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ULTRA-WIDEBAND PERFORMANCE OF PRINTED HEXAGONAL WIDESLOT ANTENNA WITH DUAL BAND-NOTCHED CHARACTERISTICS

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Abstract—In this paper, ultra-wideband characteristics of a hexagonal wide slot antenna with dual band-notched property have been proposed and experimentally investigated. By etching a pair of L-shaped slots and embedding a pair of parallel strip conductors, dual band-notched properties in WiMAX/C-Band satellite application and WLAN band are achieved respectively. Good impedance matching is obtained over a wide band by designing the feed structure with a 50 Ω microstripline loaded by a tuning stub. The stub is proposed to have one hexagonal section and one straight section. The proposed antenna operates over 2.0 GHz–10.7 GHz range, for VSWR $\leq$ 2, excluding the two rejection bands from 3.4 GHz to 4.3 GHz and 5.12 GHz to 6.4 GHz having rejection level VSWR of 7.84 and 6.5 respectively. The impedance bandwidth of the antenna is 5.35 : 1. The proposed ultra-wideband structure also exhibits constant group delay, satisfactory gain and high radiation efficiency in the pass band.

1. INTRODUCTION

Due to attractive merits, such as low profile, light weight, ease of fabrication and wide frequency bandwidth, printed wide slot antennas are considered as one of the appropriate candidates for designing the ultra-wide band (UWB) antennas [1–6]. As the federal communication commission (FCC) authorized the unlicensed use of frequency band from 3.1 GHz to 10.6 GHz for UWB devices for

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commercial applications, a great deal of research on UWB technology has come up [7]. UWB antennas as a key component of UWB communication system, have attracted more and more attention in the field of research now a days [8–15].

Over the UWB band there are many narrow band communication standards, such as Worldwide Interoperability for Microwave Access (WiMAX) service from 3.3 to 3.7 GHz, the Wireless Local Area Network (WLAN) for IEEE 802.11a in the USA (5.15–5.35 GHz, 5.725–5.825 GHz) and C-Band satellite service (3.7 GHz to 4.2 GHz) etc.. To avoid interference between the above narrow band systems and UWB systems, mitigation of interference must be considered in UWB antenna design methods. Realization of band notched UWB antenna is a feasible solution to eliminate the problem of interference with other narrow band applications, as compared to the use of extra filter. One of the usual strategies to provide this feature is to introduce stub either as slot or in the form of strip conductors within the antenna [16–20].

In this paper a printed hexagonal wide slot antenna having wide impedance bandwidth has been transformed to an ultra-wide band antenna by using a rectangular tail slot. The antenna has been fed by a 50 Ω microstrip line loaded by a tuning stub. The combination of hexagonal wide slot and rectangular tail slot is structurally different from the entire existing UWB slot antenna configuration. Band notched UWB characteristics have been realized by etching two L-shaped slots of quarter wave length acting as impedance inverter and using a pair of parallel strip conductors of half wave length acting as resonant parasitic open circuit element, with specific separation within the wide slot. The simulation software HFSS has been used in the design. The measurement has been carried out with the help of Agilent Technologies Network Analyser (N5230A).

2. ANTENNA CONFIGURATION

A novel design of a band notched UWB antenna is presented here. The reference antenna configuration is shown in Figure 1(a). The antenna is fabricated on FR4 substrate with relative permittivity 4.4 and having thickness of 1.6 mm. On one side of the substrate a wide hexagonal slot having diameter (D) of 53.7 mm with a small rectangular slot as extension with length (L_1) and width (W_1) is etched out on the ground plane to create a wide frequency band, since the hexagonal slot affects the lower and middle frequency range and rectangular slot influence the higher frequency modes. A 50 Ω microstrip feedline with length (L_f) and width (W_f) is used to feed the antenna, which is placed symmetrically along the y-axis on the opposite side of FR4 substrate. Moreover at the end of the feed line there is a tuning stub having a hexagonal section with diameter (d) and a straight section having length (L_s), to provide suitable impedance matching over a wide bandwidth. For simplicity the width of the straight section of the stub is kept the same as that of the width of feed line. The optimized design parameters for the reference antenna are $D = 53.7\,\text{mm}$, $d = 11.5\,\text{mm}$, $L_1 = 6\,\text{mm}$, $W_1 = 5\,\text{mm}$, $L_f = 30.75\,\text{mm}$, $W_f = 3\,\text{mm}$, $L_s = 8.45\,\text{mm}$ to act as UWB antenna without any notch bands.

In order to create band notched behavior within ultra wide band range, two types of resonating structures are embedded in the reference UWB antenna as shown in Figure 1(b). To decrease potential interferences between UWB systems and the existing narrow band systems, the dual band-notched characteristics are created by inserting a pair of L-shaped slots and a pair of straight parallel strip conductors within the wide hexagonal slot with specific separation between similar elements. The notch band width and it's centre frequency can be easily adjusted by the parameters of the slots and strips.

The first notch is produced by a pair of L shaped slots as shown in Figure 1(b). The length of the slots ($L_2 + W_2$) is about quarter wavelength of notch frequency at 3.8 GHz acting as impedance inverter. The wave length can be approximately calculated by the formula as follows [18].

$$\lambda_g \approx \frac{c}{f\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where ε_r, c and f are relative permittivity, velocity of EM wave in free space and centre frequency of desired stop band respectively. The width of the slots (W_t) determines the selectivity of stop band at the desired frequency. The optimal parameters of the slot to provide

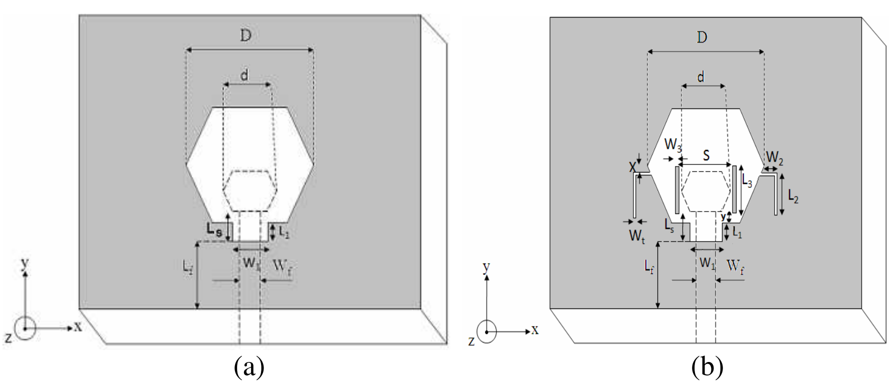


Figure 1. Schematic diagram of (a) reference UWB antenna. (b) Proposed band-notched UWB antenna.

the notched band around 3.8 GHz are $L_2 = 10.6$ mm, $W_2 = 2.7$ mm, $W_t = 0.5$ mm, $X = 9.6$ mm. Besides this, a pair of straight parallel strip conductors embedded within the wide hexagonal slot acting as resonant parasitic open circuit elements, are used to achieve the notch around 5.7 GHz. The lengths of the strips are about half wave length of desired notch frequency. By tuning the length and spacing between parallel strips desired notch band can be obtained. The optimal parameters of the parallel strips are $L_3 = 16.5$ mm, $W_3 = 0.3$ mm, $S = 13.4$ mm and $Y = 1.25$ mm. The photographic view of the proposed band-notched UWB antenna is now shown in Figures 2(a) and 2(b).

(a) (b)

Figure 2. (a) Slot-side view of the prototype. (b) Feed-side view of the prototype.

3. PERFORMANCE STUDY OF ANTENNA

The prototype of the proposed antenna has been fabricated and tested. The experimental study has been carried out by Agilent Technologies PNA-L Network Analyzer (N5230A-10 MHz to 20 GHz). A comparison between the simulated and measured VSWR responses of the proposed UWB antenna is shown in Figure 3. The measured result indicates that impedance bandwidth (VSWR ≤ 2) covers 2.0 GHz–10.7 GHz,with two notch bands (VSWR > 2) between 3.4 GHz–4.3 GHz and 5.12 GHz–6.40 GHz having rejection level VSWR of 7.84 ($S_{11} = -2.2$ dB) and 6.5 ($S_{11} = -2.6$ dB) respectively, which is enough to reject a half power of the transmitting/receiving signal. From the figure it is observed that the experimental result exhibits good agreement with the simulation result with acceptable discrepancy. The experimental result of the reference antenna VSWR response is also shown for comparison.

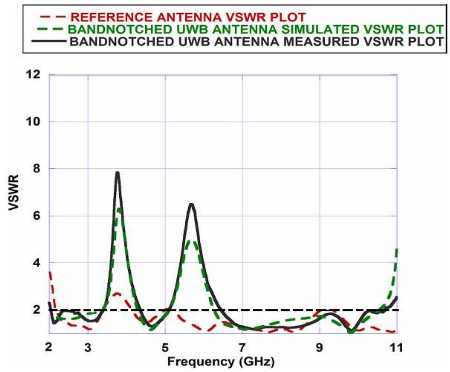
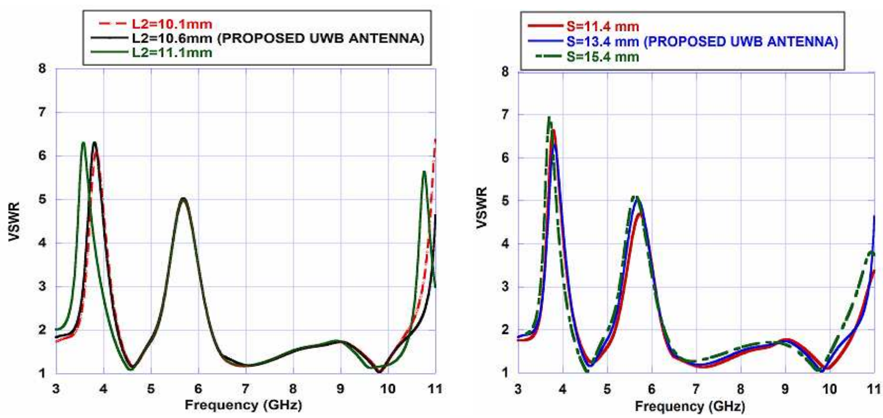


Figure 3. Comparison between simulated and measured VSWR responses of proposed band notched UWB antenna and reference UWB antenna.



(a) (b)

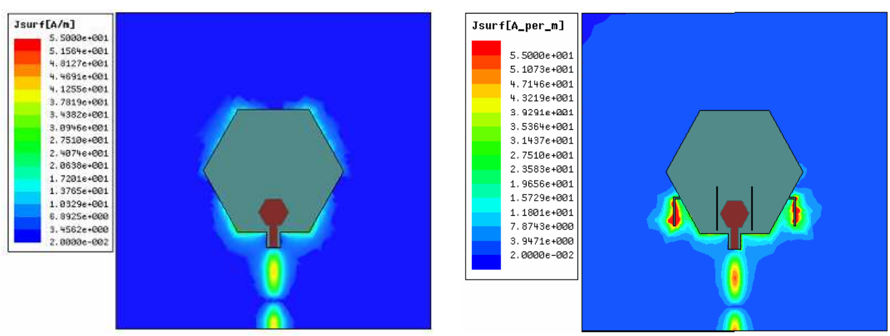
Figure 4. (a) Simulated VSWR response of proposed antenna for different values of L_2. (b) Simulated VSWR response of proposed antenna for different values of S.

The proposed antenna may be suitable for UWB applications with notched band maximum VSWR levels satisfactory for providing acceptable rejection of WiMAX, C-band satellite and WLAN system to avoid interferences.

The simulated VSWR responses of the proposed antenna for the variation of L_2 and S are shown in Figure 4. It is seen in Figure 4(a), that upon changing L_2 keeping other parameters constant, the lower notch band moves keeping upper notched band unaffected. The overall length $(L_2 + W_2)$ mainly determines the property of lower notched band. The location (X) of two L-shaped slots from the centre line of hexagonal slot, is also responsible for suitable band notched characteristics as it adjusts the coupling level with feed structure. The width W_t of the quarter wave slot determines the selectivity of lower notched band. It reveals that the proposed antenna has stable upper notched band characteristics for the variation in lower stop band. However the lower notched band is highly sensitive for variation in strip length L_3. The optimum length L_3 (16.5 mm) of the two parallel strip conductors has been found for the proposed antenna. The small change in spacing (S) between the two strips does not significantly influence the antenna performance however a small change in maximum VSWR values of both the notch level is observed.

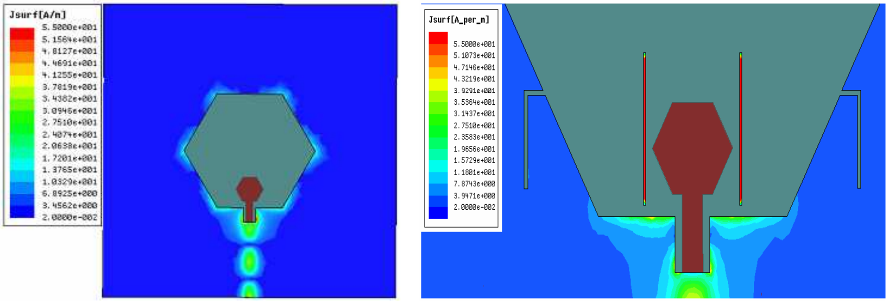
A study on the effect of different feed length (L_f) has also been done on the proposed band notched UWB antenna. When the length of the feed is reduced by 10 mm, i.e., from 30.75 mm for the case of prototype to 20.75 mm, it is found that the antenna is still exhibiting the same UWB performance in respect of impedance and radiation characteristics. In case of 15 mm reduction in feed length ($L_f = 15.75$ mm), the VSWR response is almost similar to 20.75 mm feed length case but a slight fall in rejection level of second notched band for WLAN application is observed. The radiation patterns are also similar with 20.75 mm feed length cases, with slight increase in ripple.

The simulated current distributions for the reference UWB antenna and band notched UWB antenna at the frequencies of 3.8 GHz and 5.7 GHz are shown in Figures 5 and 6. It is observed in Figure 5(b) that at the desired notch frequency 3.8 GHz, only the L-shaped slots are active with increased current distribution. Here the increased current distribution is formed due to the inclusion of the said slots



(a) (b)

Figure 5. Surface current distributions of the (a) reference and (b) proposed structure at 3.8 GHz.



(a) (b)

Figure 6. Surface current distributions of the (a) reference and (b) proposed structure at 5.7 GHz.

resonating feature. On the other hand increased current distribution on parallel strip conductors emerges at 5.7 GHz (Figure 6(b)). So the strips resonating near 5.7 GHz provide suitable confinement of energy while other parts of antenna are inactive confirming the independence of the other notched frequency band of the proposed band notched UWB structure. The reference UWB antenna current distributions at the respective notched band centre frequencies, i.e., 3.8 GHz and 5.7 GHz are shown in Figures 5(a) and 6(a), where enhanced current distribution is not observed at any part of the reference UWB antenna due to absence of notching elements. Thus from both the VSWR characteristics and simulated surface current distribution, this may be concluded that the L-shaped slots and parallel strip conductors introduce the two notched band functions.

The far field radiation characteristics of the proposed dual band-notched antenna are also investigated. Figure 7 shows the E-plane (y-z plane) and H-plane (x-z plane) radiation patterns at 4.5 GHz, 7.0 GHz and 9.0 GHz. The figures exhibit nearly omnidirectional radiation pattern in H-plane (x-z plane) and dipole like radiation pattern in E-plane (y-z plane) with little degradation in higher frequencies. The antenna exhibits large cross-polarization level in H-plane which reveals the excitation of higher order modes in respective directions.

Figure 8 represents the simulated peak value of antenna gain versus frequency within UWB operation range. It is observed that there are two sharp fall in gain around 3.8 GHz and 5.7 GHz, which confirms the effective band notched operation. For other frequencies outside rejection band, gain remains well satisfied.

The efficiency variation of the proposed band notched UWB antenna is shown in Figure 9. The antenna exhibits high radiation efficiency. Sharp fall in efficiency is observed when it operates in the

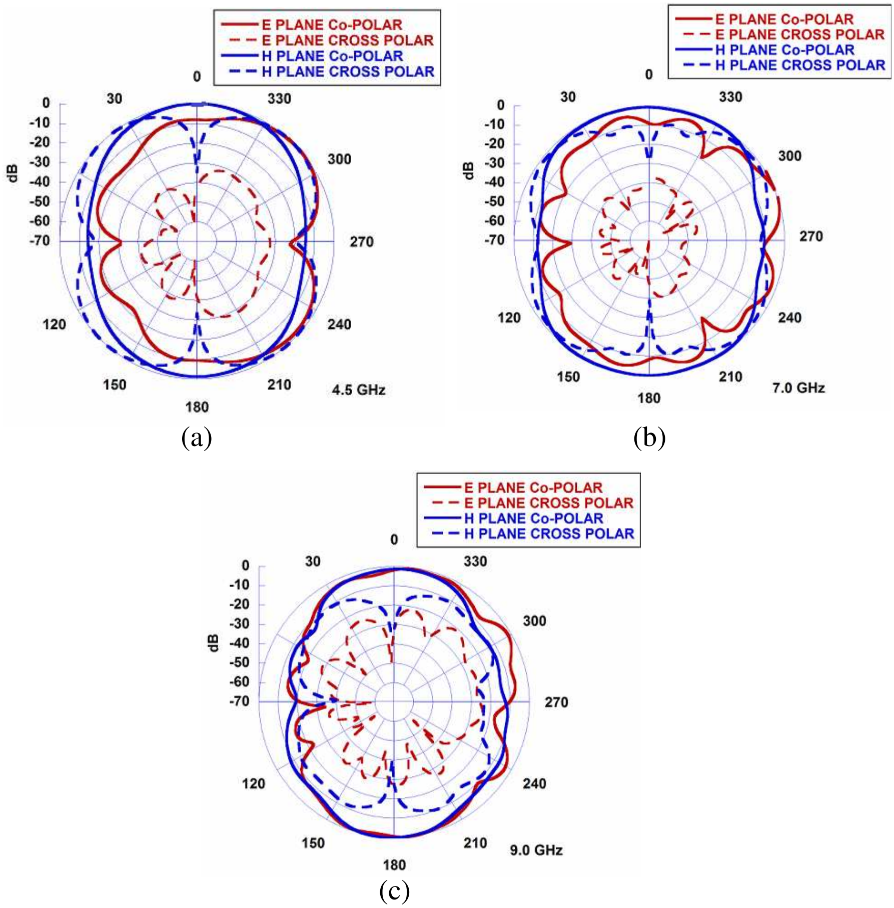


Figure 7. E-plane and H-plane radiation patterns at (a) 4.5 GHz, (b) 7.0 GHz, (c) 9.0 GHz.

designed rejection band.

Another critical parameter for UWB antenna is the group delay, which indicates the far field phase linearity. It is the measurement of time domain signal distortion introduced by the antenna. Group delay and magnitude transfer function (S_{21}) of the proposed band notched UWB antenna are depicted in Figure 10, which are measured by using two identical fabricated prototypes placed at a distance of 30 cm. Small transfer function fluctuation has been observed. There is large group delay variation at two frequency points but those large variations in group delay lies either within the stop band range or outside the UWB range. This indicates that the antenna has a good time domain characteristic and a small pulse distortion.

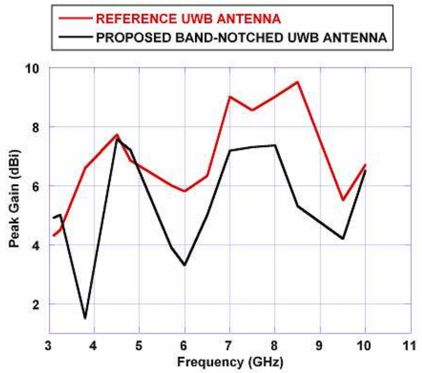


Figure 8. Simulated peak antenna gain versus frequency for band-notched UWB antenna and reference UWB antenna.

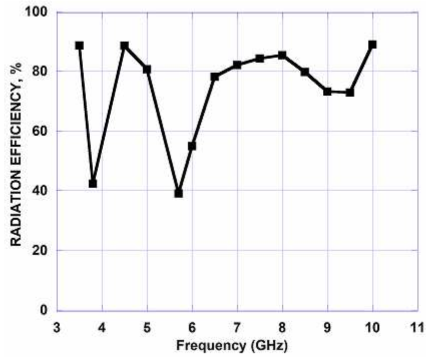


Figure 9. Simulated radiation efficiency versus frequency for band-notched UWB antenna.

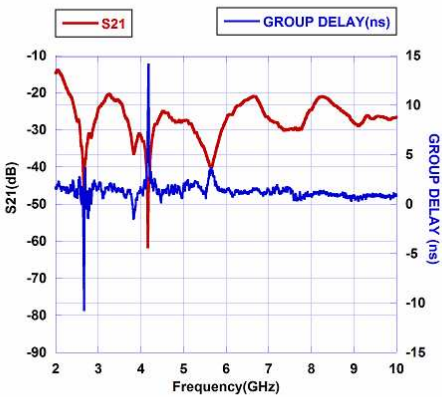


Figure 10. Measured group delay and transfer function of the proposed band notched UWB antenna.

All the above performances show that the proposed antenna has good band notched characteristics which effectively minimize the potential interferences between UWB systems and existing narrow band systems and further exhibits satisfactory group delay, gain and efficiency in pass band.

4. CONCLUSION

In this paper, a novel hexagonal wide slot UWB antenna having dual band-notched characteristics has been proposed and experimentally investigated. The small rectangular slot, as an extension of the hexagonal slot, is responsible for the conversion of wide band hexagonal slot antenna into ultra wide band antenna. A pair of L-shaped slots and two parallel strip conductors are introduced to provide notched band for WiMAX/C-Band satellite and WLAN band respectively. Inclusion of above elements does not affect the ultra-wide band operation of the original UWB antenna. Satisfactory results have been found in respect of bandwidth, radiation pattern, gain, efficiency, rejection of existing narrow band systems and group delay response. The electrical characteristics of the proposed band notched UWB antenna confirm it's suitability in various UWB applications.

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