demonstrated the band-notch can be electronically controlled without compromising the antenna's characteristic features. This is achieved by strategically located PIN diodes on the antenna.

Index Terms **─** Microstrip-fed monopole antenna, switchable band notch antenna, Ultra-Wideband (UWB) antenna.

I. INTRODUCTION

Ultra-wideband is a radio technology that can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of radio spectrum. This technology has been widely used in non-cooperative radar imaging, target sensor data collections, and other military communications during the past two decades [1]. Regulatory setting of Federal Communications Commission (FCC) approved the frequency range of 3.1~10.6 GHz for commercial use of UWB systems in 2002. With regards to advantages of UWB antennas, such as high data transmission rate (100 M to 1 G/bps) over short distances, small size, [2] low power consumption (~200 μW), omni-directional pattern, low group delay, constant gain, and linear phase response, there is no surprise that the design of these antennas have drawn researchers' attention in recent years.

A suitable UWB antenna should be capable of operating over the allocated range of frequency, moreover satisfactory radiation properties over the entire frequency range are also necessary [3].

The existing narrow band wireless systems, such as Wireless Local Area Network (WLAN) and Hyperlink using IEEE 802/11a protocol, which are operating over 5.15-5.35 GHz (Band A) for indoor mobile and 5.47-5.725 GHz (Band B) for indoor and outdoor WLAN networks. The higher band 5.725-5.825 GHz (Band C), is a licensed band to be used for the installation of Fixed Wireless Access (FWA) services between stationary points [4,5]. In addition, Worldwide Interoperability for Microwave Access (WiMax) using the frequency band of 3.15-3.85 GHz, can cause the performance degradation of UWB systems due to the absence of band pass filters [6,7]. To overcome electromagnetic interference between UWB and other narrow band systems, various UWB antennas have been designed by different researchers to omit the undesirable bandwidth to avoid any kind of interference [9].

In this way, etching different kinds of slots on the patch or ground of antenna, such as U-shaped [8] or V-shaped slots is most commonly used [10]. Also, other techniques such as adding a parasitic

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element [12,13], using folded strips, etching Split Ring Resonator (SRR) [14], and embedding resonator cells feeding line of antennas [15,16] can effectively filter the undesired bands.

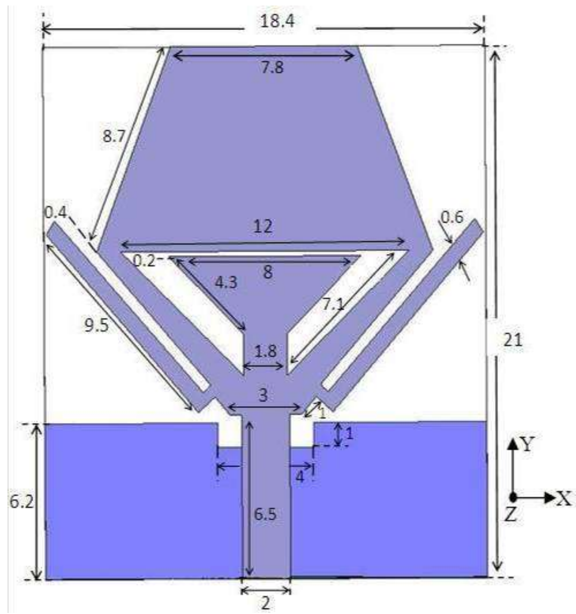
The technique proposed in this paper elicits the inherent advantages of planar antennas for operation across the entire UWB spectrum. This is achieved by embedding an inverted open-loop triangular slot on the patch and incorporating open-end resonator structures on both sides of the patch. The proposed antenna has an impedance bandwidth of 15.7 GHz between 2.6 GHz to 18.3 GHz for VSWR < 2, and it radiates omni-directionally in both the E- and H-planes. Moreover, by mounting PIN diodes across the slot and between the open-end resonator structure and the patch, the notch bands can be electronically controlled.

II. ANTENNA DESIGNATION

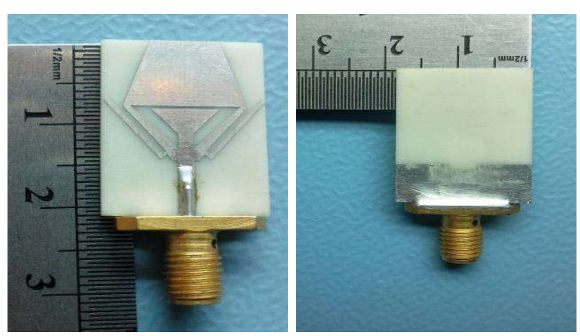
Figure 1 (a) shows the physical geometry of the proposed antenna that comprises of a hexagonal shaped radiator with a 50 Ω microstrip feed-line, an inverse triangular shaped slot with a narrow horizontal section, and open-end resonator arms connected to the patch. The antenna was designed to operate at a frequency range between 2.7 to 18 GHz, with two notched bands that are determined by the slot and resonator structures. The microstrip monopole antenna was simulated and its performance optimized using HFSS.

The antenna's optimized parameters and photograph are shown in Fig. 1. The microstrip feed-line is 2 mm corresponding to a characteristic impedance of 50 Ω. The antenna was fabricated on Rogers 4003 substrate with thickness of 1.6 mm, relative dielectric permittivity ε_r=3.55, and dielectric loss $\tan\delta$ =0.0027. The proposed antenna is relatively small with dimensions 18.4×21 mm^2.

It is well known that microstrip patch antenna structures designed to operate at a given resonant frequency possess a limited bandwidth. This limitation can be compensated by introducing additional radiating patches located close to the main radiator. In the proposed antenna, the open-end resonant structures are electromagnetically coupled to the radiating patch in such a way as to perturb the antenna to extend its bandwidth response. Furthermore, the open-end resonator structures provide the desired rejection notch band. The gap between the plate and the open-end resonator arms was set to 0.4 mm to enhance its electromagnetic coupling with the radiating patch and to broaden the antenna's impedance bandwidth. To comprehend the phenomenon behind this dual band-notch performance and UWB frequencies, Fig. 2 (a,b,c) shows the simulated current radiation at 3.5 GHz for WiMax band that is first frequency band notch, and 5.5 GHz for WLAN band at the middle of the second stop band, and 8 GHz for operating in UWB systems.

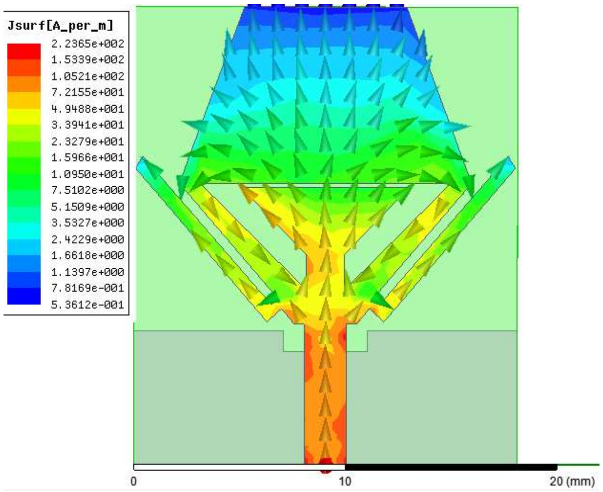


(a)

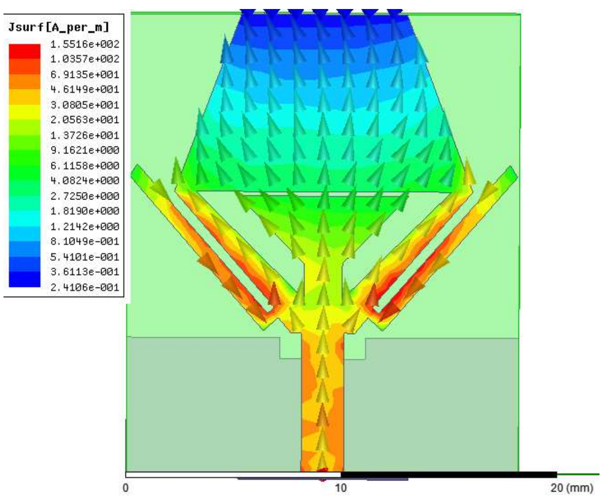


(b) (c)

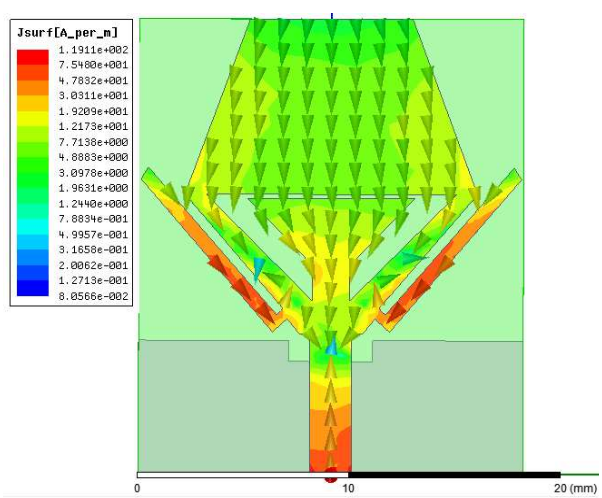
Fig. 1. (a) Geometry of proposed antenna, (b) top view of the proposed UWB antenna, and (c) bottom view of the antenna with ground plane.



(a) 3.5 GHz



(b) 5.5 GHz



(c) 8 GHz

Fig. 2. Simulated surface current on the radiation patch: (a) 3.5 GHz, (b) 5.5 GHz, and (c) 8 GHz.

The regions of greatest current intensity are over the open-loop resonator structures and the adjacent region on the patch. It can be observed from Fig. 2 (b), that the direction current in the resonator and the adjacent patch are oppositely directed, therefore, we can eliminate the WiMax band. It is also discernable, the intensity is greatest in the lower part of the feed-line too. Moreover, the region around the middle section of the slot has least current intensity.

III. SIMULATION AND MEASUREMENT RESULTS

A. Stop bands design

In the previous section, the proposed antenna with optimal geometrical parameters was analyzed. The fabricated antenna's performance was measured using Agilent's Network Analyzer E8361c. The VSWR response of the microstrip monopole antenna under three scenarios now described, is depicted in Fig. 3. The first stop-band with central frequency of 3.5 GHz is located at the WiMax band, and is achieved by inserting an inverted open-loop triangular slot in the middle of the hexagonal shaped radiating patch. The second stop-band with central frequency of 5.5 GHz is located at the WLAN band, and is created by adding open-end resonator arms on both sides of the patch.

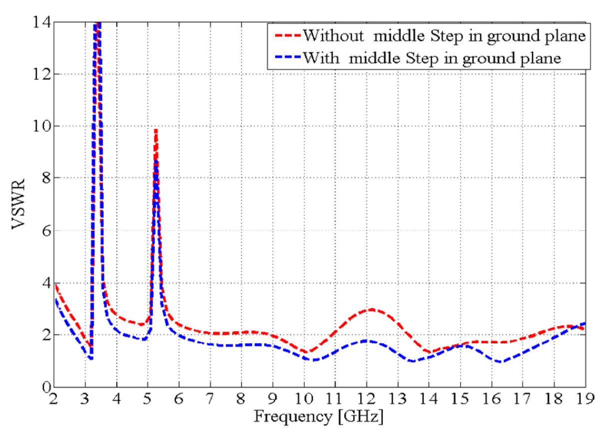


Fig. 3. Simulated VSWR for the antenna with and without middle step in ground-plane.

The antenna's mismatch improves between 11-13.4 GHz by creating a step in the ground-plane around the feed-line near the patch, and hence, its impedance bandwidth improves significantly as shown in Fig. 3. This is because, by cutting a notch in the ground-plane provides an additional current path, which changes the inductance and the capacitance property of the feed-line at that point. The overall bandwidth improves from 2.9-11.0 GHz to 2.6-18.2 GHz. It should be noted that the effect of mutual coupling between the first and second notched bands of the antenna does not adversely affect the overall response of the antenna. As the antenna configuration is symmetrical with respect to x-axes, this improves its co-polarized patterns and suppresses its cross-polarized radiation.

The simulated and measured VSWR of the proposed antenna is shown in Fig. 4. The measured bandwidth of fabricated antenna is between 2.8 and 17.7 GHz for VSWR<2. The first rejection frequency band is from 3.3 to 4.2 GHz, and the second band notched characteristics is exhibited between 5.2 to 6 GHz. The correlation between the simulation and the experimental results is excellent; it is result of faithful designation of monopole antenna, precise assembly of the antenna with low loss connectors, and accuracy calibration band with return loss better than 50 dB from 1 to 20 GHz with network analyzer.

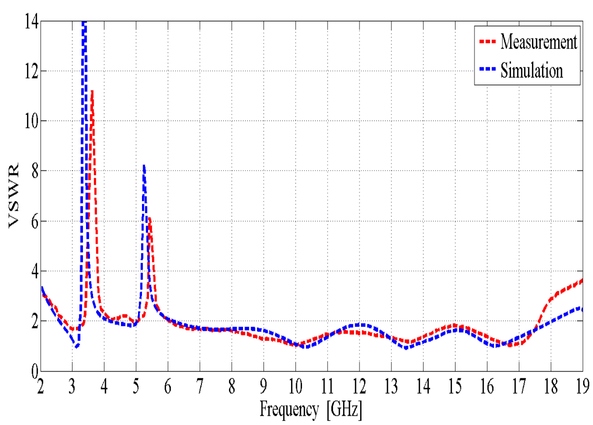


Fig. 4. Simulated and measured VSWR of the proposed antenna.

If we consider the simulation and the measurement graphs in Fig. 4, it can be found a shift in the peaks in both the stop bands that refer to the 5% tolerance in relative permittivity ε_r and substrate thickness that here is 1.6 mm. As we know, the effective relative permittivity of a patch antenna is defined as:

$$\varepsilon_r^{eff} = (\frac{\varepsilon_r + 1}{2}) + (\frac{\varepsilon_r - 1}{2})[1 + 12(\frac{h}{w})]^{-1/2} .$$

In addition, the guided wavelength is defined as:

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_r^{eff}}} .$$

So if we assume the effective relative permittivity is increased with the tolerance in the fabrication process as mentioned above, therefore, the guided wavelength becomes lower than expected value and causes a frequency shift in both notch bands.

B. Switching modes by PIN diode

To realize an UWB antenna with reconfigurable band-notch characteristics, PIN diodes were employed [11]. The PIN diodes were located across the horizontal thin section of the triangular slot in the patch, and between the open-end resonator arms and the main patch, as shown in Fig. 5.

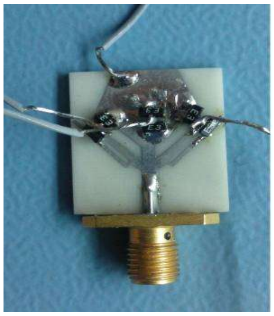
The PIN diodes were strategically located in the antenna's structure based on the surface current distribution in Fig. 2. To enable the notched bands to be electronically selected by simply switching the diodes either 'on' or 'off' without compromising the antenna's overall performance.

The current distribution on the middle of the triangular slot and the end of the resonator stubs that connected to the patch by PIN diodes, has the minimum dense and the potential deference that can be changed on the current direction on the radiating elements. The selectivity function enhances the functionality of the UWB antenna.

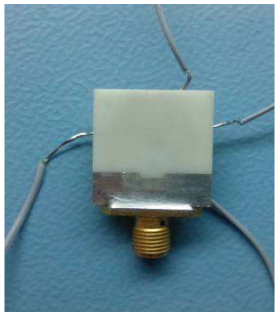
In Fig. 5 (c), the PIN diode labelled (a) can switch either 'on' or 'off' the first notch band of the antenna centered at the frequency of the WiMax system. PIN diodes labelled (b) and (c) can activate or deactivate the antenna's second stop band in order to mitigate interference from WLAN devices.

The type of PIN diodes used in the proposed antenna is HSMP-3820 that has an equivalent circuit given in Fig. 5 (d). To take the ideal behaviour of the diode into account in the simulation, the PIN-diode was modelled as a lumped element capacitor in open state and as a lumped element resistor in shorted state.

The three pairs of identical PIN diodes mounted on the proposed UWB dual band-notched planar monopole antenna were modelled in accordance to its characterizing parameters; namely, resistance of 2.5 Ω in the ‘on’ state and capacitance of 0.8 pF in the ‘off’ state. The PIN diodes were activated by applying a bias voltage of 5V.



(a)



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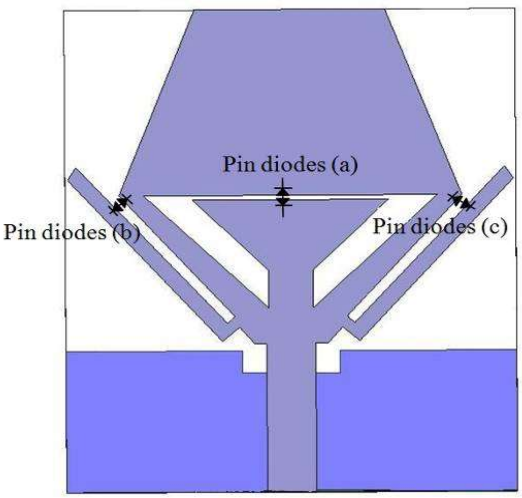
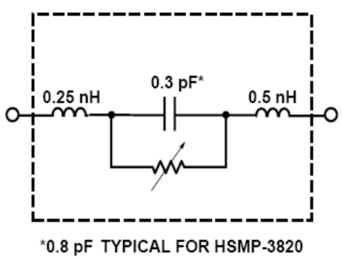


(c)



(d)

Fig. 5. (a) Photograph of antenna with PIN switching diodes, (b) back plane of the antenna, (c) location of the PIN diodes in the patch antenna, and (d) equivalent circuit of PIN diode (HSMP 3820).

Figure 6 shows the simulation result of antenna’s VSWR for various PIN diode bias conditions. The biasing wires do not simulate in HFSS software, but the resistance and the capacitance property of the PIN diodes assumed when they are in OFF or ON state. When all the PIN diodes are in the ON state, the antenna operates like a UWB monopole antenna without any notch bands. When the PIN diodes labelled (a) are in the OFF state and PIN diodes labelled (b, c) are in the ON state, only the WiMax notch is activated in overall band. When the PIN diodes labelled (a) are in the ON state and PIN diodes labelled (b, c) are in the OFF state, the WLAN notch is activated. When all PIN diodes are in the ON state, the antenna acts as a normal UWB antenna. Figure 7 shows the simulated and measured VSWR of antenna when all PIN diodes are in the ON state.

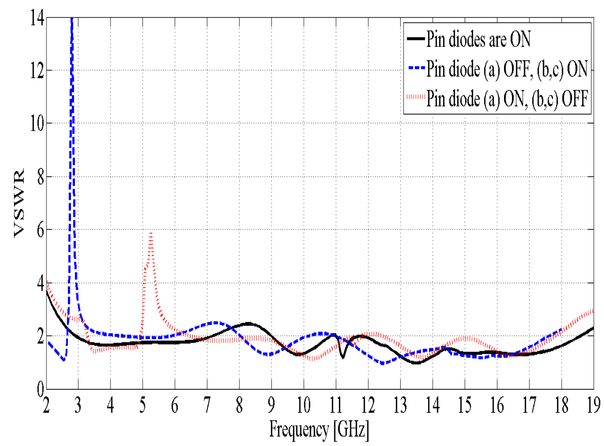


Fig. 6. Simulated VSWR for the antenna with and without band-notched function.

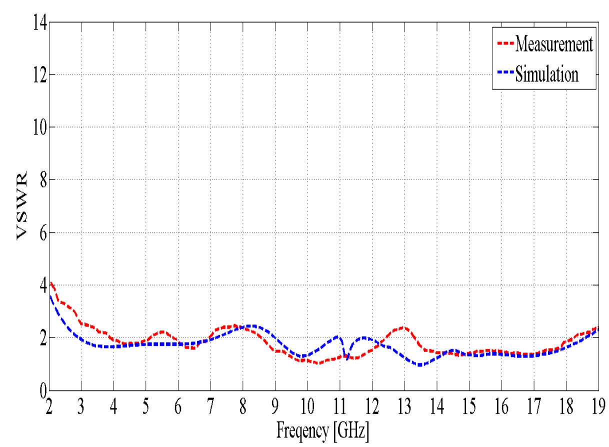


Fig. 7. Simulated and measured VSWR of the proposed antenna without band-notched function.

Figure 8 shows the variation of gain in dBi of the UWB antenna as a function of frequency under two conditions: i.e., with and without band-notch functionality. It is clear that there is sharp dip in the gain at around 3.5 GHz and 5.3 GHz, which confirms the effective operation of the dual band-notch UWB antenna. The gain generally increases with increasing frequency. The normalized radiation pattern of proposed antenna at various spot frequencies is shown in Fig. 9. The antenna's patterns are obtained when all of the PIN diodes are in the OFF state, when the antenna response operates in its dual notch-band mode. Two of the radiation patterns shown are at the center frequency of the notched bands; i.e., 3.5 GHz and 5.5 GHz, which shows suppressed radiation in the desired stop-bands due to the fact that the co- and cross-polarization pattern is near to each other in both E- and H-Plane that disturb the radiation pattern of the antenna, thus mitigating interference with WiMax and WLAN signals. Also shown is radiation pattern at 4.5 GHz, which is between the two-notched bands, where the antenna shows the distinctive difference between co- and cross-polarization levels for both H- and E-plane. At this frequency, the antenna is partially bidirectional in the E-plane and omni-directional in the H-plane. The final radiation pattern at 9 GHz demonstrates good gain performance at high frequency of antenna's operation.

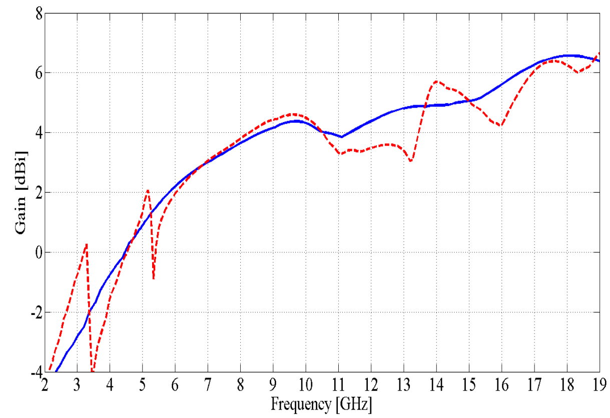
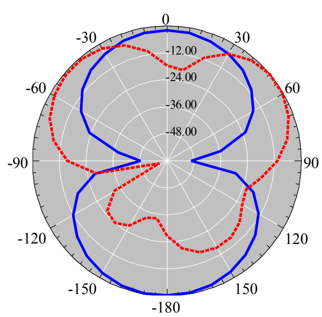
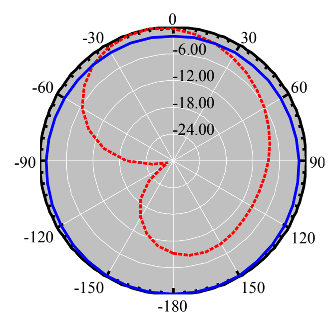


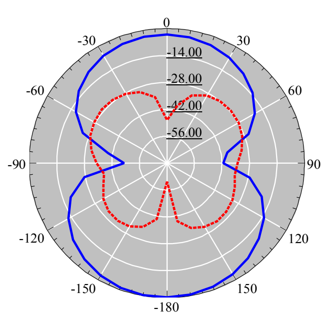
Fig. 8. Simulated Gain for the antenna with and without band-notched.



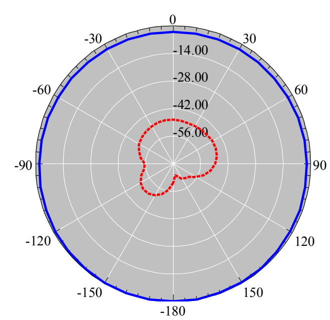
(a) E-Plane



(b) H-Plane



(c) E-Plane



(d) H-Plane

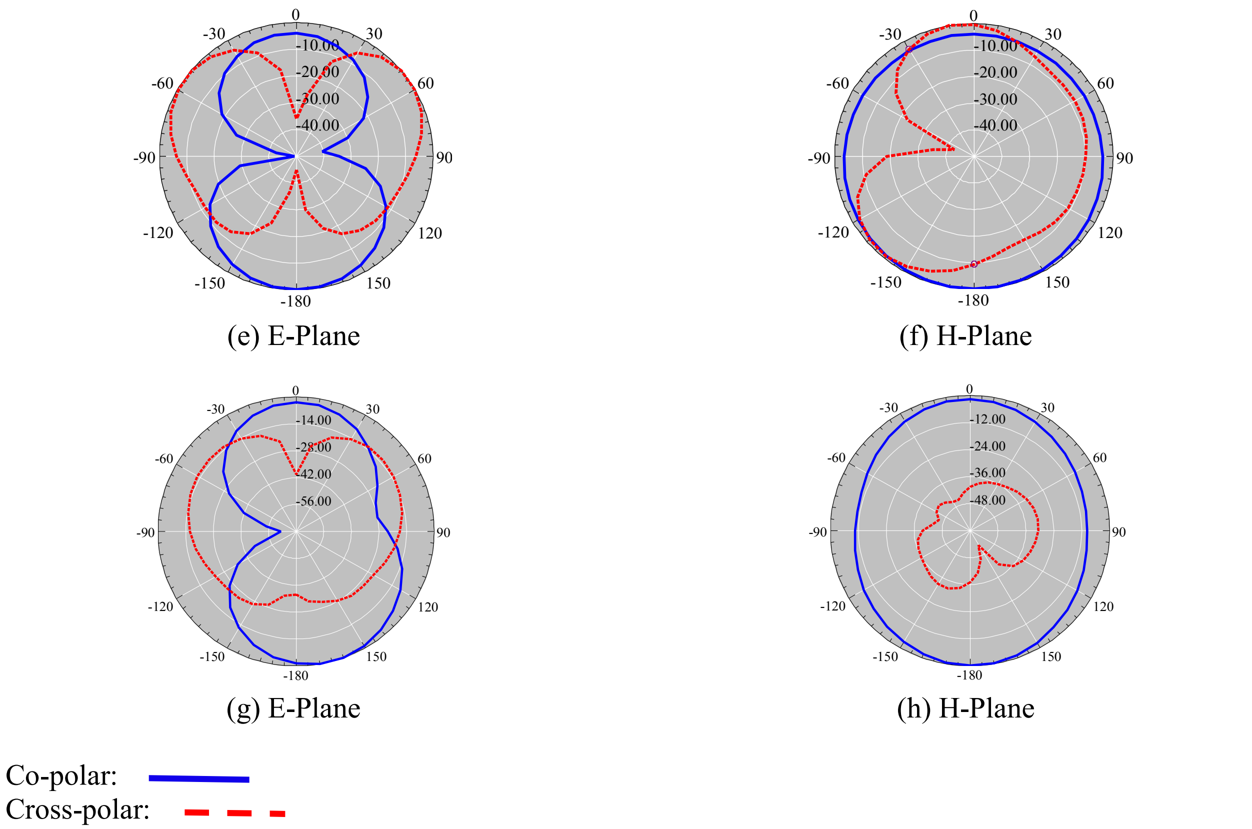


Fig. 9. E-Plane and H-plane of radiation patterns of proposed antenna: (a,b) at 3.5 GHz (central frequency of first notched band), (c,d) at 4.5 GHz (antenna operating frequency between first and second notched band), (e,f) at 5.5 GHz (central frequency of second notched band), and (g,h) at 9 GHz.

IV. CONCLUSION

A compact UWB antenna with band-notch characteristics is presented. The notch bands were obtained by embedding an inverted open-loop triangular shaped slot of varying width in the hexagonal radiating patch, and open-end resonator structures on both side of the patch. The open-end resonator structures also enhance the impedance bandwidth of the antenna. The central frequency of the notch bands were implemented at 3.5 GHz and 5.5 GHz corresponding to WiMax and WLAN bands. PIN diodes mounted across the slot and between the open-end resonator and patch enables reconfigurable functionality. The notch bands can be activated by switching the PIN diodes either 'on' or 'off' to eliminate the interfering effects of WiMax and WLAN signals. This is achieved without compromising the antenna's overall performance. The proposed antenna has a compact size of 18.4×21 mm^2 and provides omni-directional radiation pattern across the entire UWB bandwidth. The excellent features of the proposed antenna make it suitable for application in UWB systems.

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