Small Slot Antenna with Enhanced Bandwidth and Band-Notched Performance for UWB Applications

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Abstract ─ A novel ultra wideband (UWB) printed slot antenna with band-notched performance is designed and manufactured. In order to increase the impedance bandwidth of the slot antenna, we use a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane that with this structure UWB frequency range can be achieved. Additionally, by using an N-shaped slot on the radiating stub, a frequency notch band performance has been obtained. The designed antenna has a small size of 20×20 mm^2 while showing the radiation performance in the frequency band of 3.12 to over 14.27 GHz with a band rejection performance in the frequency band of 5.03 to 5.86 GHz. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

Index Terms ─ Printed Slot Antenna, N-Shaped Slot, Protruded L-Shaped Strip, Ultra-Wideband (UWB).

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of printed microstrip with different geometries have been experimentally characterized [1]-[3]. Moreover, other strategies to improve the impedance bandwidth have been investigated [4]-[5]. The Federal Communication Commission (FCC)'s allocation of the frequency range 3.1–10.6 GHz for UWB systems and it will cause interference to the existing wireless communication systems, such as, the wireless local area network (WLAN) for operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands), so the UWB antenna with a single band-stop performance is required [6-8].

A novel and compact microstrip-fed slot antenna with additional resonance and band-notched characteristics for UWB applications has been presented. This paper focuses on a slot antenna for UWB applications, which combines the square radiating stub approach with an N-shaped slot, and the ground plane with a rectangular slot with a pair of L-shaped strips protruded inside the slot that achieves a fractional bandwidth of more than 125%. In the proposed structure, first by inserting a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane, additional resonance is excited and hence much wider impedance bandwidth can be produced, especially at the higher frequencies. In order to generate a single band-notch function, for the first

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time, we use an N-shaped slot on the square radiating stub. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results show that the proposed slot antenna could be a good candidate for UWB applications

II. ANTENNA DESIGN

The slot antenna fed by a 50 Ω microstrip line is shown in Fig 1, which is printed on a FR4 substrate of thickness 0.8 mm, permittivity 4.4, and loss tangent 0.018. The basic antenna structure consists of a square radiating stub, a 50 Ω microstrip feed-line, and a ground plane with a rectangular slot. The square radiating stub has a width W. The radiating stub is connected to a feed line of width W_f and length L_f, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane with a rectangular slot is placed. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission

In this study, to design a novel antenna, the antenna with N-shaped slot and a rectangular slot with a pair of L-shaped strips protruded inside the slot is proposed. Based on Electromagnet Coupling Theory (ECT), the L-shaped strips protruded inside the slot on the ground plane are playing an important role in the broadband characteristics of this antenna, because it can adjust the electromagnetic coupling effects between the feed-line and the ground plane, and improves its impedance bandwidth without any cost of size or expense [9]. This phenomenon occurs because, with the use of L-shaped strips protruded inside the slot, additional coupling is introduced between the feed of the square patch and the ground plane [10]. As illustrated in Fig. 1, the N-shaped slot is cut on the square radiating stub. The N-shaped slot perturbs the resonant response and also acts as a half-wave resonant structure [11]. At the notch frequency, the current flows are more dominant around the N-shaped slot [5]-[7]. As a result, the desired high attenuation near the notch frequency can be produced. The variable band-notch characteristics can be achieved by carefully choosing the parameter (W_n, and L_n) for the N-shaped slot. In this structure, the width, W_n, is the critical parameter to control the filter bandwidth. On the other hand, the center frequency of the notched band is insensitive to the change of W_n. The resonant frequency of the notched band is determined by L_n. In this design, the optimized length is set to band-stop resonate at approximately, where and corresponds to band-notch frequency (5.5 GHz), and also is fixed at 5. 5 mm.

In this work, we start by choosing the aperture length L_S. We have a lot of flexibility in choosing this parameter. The length of the aperture mostly affects the antenna bandwidth. As L_S decreases, so does the antenna BW and vice versa. Next step, we have to determine the aperture width W_S. The aperture width is approximately $\lambda_S/2$, where λ_S is the slot wavelength that depends on a number of parameters such as the slot width as well as the thickness and dielectric constant of the substrate on which the slot is fabricated. The last and final step in the design is to choose the length of the radiating patch W_P. A good starting point is to choose it to be equal to $W = \lambda_m/4$, where λ_m is the guided wavelength in the microstrip line [6].

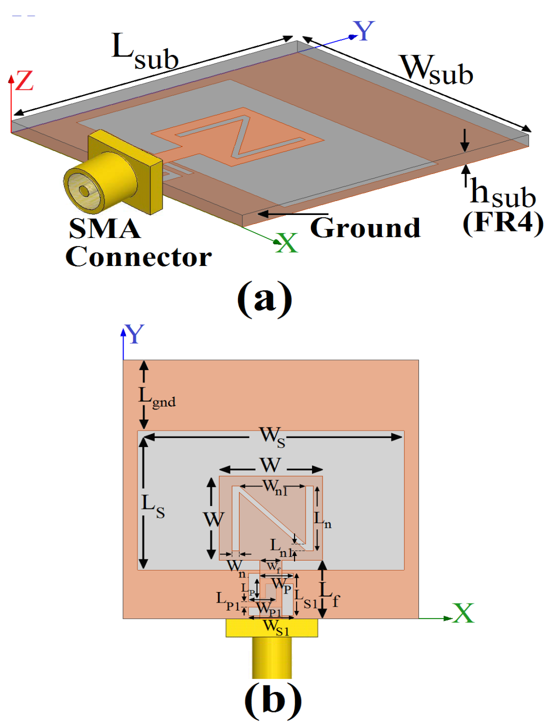

Fig. 1. Geometry of the proposed slot antenna, (a) side view, and (b) top view.

The optimal dimensions of the designed antenna are as follows: $W_{sub} = 20mm$, $L_{sub} = 20mm$, $W = 7mm$, $W_f = 1.5mm$, $L_f = 4mm$, $W_S = 18mm$, $L_S = 11mm$, $W_n = 0.3mm$, $L_n = 6mm$, $W_{n1} = 3.5mm$, $L_{n1} = 0.4mm$, $W_{S1} = 2.5mm$, $L_{S1} = 2.5mm$, $W_P = 2mm$, $L_P = 1mm$, $W_{P1} = 1.75mm$, $L_{P1} = 0.25mm$, and $L_{gnd} = 3mm$.

III. RESULTS AND DISCUSSIONS

In this Section, the planar slot antenna with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [12].

Figure 2 shows the structure of the various antennas used for simulation studies. Return loss characteristics for ordinary slot antenna (Fig. 2(a)), with a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane (Fig. 2(b)), and the proposed antenna structure (Fig. 2(c)) are compared in Fig. 3. It is found that by inserting the a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane, the antenna can create the third resonant frequency at 10.5 GHz based on an over-coupling condition and hence the impedance bandwidth is effectively improved at the upper frequency [4]. Also as shown in Fig. 3, in this structure, the N-shaped slot is used in order to generate the frequency band-stop performance. Also the input impedance of the various slot antenna structures that shown in Fig. 2(b) and 2(c), on a Smith Chart is shown in Fig. 4.

In order to understand the phenomenon behind these new additional resonances and band-notch performance, the simulated current distribution on the ground plane and the radiating patch for the proposed antenna at the resonances frequencies of 4 GHz, 9 GHz, and 10.5 GHz and the notch frequency of 5.5 GHz are presented in Figs. 5(a), 5(b), 5(c) and 5(d), respectively.

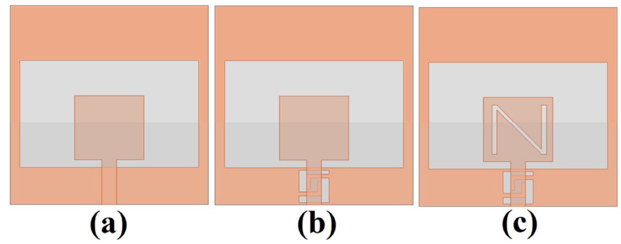

Fig. 2. (a) The ordinary slot antenna, (b) the antenna with a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane (c) the proposed slot antenna.

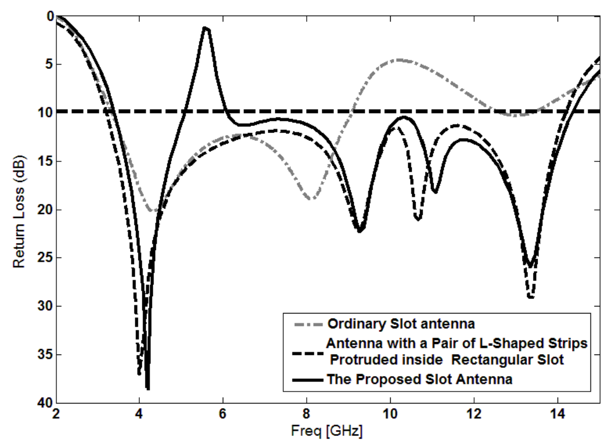

Fig. 3. Simulated return loss characteristics for antennas shown in Fig. 2.

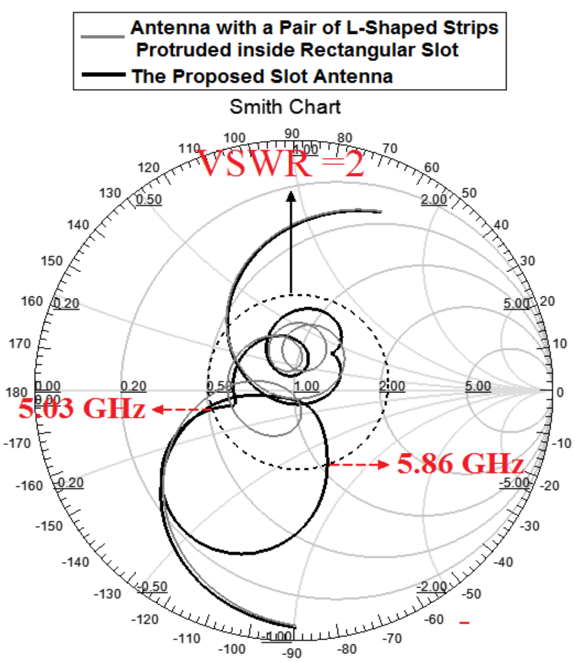

Fig. 4. The simulated input impedance on a Smith chart of the various slot antenna structures shown in Fig. 2(b) and 2(c).

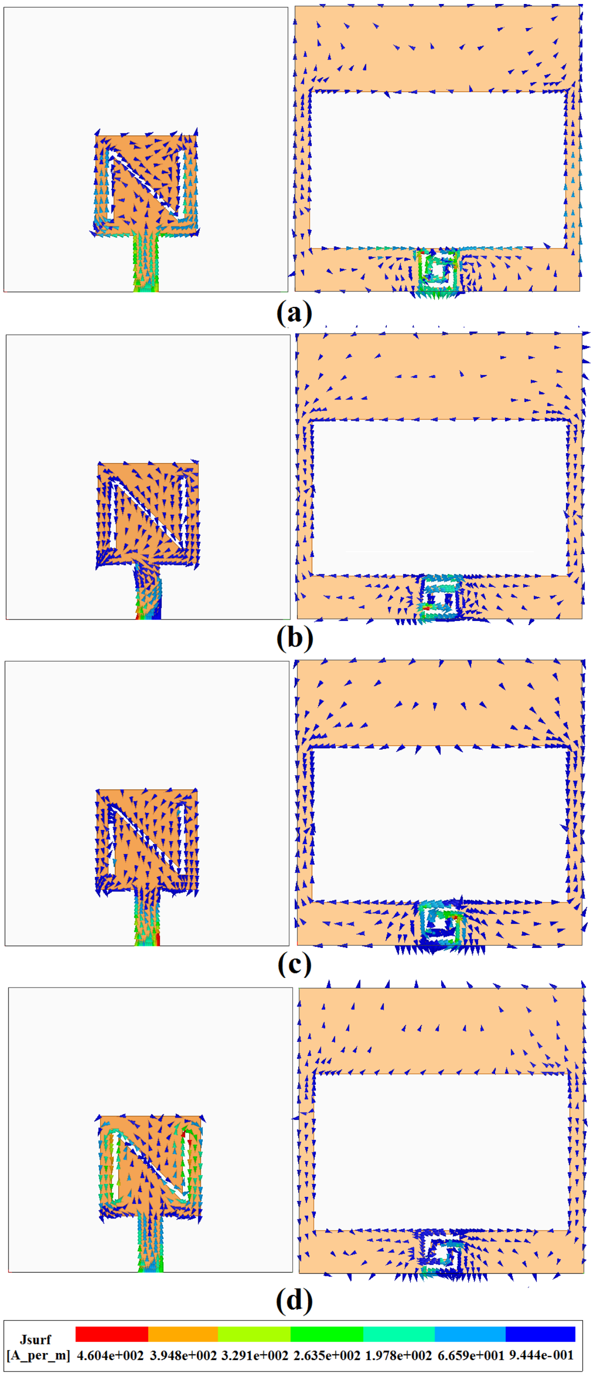

Fig. 5. Simulated surface current distributions for the proposed antenna on the radiating patch and the ground plane at resonances frequencies, (a) 4 GHz, (b) 9 GHz, (c) 10.5 GHz, and (d) at notch frequency (5.5 GHz).

It can be observed on Figs. 5(a), 5(b), and 5(c) that the current concentrated on the edges of the interior and exterior of the protruded L-shaped strips and the feed-line and radiating patch edges at resonances frequencies. Therefore the antenna impedance changes at these frequencies due to the resonant properties of the proposed structure. In addition, by inserting a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane the impedance bandwidth is effectively improved at the upper frequency [2]. It can be observed on Fig. 5(d) that the current concentrated on the edges of the interior and exterior of the N-shaped slot at 5.5 GHz. This figure shows that the electrical current for the notch frequency (5.5 GHz) does change direction along the N-shaped slot, due to the band notch properties of the proposed structure.

In this study, the N-shaped slot in the square radiating stub with variable dimensions is used in order to generate the frequency band-stop performance as displayed in Fig. 1. The simulated VSWR curves with different values of L_n are plotted in Fig. 6. As shown in Fig. 6, when the interior length increases from 4.8 to 6.6 mm, the center of notch frequency is decreases from 5.95 to 4.35 GHz. From these results, we can conclude that the notch frequency is controllable by changing the interior length of N-shaped slot.

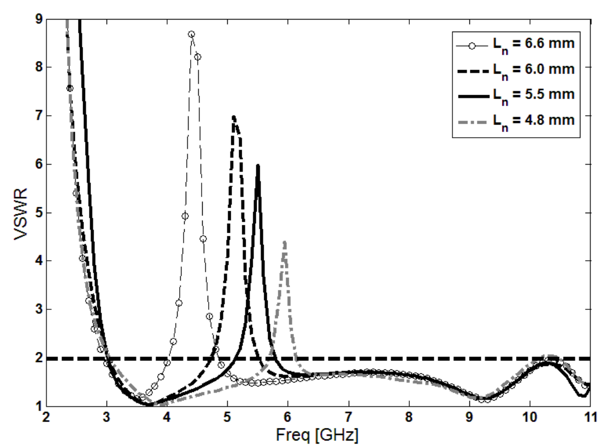

Fig. 6. Simulated VSWR characteristic with different values of L_n.

Another main effect of the N-shaped slot occurs on the filter bandwidth. In this structure, the width W_n, is the critical parameter to control the filter bandwidth. Figure 7 illustrates the simulated VSWR characteristics with various width of W_n. As the interior gap distance of the W_n increases from 0.2 to 0.6 mm, the filter bandwidth is varied from 0.7 to 1.5 GHz. Therefore the bandwidth of notch frequency is controllable by changing the width of W_n.

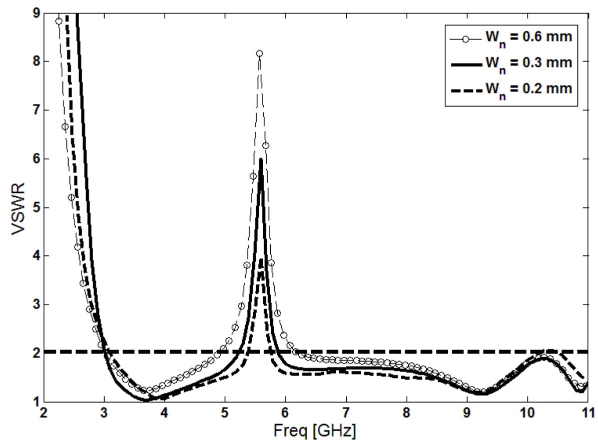

Fig. 7. Simulated VSWR characteristic with different values of W_n.

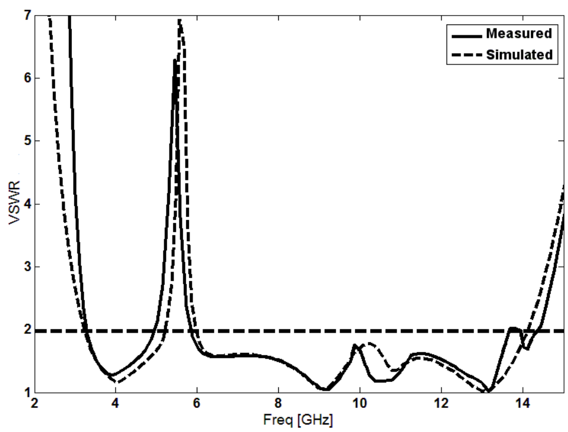

Fig. 8. Measured and simulated VSWR for the proposed slot antenna.

The proposed antenna with optimal design was built and tested. Figure 8 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna satisfies the VSWR<2 requirement from of 3.12 to over 14.27 GHz with a band rejection performance in the frequency band of 5.03 to 5.86 GHz. As shown in Fig. 8, there exists a discrepancy between measured data and the simulated results this could be due to the effect of the SMA port. In order to confirm the accurate VSWR characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully.

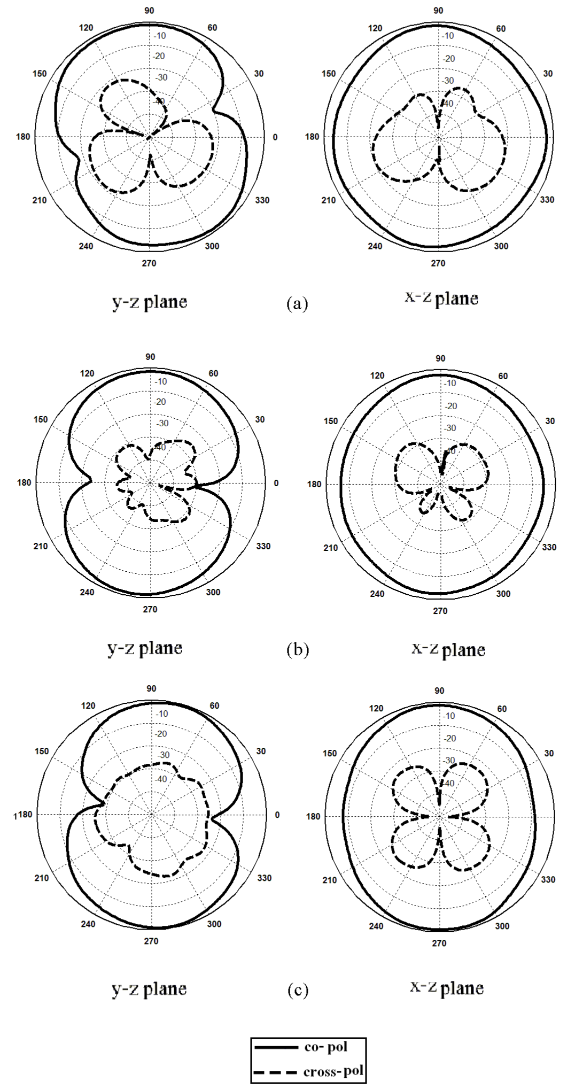

Fig. 9. Measured radiation patterns of the proposed antenna. (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

Fig. 9 the measured radiation patterns including the co-polarization and cross-polarization in the *H*-plane (*x*-*z* plane) and *E*-plane (*y*-*z* plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in *x*-*z* plane are nearly omnidirectional for the three frequencies.

Figure 10 shows the effects of the a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane and the N-shaped slot on the radiating stub on the maximum gain in comparison to the ordinary slot antenna without them. A two-antenna technique is used to measure the radiation gain in the z axis direction (x-z plane). As shown in Fig. 10, the ordinary antenna has a gain that is low at 2 GHz and increases with frequency. It is found that the gain of the ordinary slot antenna is decreased with the use of the rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane and the N-shaped slot on the radiating stub. It can be observed in Fig. 10 that by using these structures, a sharp decrease of maximum gain in the notched frequency band at 5.5 GHz are shown. For other frequencies outside the notched frequencies band, the antenna gain with the filter is similar to those without it.

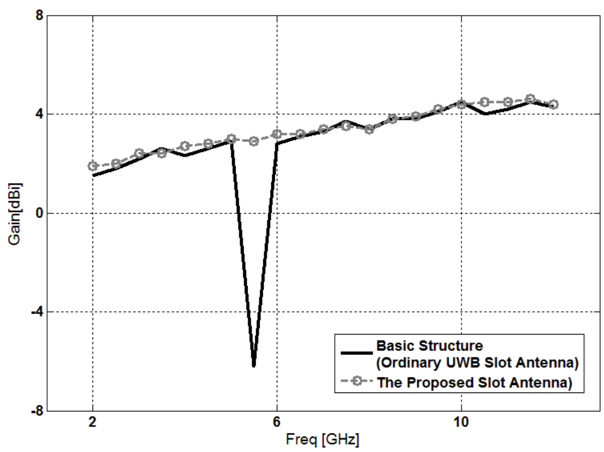

Fig. 10. Maximum gain comparisons for the ordinary slot antenna (simulated), and the proposed antenna (measured) in the z axis direction (x-z plane).

V. CONCLUSION

In this letter, a novel compact printed slot antenna has been proposed for UWB applications. The fabricated antenna satisfies the VSWR<2 requirement from of 3.12 to over 14.27 GHz with a band rejection performance in the frequency band of 5.03 to 5.86 GHz. By inserting a rectangular slot with a pair of L-shaped strips protruded inside the slot on the ground plane, additional resonance is excited and hence much wider impedance bandwidth can be produced, especially at the higher band. n order to generate a single band-notch function, for the first time, we use an N-shaped slot on the square radiating stub. The proposed antenna has a simple configuration and is easy to fabricate. Experimental results show that the proposed antenna could be a good candidate for UWB application.

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