Band-Notch Slot Antenna with Enhanced Bandwidth by using Ω-Shaped Strips Protruded inside Rectangular Slots for UWB Applications

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Abstract **─** A novel method for designing a new slot antenna with band-notch characteristic for UWB applications has been presented, in this paper. The proposed antenna consists of a slotted ground plane with an extra rectangular slot on its top, in which a Ω-shaped strip is protruded, and a square-ring radiating stub in which a Ω-shaped strip is protruded. By inserting the rectangular slot with a Ω-shaped strip which is protruded inside this slot, in the ground plane, additional resonance is excited and hence much wider impedance bandwidth can be produced, especially at the higher band, which consequently results in a wide usable fractional bandwidth of more than 125% (3.07-14.03 GHz). In order to generate a band-notch characteristic, we use a square-ring radiating stub with a Ω-shaped strip which is protruded inside this radiating stub. The measured results reveal that the presented slot antenna offers a wide bandwidth with a band-notch operation which notches the WLAN band (5.02-5.97 GHz). The designed antenna has a small size of 20×20 mm^2. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest.

Index Terms **─** Band-notch function, microstrip-fed slot antenna, protruded Ω-shaped strip, ultra-wideband (UWB) applications.

I. INTRODUCTION

In UWB communication systems, one of the key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band [1]. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of

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the geometry of the planar antenna have been investigated [2-5].

The Federal Communication Commission (FCC)'s allocation of the frequency range 3.1–10.6 GHz for UWB systems causes interference to the existing wireless communication systems, such as the wireless local area network (WLAN) which operates 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 [6-9].

A novel and compact microstrip-fed slot antenna with band-notch characteristic for UWB applications has been presented. Firstly, by inserting a rectangular slot, inside which a Ω-shaped strip is protruded, in the top section of ground plane, additional resonance is excited and hence much wider impedance bandwidth which covers UWB frequency range can be produced. Secondly, to generate a single band-notched function, we use a square-ring radiating stub with a Ω-shaped strip protruded inside the square ring. Good VSWR 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 presented small 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 slot antenna structure consists of a square stub, a feed line, and a ground plane. The square stub is connected to the 50 Ω microstrip feed-line. On the other side of the substrate, a conducting ground plane is placed. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission.

In this design, to achieve a bandwidth enhancement and a full coverage of UWB frequency range, we etched a rectangular slot inside the ground plane, in which a Ω-shaped strip is protruded. Based on the defected ground structure (DGS), the modified rectangular slot with a Ω-shaped strip protruded inside the slot acts as an impedance matching element to control the impedance bandwidth of the proposed antenna, because it can create additional surface current paths in the antenna and therefore, additional resonance is excited and hence, much wider impedance bandwidth can be produced, especially at the higher band. As illustrated in Fig. 1, the Ω-shaped strip which is protruded inside the square-ring radiating stub is symmetrical with respect to the longitudinal direction. In this structure, the square ring with a Ω-shaped strip which is protruded inside the square-ring radiating stub can perturb the resonant response and also acts as a half-wave resonant structure [5–6]. At the notched frequency, the current flows are more dominant around the protruded element, and they are oppositely directed between the protruded element and the square-ring radiating stub. As a result, the desired high attenuation near the notched frequency can be produced.

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. At the 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. λ_S 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. 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.

The final values of presented slot antenna design parameters are as follows:

Table 1. The final dimensions of the designed antenna

Param	mm	Param	mm	Param	mm
W_{sub}	20	L_{sub}	20	W_s	18
L_s	11	W	7	L_{gnd}	6
W_f	1.5	L_f	4	W_R	6
L_p	4.5	W_p	2	L_{p1}	4.5
W_{p1}	2.5	L_{p2}	5	W_{p2}	2
L_{p3}	0.5	d	7	L_x	5
W_x	6	L_{x1}	2.5	W_{x1}	2
L_{x2}	2.5	W_{x2}	1	L_{x3}	3.5
L_{x4}	0.5				

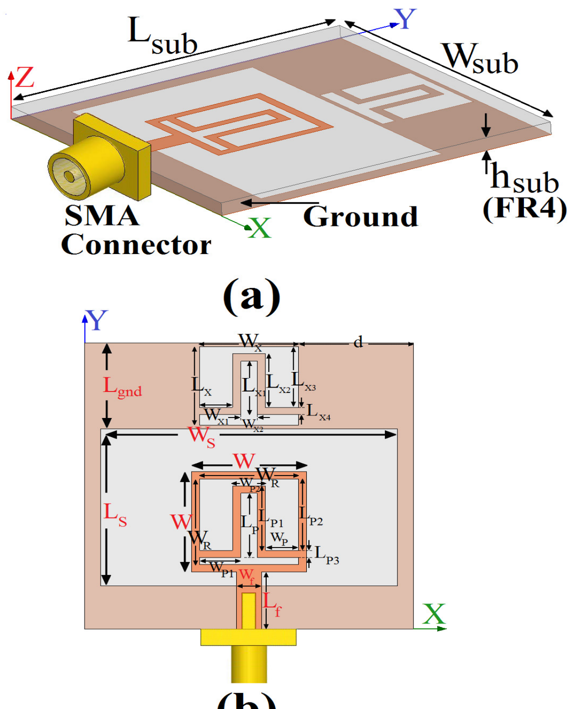

Fig. 1. Geometry of proposed slot antenna, (a) side view, (b) top view.

III. RESULTS AND DISCUSSIONS

In this section, the proposed 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 proposed microstrip-fed slot antenna was fabricated and tested to demonstrate the effect of the presented structure. The parameters of this proposed antenna were studied by changing one parameter at a time while others were kept fixed. The simulated results are obtained using the Ansoft simulation software high frequency structure simulator (HFSS) [9].

The configurations of various antenna structures are shown in Fig. 2. VSWR characteristics for ordinary slot antenna (Fig. 2 (a)), slot antenna with a rectangular slot with an Ω-shaped strip protruded inside the slot in the ground plane (Fig. 2(b)), and the proposed slot antenna structure (Fig. 2 (c)), are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by the presence of the rectangular slot and the protruded Ω-shaped strip, which are placed in top section of the ground plane. Moreover, the notched frequency bandwidth is sensitive to the square-ring radiating stub which has a Ω-shaped strip protruded inside the square ring.

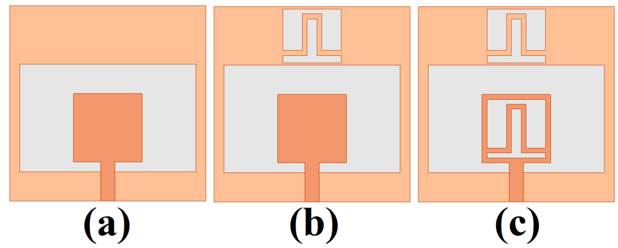

Fig. 2. (a) Basic structure (ordinary slot antenna), (b) antenna with a rectangular slot with a Ω-shaped strip protruded inside the slot in the ground plane, (c) the proposed slot antenna.

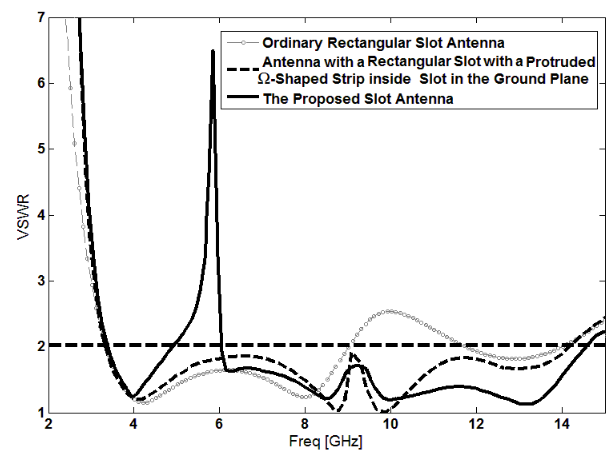

Fig. 3. Simulated VSWR characteristics for antennas shown in Figure 2.

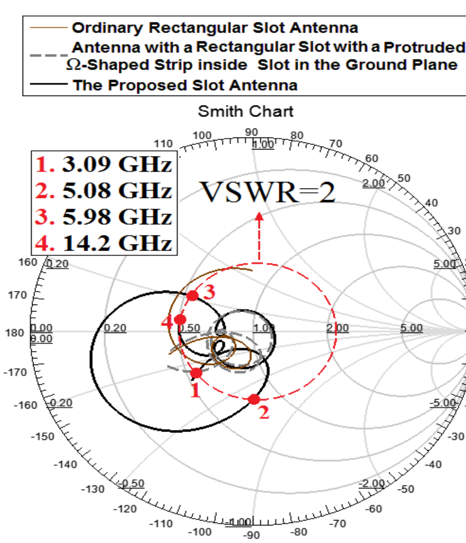

Fig. 4. Smith chart demonstration of simulated input impedance of the various antenna structures which are shown in Fig. 2.

Also the input impedance of the various slot antenna structures that are shown in Fig. 2, are presented on a Smith Chart, as shown in Fig. 4.

To understand the phenomenon behind this bandwidth enhancement, the simulated current distributions on the ground plane for the slot antenna with a rectangular slot in the top section of the ground plane, which has a Ω-shaped strip protruded inside it, at 9.85 GHz is presented in Fig. 5 (a). It can be observed in Fig. 5 (a) that at 9.85 GHz the current concentrates on the edges of the rectangular slot and the interior and exterior edges of the protruded Ω-shaped strip, which are placed on top section of the ground plane. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the protruded strips. It is found that by using this structure, third resonance is generated at 9.85 GHz [4]. Another important design parameter of this structure is the square-ring radiating stub with a Ω-shaped strip which is protruded inside the square ring. Fig. 5 (b) presents the simulated current distributions on the radiating stub plane at the notched frequency (5.5 GHz). As shown in Fig. 5 (b), at the notched frequency the current flows are more dominant around the edges of the square-ring radiating stub and the Ω-shaped strip which is protruded inside the square-ring. As a result, the desired high attenuation near the notched frequency can be produced [7].

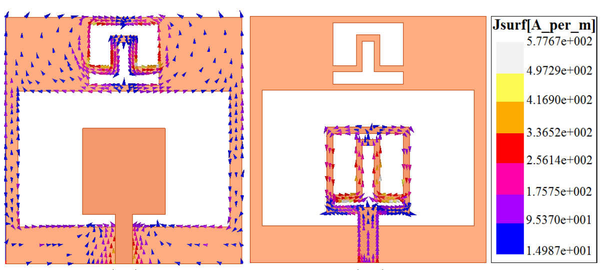

Fig. 5. Simulated surface current distributions (a) on the ground plane for the slot antenna with a rectangular slot with a Ω-shaped strip protruded inside the slot in the ground plane at 9.85 GHz, (b) on the radiating stub for the proposed antenna at notch central frequency (5.5 GHz).

VSWR characteristics for various values of the feed gap distance of the bottom edge of the square radiating stub and the ground plane (*d*) were analyzed and are illustrated in Fig. 6. From the results, it is observed that the feed gap distance *d* is an important parameter in determining the sensitivity of impedance matching.

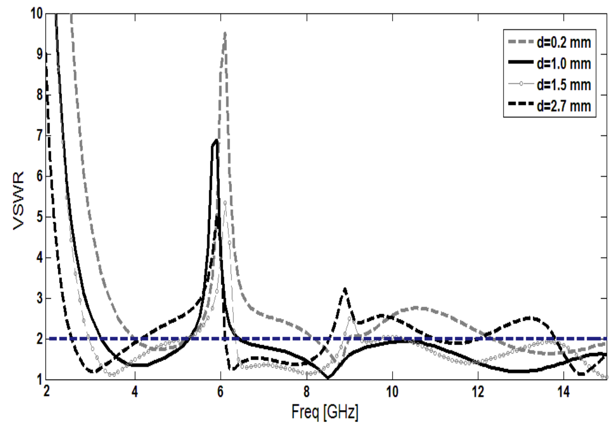

Fig. 6. The effect of various values of d (the feed gap distance) on VSWR.

By adjusting *d*, the electromagnetic coupling between the bottom edge of the square ring radiating stub and the ground plane can be properly controlled [6]. It is seen that the lower-edge frequency of the impedance bandwidth is reduced with increasing the gap distance, but the matching became poor for larger values. Therefore it can be seen that the optimized gap, *d*, is 1 mm.

The measured and simulated VSWR characteristics of the proposed antenna are shown in Fig. 7. The fabricated antenna covers the frequency band of 3.07 to over 14.03 GHz with a band-notch function around 5.02-5.97 GHz. As shown in Fig. 7, there exists a discrepancy between the measured data and the simulated results. In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of a SMA connector and a microstrip line (the microstrip feed-line is excited by a SMA connector) whereas the simulated results are obtained using the Ansoft simulation software (HFSS), that in HFSS by default, the antenna is excited by a wave port that it is renormalized to a 50-Ohm full port impedance at all frequencies, therefore this discrepancy between measured data and the simulated results could be due to the effect of the SMA port [6]. In order to confirm the accuracy of VSWR characteristics for the designed antenna, it is recommended that the manufacturing and measurement processes need to be performed more carefully. In conclusion, as the slot antenna is a short radiator, the SMA connector can degrade its impedance matching.

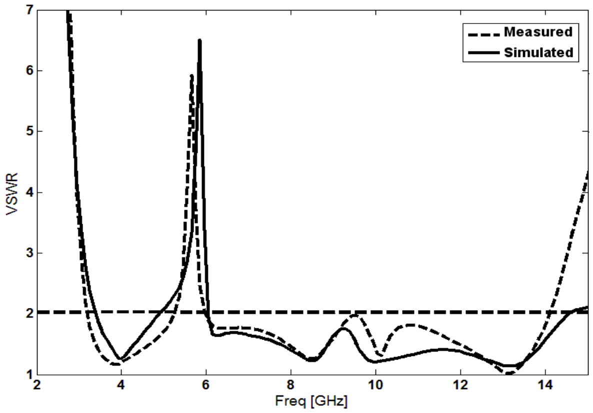

Fig. 7. Measured and simulated VSWR characteristics of the proposed antenna.

Figure 8 illustrates the measured radiation patterns, including the co–polarization and cross–polarization, in the H–plane (x–z plane) and E–plane (y–z plane). It can be seen that the radiation patterns in *x–z* plane are nearly omnidirectional for three frequencies.

The radiation patterns have been measured inside an anechoic chamber. A two-antenna technique is used to measure the radiation patterns in the z axis direction (x-z plane). Single polarization standard horn is used as transmitter and the fabricated antenna is put as receiver (antenna under test). These measurements were obtained using indoor anechoic chamber room. Several requirements are needed to take into consideration during the measurement process. Obtaining true patterns depends primarily on accurately positioning the probe, accurately measuring the field, and eliminating distortions in the field introduced by the room, track, or the probe itself. The room reflections must be lower than the basic side-lobe-level. The probe itself must have low reflections and accurate position. The measured radiation patterns were plotted into horizontal (H) and vertical (V) cuts. The H-cut is cut for the azimuth plane with fixed elevation angle at 0^0 and vary the azimuth angle. The V-cut is cut for the elevation plane with fixed azimuth angle at 0^0 and vary the elevation angle.

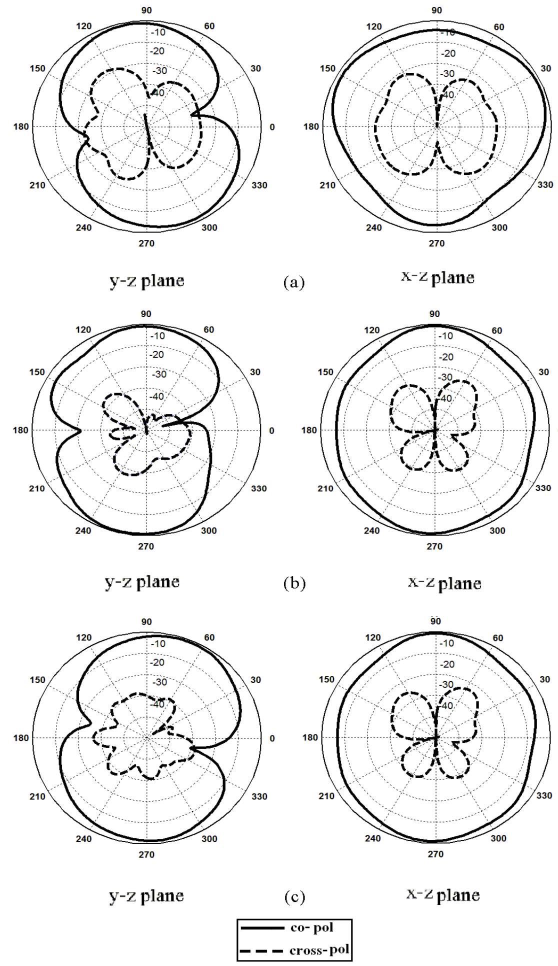

Fig. 8. Measured radiation patterns of the proposed antenna. (a) 4.8 GHz, (b) 7.5 GHz, and (c) 10 GHz.

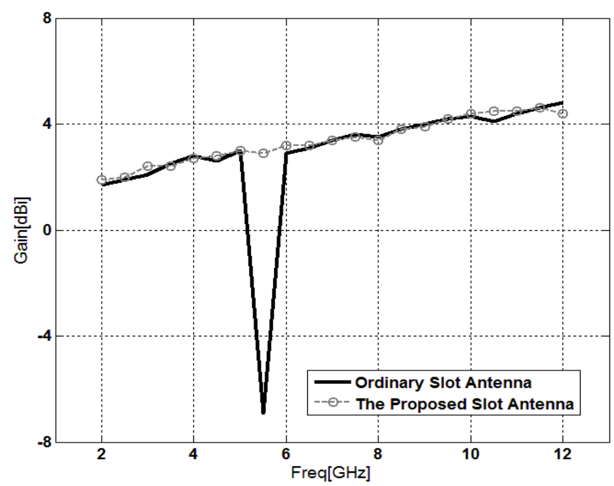

Fig. 9. Maximum gain comparison for the ordinary slot antenna (simulated), and the proposed antenna (measured) in the z axis direction (x-z plane).

Figure 9 shows the effects of the rectangular slot with a **Ω**-shaped strip protruded inside the slot in the ground plane, and a square-ring radiating stub with a **Ω**-shaped strip protruded inside the square ring on the maximum gain in comparison to the ordinary slot antenna without them. As shown in Fig. 9, the ordinary slot antenna has a gain that is low at 3 GHz and increases with frequency. It is found that the gain of the ordinary antenna is decreased with the use of the rectangular slot with a **Ω**-shaped strip protruded inside the slot in the ground plane, and the square-ring radiating stub with a **Ω**-shaped strip protruded inside the square ring. It can be observed in Fig. 9 that by using these structures, a sharp decrease of maximum gain at the notched frequency band of 5.5 GHz occurs. For other frequencies outside the notched frequencies band, the antenna gain with the filter is similar to those without it.

V. CONCLUSION

A new slot antenna with band-notch function for UWB applications is presented. The proposed antenna can operate from 3.07 to 14.03 GHz with WLAN rejection band performance around 5.02–5.97 GHz. In order to enhance the bandwidth we use a rectangular slot with a **Ω**-shaped strip protruded inside the slot in the ground plane, and also by using a square-ring radiating stub with a **Ω**-shaped strip protruded inside the square ring, a frequency band-notch function can be achieved. The designed antenna has a small size of 20×20 mm^2. Simulated and experimental results show that the proposed slot antenna could be a good candidate for UWB applications.

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