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COMPACT UWB ANTENNA WITH INVERTED HAT SHAPED RESONATOR AND SHORTENING VIA PINS FOR FILTERING PROPERTIES

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Abstract—A modified ultra-wideband (UWB) printed rectangular antenna fed by a microstrip line is proposed. Overall dimension of the antenna is as compact as $14 \times 14 \times 1\,\mathrm{mm}^3$. The main features of the proposed antenna are its compact size and its filtering characteristic over WLAN band. Through adjusting the dimensions of the elements of the antenna, notch frequency in different ranges of the UWB can be obtained. The resulting VSWR < 1.5 impedance bandwidth is between 3.6–9.6 GHz. Antenna presents a stable gain and omnidirectional radiation pattern in its operational frequencies.

1. INTRODUCTION

Recently, rapid developments in ultra-wideband (UWB) [1], communication systems led to a great demand of UWB antennas, among which coplanar waveguide (CPW) is one of the promising candidates. The great concentration towards the UWB system is caused by its merits such as high data rate, small power emission, high security, low cost for short range access and remote sensing purposes. But there are many narrowband communication systems that coexist with the UWB communication system, which leads to interferes with the functioning of the UWB systems. Most distinguished among them is the Wireless Local Area Network (WLAN), which operates with the center frequency of 2.4 GHz (2400–2484 MHz), 5.2 GHz (5150–5350 MHz) and 5.8 GHz (5725–5825 MHz). To lessen this interference problem, different UWB antennas with band notched properties have been developed [2–16]. The simple and most commonly used approach is to

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integrate diverse shapes and sizes of slots into the radiator. In [3] a U-shaped slot is employed in the bear head shaped patch. A hat shaped slit [4] is carved from the radiator. An upturned C shaped [5] slot is carved from the triangular shaped patch with the beveled ground plane. A curved slot [6] is cut from the circular shaped patch. Within the circular slot a cutting pie [8] with flare angle θ is cut from the circular radiator. However, most of the antennas are designed with only one notched sub band [9], mainly in the 5 GHz frequency band of WLAN. Recently, several antennas with two notched sub bands [10–11] or triple notched sub bands [12, 13] were presented. In [13], the antenna generated three notches, with one notch in the frequency band of 3.3–3.9 GHz for WiMax. However, the remaining two notches together notched only the 5 GHz band of WLAN. Based on the background of the researches above, this paper proposes a simple, compact yet efficient microstrip planar UWB antenna with band-notched characteristics controllable in 3–4.42 GHz (WiMax), 4.8–6 GHz (WLAN). The notched operations are achieved by inserting an up righted hat-shape coupling strip under the radiating patch, and by inserting two shortening via pins for WLAN and WiMax operating frequency band respectively. It is easy to tune the notch center frequency with the change in total length of the up righted hat-shaped resonator. The proposed antenna yields an impedance matching bandwidth of 3.6–9.6 GHz, except the bandwidths of 3–4.42 GHz for WiMax and 4.8–6 GHz for IEEE802.11a and HIPERLAN/2 WLAN systems. Antenna has an omnidirectional radiation pattern and low cross polarization. Gain of the antenna is stable over the whole frequency band which is an advantage for its application.

2. ANTENNA DESIGN

As the UWB frequency band starts from 3.1 GHz, the design was initiated by selecting appropriate values of G, according to this particular frequency. The antenna has the miniaturized dimensions of $14 \times 14 \times 1\,\text{mm}^3$, and fabricated on a cheap FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and loss tangent of $\tan\delta = 0.02$. As shown in the Fig. l, the modified rectangle radiator is fed by $50\,\Omega$ microstrip feed. The radiating patch consists of three rectangular patches which their height is optimized to L_1, L_2, and L_3 to meet the UWB operating frequency band. A small change in these values will degrade the operating bandwidth. The feed line width is optimized to 1.875 mm to meet the $50\,\Omega$ impedance matching. The final parameters are optimized as $G = 14\,\text{mm}$, $L_1 = 4\,\text{mm}$, $L_2 = 2\,\text{mm}$, $L_3 = 4\,\text{mm}$, $L_c = 7\,\text{mm}$, $L_g = 2.5\,\text{mm}$, $W_f = 1.875\,\text{mm}$, $W_c = 6\,\text{mm}$, $W_a = 2.5\,\text{mm}$,

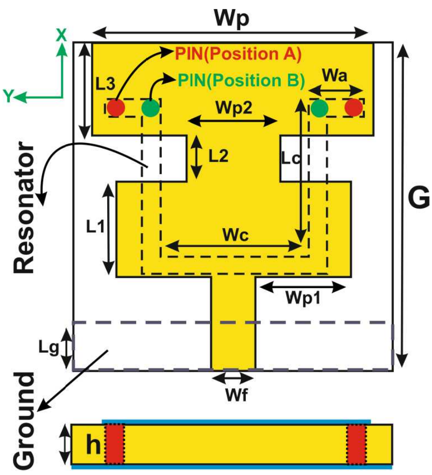

Figure 1. Geometry and details of the proposed antenna (dashes represent the bottom side of the substrate).

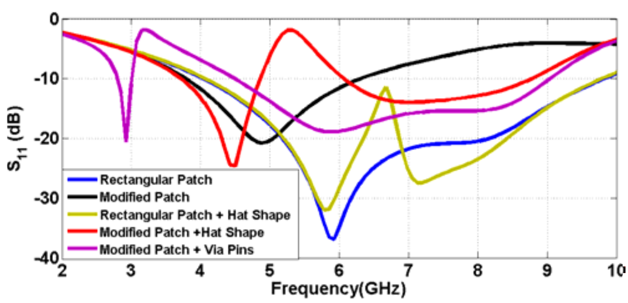

Figure 2. S_{11} variations of various designs.

$W_p = 12\,\text{mm}$, $W_{p1} = 4\,\text{mm}$, $W_{p2} = 4\,\text{mm}$ $h = 1\,\text{mm}$. Design procedure of the antenna is based on the simple rectangular patch. As it can be seen from the Fig. 2 the impedance matching bandwidth of this antenna is between 4–10 GHz. As this papers tries to filter the unwanted WLAN operating band, an up righted hat-shaped resonator with 1 mm width is designed under the rectangular radiating patch. As a fact, the design perception of the band-rejection function is to compose the input impedance singular (minimum resistance) at the sub-resonant frequency. Obvious from the Fig. 2 this design was unable to create the desired stop band.

To overcome this problem, the modified rectangular patch in Fig. 1 (But without pins) is presented. Considering this design the operating bandwidth between the 4.8–6 GHz is filtered. At the notch frequency, the surface currents are concentrated around the hat-shaped resonator, and they are oppositely directed between the resonator and the radiating patch. Hence, the resultant radiation fields cancel out, and high attenuation near the notch frequency is produced.

For detailed study of this design, simulation results for the modified patch without the inverted hat-shaped resonator are also presented. Comparing with the antenna with resonator, it could be seen that the resonator not only creates notch but also improves the impedance matching of the antenna through coupling and increasing the electrical length of the antenna. Besides WLAN systems, WiMax from 3.3–3.6 GHz also operates in the UWB band. To minimize the potential interferences between UWB system and narrowband systems, we did not redesign a new antenna structure, instead modified the current design by adding two shortening via pins from the edge of the up righted hat shaped resonator to the radiating patch (Fig. 1). Performing this modification the frequency band between 3–4.42 GHz is filtered. This is presented in Fig. 2. This modification presents the flexibility of the design.

3. PARAMETRIC STUDY OF THE ANTENNA

3.1. Width of the Up Righted Hat-shaped Coupling Strip

The commercial simulation tool Ansoft HFSS is employed in this paper to perform the design and optimization process. Since the up righted hat-shaped resonator is the main factor in the filtering process, it should be designed in a way that small variations in its width during the fabrication process, does not affect the performance of the antenna. Effect of variations of the width of the antenna on the antenna's return loss is studied. As presented in Fig. 3 antenna has a very small variation over its center frequency of 5.6 GHz as the resonator's width is changed from 0.5 mm to 1.5 mm. This approves the robustness of the design to the fabrication errors.

3.2. Effect of Variation of the Coupling Strip on Notch Frequency

To reduce the interferences from the IEEE802.11a and HIPERLAN/2 WLAN systems, the band-notched function is desirable in the UWB systems. As it can be seen from Fig. 1, antenna creates the 5.6 GHz (4.8–6 GHz) frequency band notch. The notch frequency given the

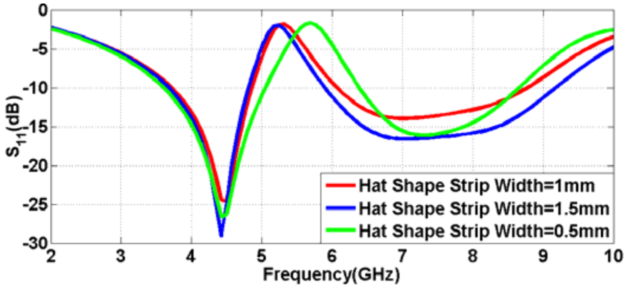

Figure 3. S_{11} variations considering different coupling slot width.

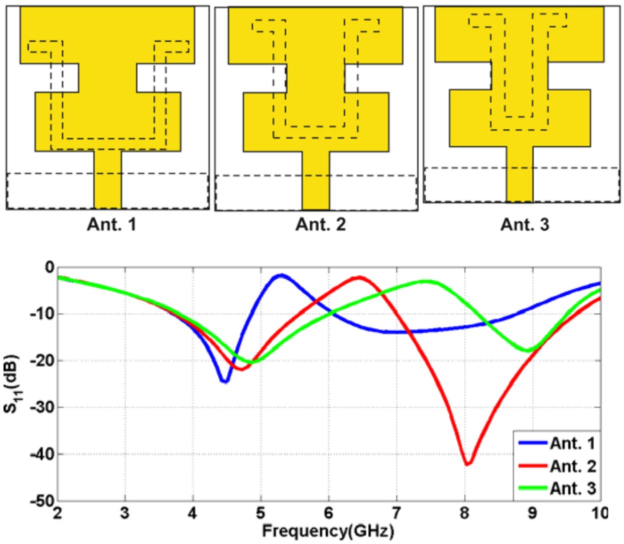

Figure 4. S_{11} of three different iterations of coupled strip length.

dimensions of the band notched feature can be postulated as

$$f_{\text{notch}} = \frac{c}{2L\sqrt{\varepsilon_r}} \tag{1}$$

where c, ε_r, L are the speed of light in free space, the effective dielectric constant and the total length of the resonator, respectively. Through different studies and tests done by the HFSS, and considering (1), the overall length of the up righted hat shaped resonator is optimized as 28 mm (Ant. 1). Different iterations of this length is performed to study the effect of over length of the resonator on the frequency band, and it is observed that by decreasing the overall length of the coupling resonator, bandwidth and notched band shifts to right. It is

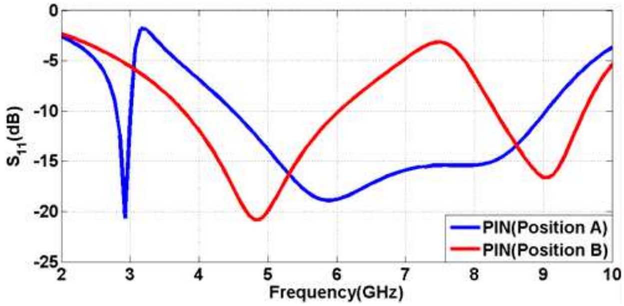

Figure 5. S_{11} of the Ant. 1 with different Pin Locations.

demonstrated in Fig. 4. When the overall length is 21 mm (Ant. 2), antenna experiences a notch band between 5.6–7 GHz and a new resonance emerges in 8 GHz which is also due to the increase in the electrical size of the antenna. This new resonance emerges at 9 GHz when the overall length is 16 mm (Ant. 3).

3.3. Effect of Variation of the Location of the Pin on Notch Frequency

On the substrate, two via-pins with diameters of 1 mm are used to connect the up righted hat-shaped resonator to the radiating patch. The simulation results show that by adjusting the total lengths of the up righted hat-shaped resonator to be approximately half-wavelength of the desired notched frequency, a devastating interference can take place. As it is presented in Fig. 5, changing the pins location from position A to position B, shifts the center frequency of the stop band from 3.6 GHz to 7.6 GHz.

Figure 6 shows the simulated surface current density of the proposed notched antenna with and without pins (Fig. 1. and Ant. 1 respectively). As shown in Fig. 6(a), for the lower-frequency notch (3–4.42 GHz), the current density is concentrated over the upper edges of the up righted hat-shaped resonator near pins, while for the upper notch (4.8–6 GHz) the current is concentrated over the center of the resonator (Fig. 6(b)).

Finally, prototypes of antennas with and without pin were fabricated and measured using an Agilent-N5230A vector network analyzer and are presented in Fig. 7. The measured S_{11} of the antennas are presented in Fig. 8. As it can be seen there is a reasonable agreement between the simulated and measured results. There are some disagreements which are due to the soldering, and filling via

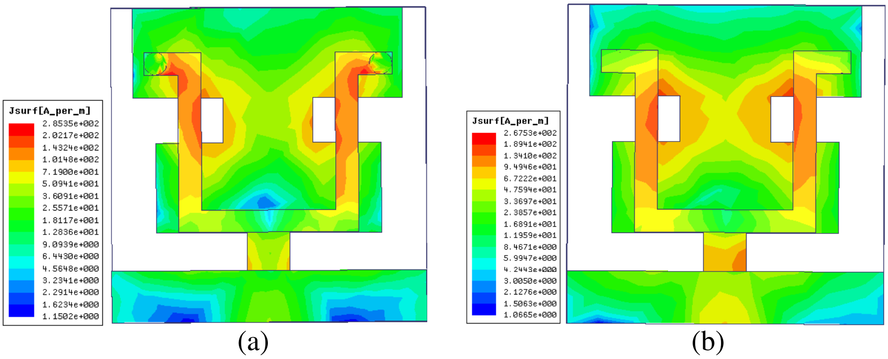

Figure 6. Current distribution for antenna with up righted hat shaped resonator, (a) with pin (3.6 GHz), (b) without pin (5.6 GHz).

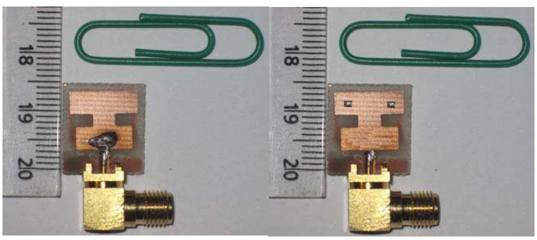

Figure 7. Photograph of the proposed notched UWB antennas.

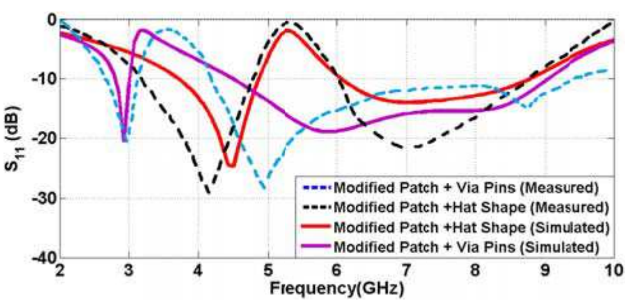

Figure 8. Measured and simulated S_{11} of the antennas.

wholes with solder and effect of the SMA connectors as well.

The radiation patterns in the x-y (Phi) and x-z (Theta) planes at the operating frequencies of 4.4 GHz and 7.2 GHz are measured and illustrated in Figs. 9(a) and (b), respectively. The dipole-like radiation patterns in the x-z plane and nearly omni-directional radiation patterns in the x-z plane are observed for co-polarization.

Blue curves gives the co-polarization and the red ones give the cross polarization of the antenna for two principle planes for $\theta = 0°$ and $\theta = 90°$. Measured antenna gain which is presented in Fig. 10 illustrates that the antenna has much less gain at the notch frequencies which is due to severely increasing current distribution on the up righted hat-shaped resonator and via pins at the notch frequencies. Antenna has the maximum gain of 2 dBi.

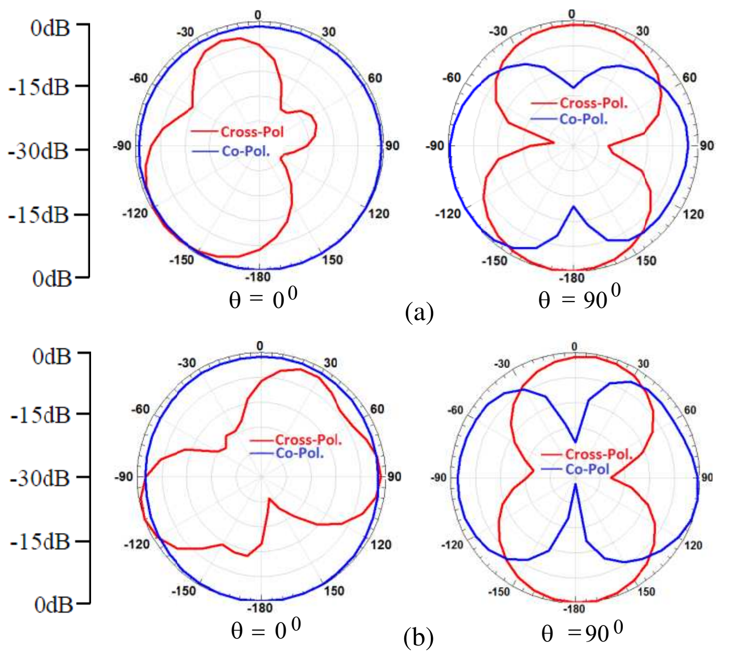

Figure 9. Measured Radiation pattern of the antenna in (a) 4.4 GHz, (b) 7.2 GHz.

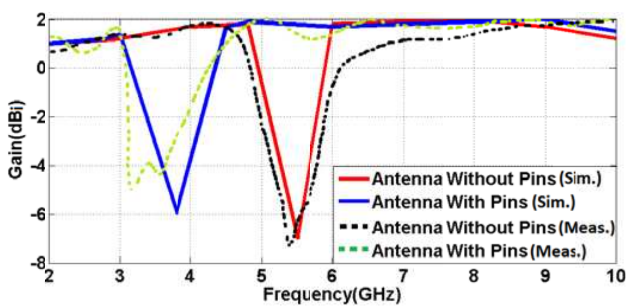

Figure 10. Measured and simulated gain of the antennas.

4. CONCLUSION

A miniaturized microstrip UWB antenna with controllable notch bands presented. Antenna own an UWB operating band and presents filtering properties for WiMax and WLAN operating band. Four Antenna designs with and without via pins based on the same platform of small size of 14 $(0.2\lambda) \times 14$ (0.2λ) are presented. This design is very suitable for new and compact UWB communication applications. It offers controllable notch property which can be controlled through changing the parameters presented in parametric study.

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