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A Generalized Concept for Band Notch Generation in Ultra-Wide Band Antennas

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Abstract—In this paper a generalized concept to generate two band notches by adding parasitic elements having predictable positions to a wide slot ultra-wide band (UWB) antenna is proposed. The elimination of the wireless local area network (5.15–5.825 GHz) is achieved by a pair of radiating parasitic elements. Each element operates as a quarter wavelength resonator. A pair of half wavelength resonators in a form of a pair of parasitic strips is engraved in the ground plane side of the substrate directly behind the antenna tuning stub to break the coupling between the feed line and the slot, which represents the basic operation concept of the wide slot antenna, at the X-band satellite communications down link (7.25–7.745 GHz). Analysis shows that the proposed mechanisms are suitable for all wide slot antennas. The simulation and measured parameters are in good agreement, and results also show that the antenna has high voltage standing wave ratio and low gain inside the eliminated bands, while outside the notched bands it has a bandwidth that covers the entire UWB band and has very stable radiation characteristics.

1. INTRODUCTION

Antennas operating in the Ultra-wide Band (UWB) frequency range have been of research interest to many researchers due to its high data rate and multimedia transmission properties. The planar version of UWB antenna, which is suitable for UWB indoor communications gadgets, can be classified into two categories. The first one, called the monopole UWB antenna, is simpler in design and easier to be fabricated than the second category called the wide slot antenna, which has more stable radiation characteristics along the operating frequency band and smaller undesired electric coupling with the nearby components because of its small electric near field [1]. Unfortunately, the existence of some wireless applications within the UWB frequency band leads to have noticeable interference between the UWB applications and the already existed applications. Therefore, the researchers have been fueled to design UWB antennas having the ability of filtering out any radiation that can cause interference with the other applications instead of using band stop filters which complicate the system design noticeably.

The conventional technique that is used for band notch generation is by embedding narrow slots on the radiating patch and/or the ground plane [2–5]. In recent years, researchers have used parasitic patches to generate band notches [6–12], instead of engraving slots, because the slots have more parameters such as the slot position and the slot width that need to be optimized than the parasitic patches which are less sensitive to these parameters. A parasitic arc-shaped strip opposite to the patch of a quasi-self-complementary monopole antenna has been used to protect the antenna from interference from Wireless Local Area Network (WLAN) [6], while an open loop resonator located on the back of a monopole antenna substrate has been used to reduce the WLAN interference [7]. Two sharp band notches produced by attaching two pairs of parasitic radiators to the radiating patch of a monopole antenna was also considered [8], while U-shaped stub and inverted T-shaped stub have been engraved

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on the trapezoidal patch on a monopole antenna to remove the WiMax and WLAN interference [9]. In addition, a miniaturized UWB Antenna has been attached with step impedance resonator to generate band notch at the WLAN applications [10] and WiMax and WLAN interference has been canceled by adding Tri-Arm resonator to a rectangular monopole antenna [11]. A pair of split ring resonator has been placed on both sides of the transmission line of a half circular monopole antenna to reduce the effect of X-band satellite radiation [12].

In this paper we analyze through experiments and simulations, the physical effects of our previous study [13], and apply the results to propose a generalized design concept that has application in all wide slot UWB antennas. Specifically, a pair of parasitic strips has been placed in the ground plane side along a part of the stub circumference to eliminate the X-band Satellite communications down link (7.25–7.745 GHz) by distorting the coupling between the triangular stub and the wide slot of the antenna at that frequency band. Another pair of radiating parasitic elements has been attached to the ground plane to radiate in such a way that cancels the radiation of the original UWB antenna at the WLAN band (5.15–5.825 GHz). Analyses show that these proposed parasitic elements are more general than those proposed in [6–12] since the proposed parasitic elements have predictable positions, and these predictions can be generalized for all wide slot antennas. Moreover, their simple structure does not complicate the antenna analysis significantly. The simulation and measured results are in very good agreement and clearly show the band notch effects on the return loss and the antenna gain as well as the stability of the radiation characteristic of the antenna outside the eliminated bands.

2. ANTENNA STRUCTURE

Figure 1 illustrates the antenna front and back views with the numerical values of their parts. The front view includes the $50\,\Omega$ microstrip transmission line and the triangular stub which provides strong coupling with the dome shaped slot engraved on the other side of the antenna [13]. On the other hand, the back view of the antenna holds the antenna ground plane, the dome shaped slot, and the parasitic elements which generate the required band notches. The 5.5 GHz WLAN radiation is eliminated by a pair of radiating parasitic elements placed at the both sides of the antenna. These two parasitic elements have a horizontal part having length equal to 1 mm, while their vertical parts (V) are going to follow an optimization process to place the band notch at the WLAN frequency band. A pair of parasitic strips is placed exactly behind the stub circumference to cancel the radiation of the X-band Satellite communications down link (7.25–7.745 GHz). The horizontal part of each parasitic strip is also submitted an optimization process to control the position of the band notch. The width of all parasitic elements is selected to be 0.7 mm. It is worth to mention that the antenna substrate is FR4 with dielectric constant $\varepsilon_r = 4.3$ and loss tangent of 0.025.

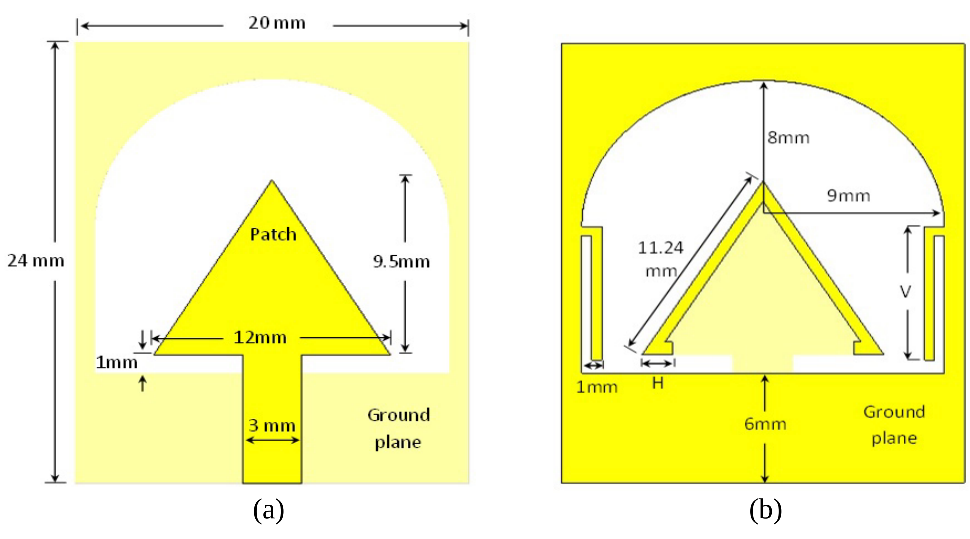

Figure 1. The geometry of the proposed antenna, (a) the front view and (b) the back view.

3. BAND NOTCH GENERATION

This section demonstrates the physical effect of each pair of parasitic elements on the overall antenna behavior. In addition, the length of each parasitic element is modified to meet the required band notch characteristics. The simulation suite CST Microwave Studio is used to obtain the simulated results.

3.1. WLAN Band Notch Generation

A pair of radiating parasitic elements has been attached to the both sides of the dome shaped slot. The vertical part (V) of this parasitic element has been investigated to find the optimum value that places the band notch in such a good position that reduce the interference with the 5.5 GHz WLAN. Figure 2 illustrates the antenna voltage standing wave ratio (VSWR) at $H = 1.5$ mm and different values of (V).

Since one terminal of this radiating parasitic element is short circuited by the ground plane and the other terminal is open circuited, each parasitic element operates as a quarter wavelength resonator but the total length of the two elements will be half wavelength. For this reason, the optimal vertical length is found to be equal to 7.3 mm which makes the total length of the radiating parasitic element to be equal to 8.3 mm, which is exactly equal to the quarter of the guided wavelength corresponding to the frequency 5.5 GHz. The following formula can explain the relationship between the total radiator length (L) and the resonant wavelength (λ):

$$L = \frac{\lambda}{4\sqrt{(\varepsilon_r + 1)/2}} \tag{1}$$

After this parametric study, the reasons that lead to generate band notch can be exposed by illustrating the current distribution at 5.5 GHz (see Figure 3). It is clear that the current flows downward through the radiating element, while it moves up through the ground plane, in the vicinity of the radiating element. Therefore, the radiations caused by these two currents cancel each other and the band notch is generated.

3.2. X-Band Band Notch Generation

This band notch can be generated by engraving a pair of parasitic strips in the ground plane side of the antenna, exactly behind the antenna tuning stub along its edge. The length of the horizontal part (H) of each parasitic strip has been optimized to eliminate the down link radiation of the X-band satellite communications centered at 7.5 GHz. Figure 4 shows the VSWR curves of the antenna at $V = 7.3$ mm and different values of H.

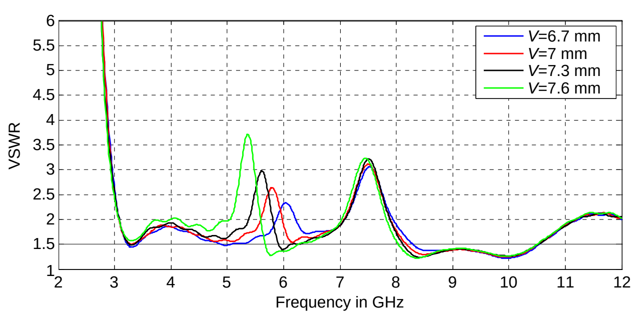

Figure 2. The voltage standing wave ratio (VSWR) of the proposed antenna at $H = 1.5$ mm and different values of V.

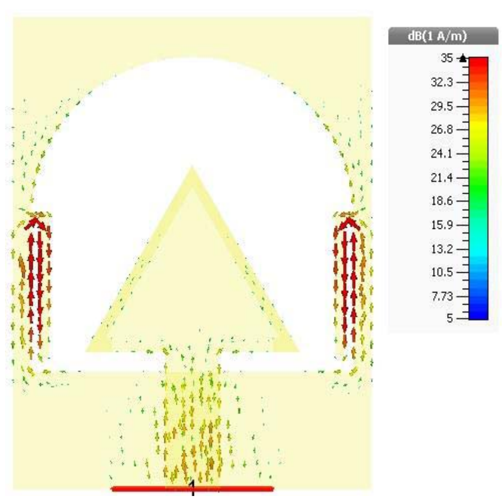

Figure 3. The current distribution of the proposed antenna at $f = 5.5$ GHz, $H = 1.5$ mm, and $V = 7.3$ mm.

At $H = 1.5$ mm and strip arm length equal to 11.24 mm, the total length of the parasitic strip will be 12.74 mm. Both terminals of the parasitic strips are open circuited, so they operate as half wavelength resonators. The total length of each parasitic strip (12.74 mm) is approximately equal to the half of the guided wavelength corresponding to the frequency 7.5 GHz, and it is follows the well-known formula:

$$L = \frac{\lambda}{2\sqrt{(\varepsilon_r + 1)/2}} \tag{2}$$

The current distribution of the antenna at $f = 7.5$ GHz is shown in Figure 5. The current flowing

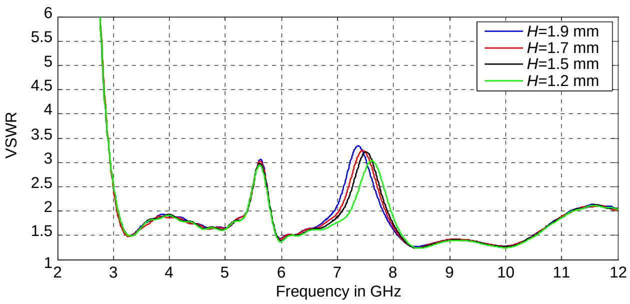

Figure 4. The voltage standing wave ratio (VSWR) of the proposed antenna at $V = 7.3$ mm and different values of H.

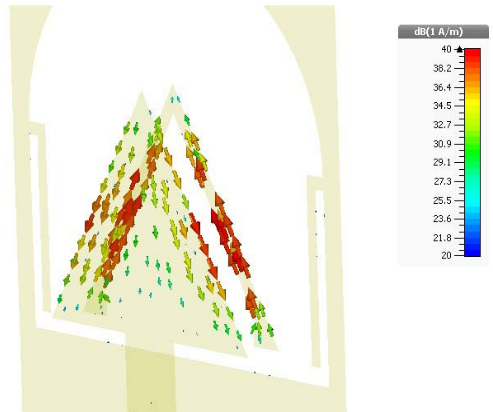

Figure 5. The current distribution of the proposed antenna at $f = 7.5$ GHz, $H = 1.5$ mm, and $V = 7.3$ mm.

Figure 6. The prototype of the proposed antenna.

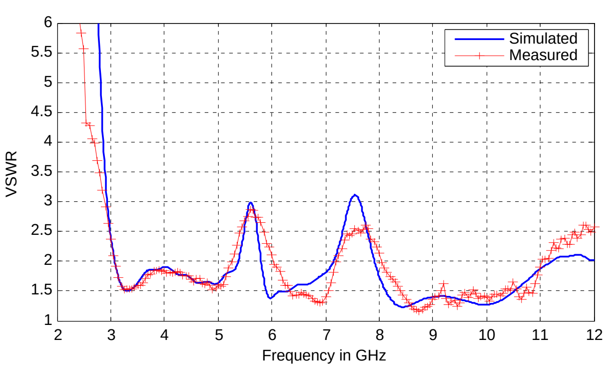

Figure 7. The simulated and measured voltage standing wave ratio of the proposed antenna.

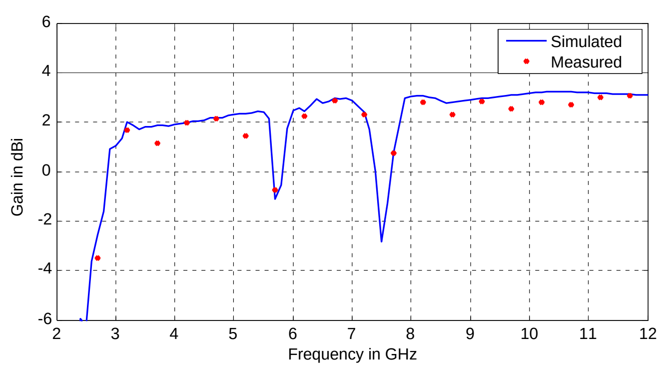

Figure 8. The simulated and measured peak gain of the proposed antenna.

through the edge of the triangular stub is exactly in the opposite direction of that flowing through the parasitic strip. As a result, the current of the parasitic strip cancels the effect of the stub current, so the coupling between the transmission line and the slot is minimized, and the radiation at that frequency is canceled.

The aforementioned physical interpretations show that these two band notch generation mechanisms are suitable not only for this special wide slot antenna but also for all wide slot antennas. The radiating parasitic antenna can be used for any wide slot antenna without any modifications, but the parasitic strips should follow the shape of the tuning stub of the slot antenna in order to break the coupling between the transmission line and the slot properly. In addition, these elements have predictable position such that the radiating parasitic elements can be positioned anywhere along the slot sides but without contacting the ground plane at its open circuit terminal, while the parasitic strips are positioned exactly behind the tuning stub.

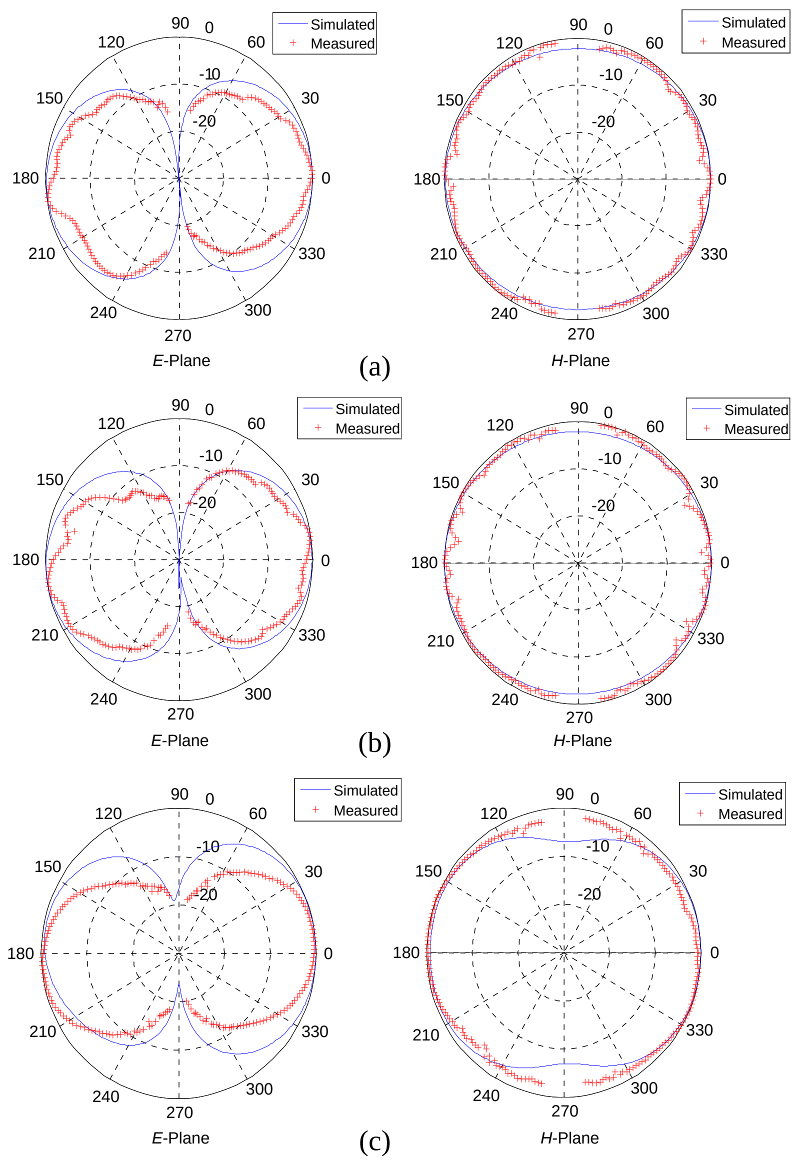

Figure 9. The measured and simulated power patterns at (a) $f = 3.4\,\text{GHz}$, (b) $f = 4.5\,\text{GHz}$, and (c) $f = 8.2\,\text{GHz}$.

4. EXPERIMENT AND RESULTS

Figure 6 shows the fabricated wide slot antenna attached to the SMA connecters. The effects of the radiating parasitic elements and the parasitic strips on the WLAN frequency band region and X-band satellite band region, respectively, can clearly be seen in Figure 7 which illustrates the measured and simulated voltage standing wave ratio (VSWR) of the proposed antenna. The parasitic elements also affect the radiation characteristics of the proposed antenna within the notched bands as shown in Figure 8. The antenna has a noticeably reduced gain within the WLAN and the X-band satellite bands which means that the antenna has a very week radiation at those frequency bands, so the interference is reduced significantly.

Outside the WLAN and the X-band notches, the antenna UWB properties are maintained. The simulated antenna bandwidth is found to be 8.1 GHz extended from 3.1 GHz to 11.2 GHz, while the measured values range is 3.1–11 GHz. The radiation characteristics outside the notched bands are so stable and this can be noticed from the gain illustration as well as the power pattern at different frequencies shown in Figure 9. Along the operating frequencies, the measured and simulated E-plane power patterns have the doughnut shape, and the measured and simulated H-plane power patterns are omnidirectional. This means that the antenna is suitable for portable UWB gadgets because its radiation characteristics are position independent and relatively frequency independent. The distortion of the measured power pattern comes from the reflections caused by the surrounding equipment inside the anechoic chamber.

The time domain characteristics can be demonstrated by illustrating the group delay of the antenna. This can be measured by aligning two antennas in three different alignment schemes: Face-to-Face, Face-to-Side, and Side-to-Side. Figure 10 shows the group delay for each of the aforesaid schemes. Within the operating band except the notched bands (3.1–11 GHz), the antenna has small deviation in the group delay which means the whole frequency components reach the receiver almost simultaneously. Therefore, at these frequencies the antenna adds a negligible amount of distortion to the transmitted

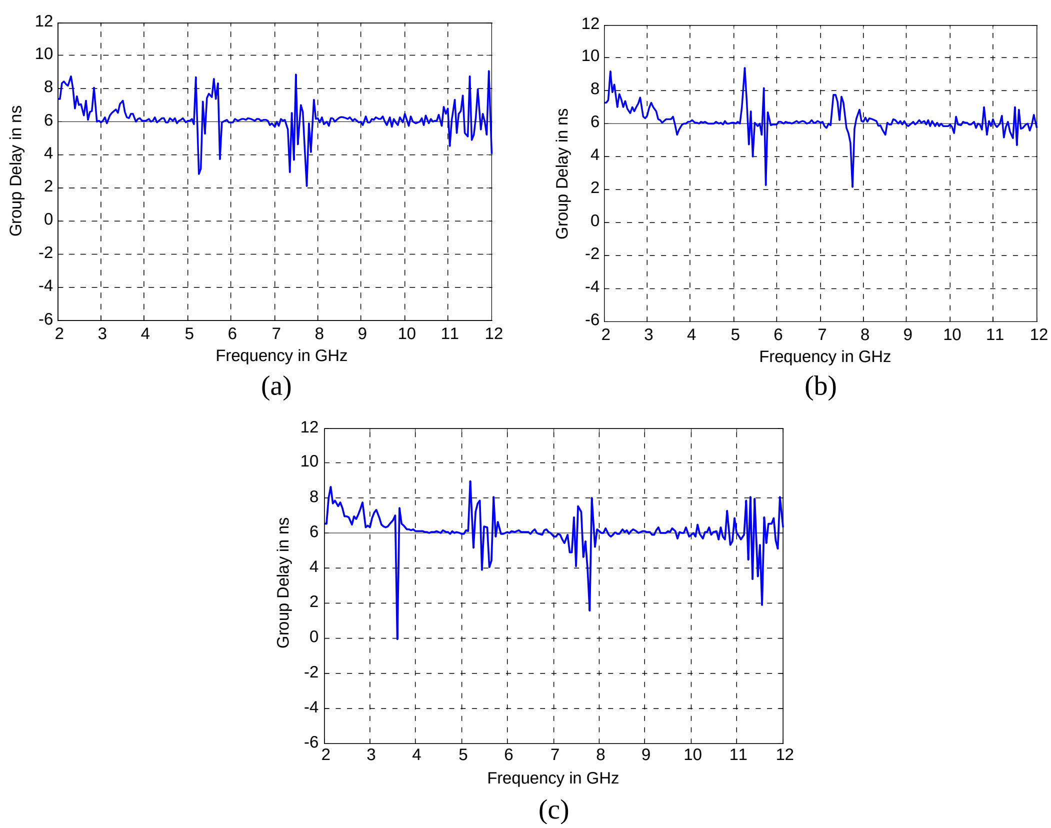

Figure 10. The measured group delay of the proposed antenna after aligning two antennas. (a) Face-to-Face, (b) side-to-Side, and (c) face-to-Side.

signal. On the other hand, the group delay has a noticeable deviation at the notched bands which means that the antenna distorts the signals whose frequency resides in the notched bands. Outside the operating band, the antenna also shows large distortion due to the large deviation in the group delay.

5. CONCLUSION

Two mechanisms for band notch generation are proposed in this paper. The first mechanism generates a band notch that cancels interference from existing WLAN frequencies. This is achieved by a pair of quarter wavelength radiating parasitic elements placed at both sides of the antenna wide slot. The other band notch is positioned at the X-band satellite communications down link with aid of a pair of parasitic strips engraved behind the antenna tuning stub along its edge. The two mechanisms are simple and have few optimization parameters with results showing high reflection and low gain within the eliminated bands. In addition, the antenna covers the entire UWB band and has stable radiation characteristics that are suitable for UWB portable devices.

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