Progress In Electromagnetics Research C, Vol. 47, 111–117, 2014

Application of Protruded Strip Resonators to Design an UWB Slot Antenna with WLAN Band-Notched Characteristic

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Abstract—In this paper, a different method for designing a novel and compact microstrip-fed slot antenna with band-notched characteristic for UWB application is proposed. In the proposed antenna, a pair of cross-shaped strips protruded inside an extra rectangular slot in the ground plane are used to crate an additional resonance in higher frequencies. By obtaining this resonance, the usable upper frequency of the antenna is extended from 9 to 14.8 GHz which provides a wide usable fractional bandwidth of more than 135%. Additionally, by using a square ring radiating stub with a pair of protruded T-shaped strips inside the ring, a desired frequency band-stop performance has been obtained. Good antenna gain and VSWR characteristics are obtained in the frequency band of interest. The proposed antenna can operate from 3.04 to 14.8 GHz for VSWR < 2 with a rejection band around 5.1 to 6 GHz to suppress any interference from wireless local area network (WLAN) systems. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

1. INTRODUCTION

After allocation of the frequency band from 3.1 to 10.6 GHz for the commercial use of ultra-wideband (UWB) systems by the federal communication commission (FCC) [1], these systems have received phenomenal gravitation in wireless communication. Designing an antenna to operate in the UWB band is quite a challenge because it has to satisfy the requirements such as ultra wide impedance bandwidth, omni-directional radiation pattern, constant gain, high radiation efficiency, constant group delay, low profile, easy manufacturing, etc. [2]. 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. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized [3–6].

In [3], a compact hexagonal structure is used to enhance the impedance bandwidth. Based on defected ground structure (DGS) and electromagnetic coupling theory (ECT), pairs of L-shaped conductor-backed plane are used to excite more resonances in [4, 5]. A novel CPW-fed E-shaped slot antenna, which provides a wide usable fractional bandwidth of more than 115%, was reported in [6]. Moreover, other strategies to improve the impedance bandwidth, which do not involve a modification of the geometry of the planar antenna, have been investigated [7, 8].

There are many narrowband communication systems which severely interfere with the UWB communication system, such as the WLAN for IEEE 802.11a operating in 5.15–5.35 and 5.725–5.825 GHz bands. Therefore, UWB antennas with band-notched characteristic to filter the potential interference are desirable. Nowadays, to mitigate this effect many UWB antennas with various band-notched properties have been developed [8–11].

A new design of microstrip-fed slot antenna with band-stop function for UWB applications is designed and manufactured. By using two cross-shaped strips protruded inside the extra rectangular

Received 6 January 2014, Accepted 7 February 2014, Scheduled 12 February 2014
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slot in the ground plane, an additional resonance in higher frequencies (9 GHz) was excited. To generate a frequency band-stop function, a pair of T-shaped strips are used inside the square-ring radiating stub. The designed antenna has a small size of $20 \times 20 \times 0.8\,\mathrm{mm}^3$.

2. ANTENNA DESIGN

The proposed antenna fed by a 50-ohm microstrip line is shown in Fig. 1, which is printed on a FR4 substrate of thickness 0.8 mm, and permittivity 4.4. The width of the microstrip feed-line is fixed at 1.5 mm. The basic antenna structure consists of a square radiating stub, a feed-line, and a slotted ground plane. The proposed antenna is connected to a 50-Ohm subminiature version A (SMA) connector for signal transmission. Final values of the presented antenna design parameters are specified in Table 1.

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. In the next step, we have to determine the aperture width

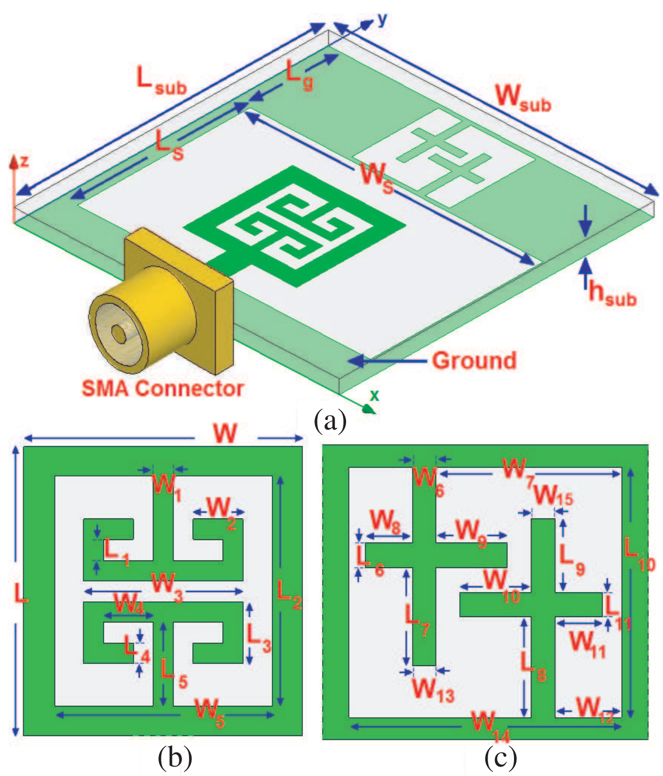

Figure 1. Geometry of proposed antenna, (a) side view, (b) radiating stub, and (c) modified DGS.

Table 1. Final dimensions of the proposed antenna.

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L	W_f	L_f	W_S	L_S
Value (mm)	20	20	0.8	7	7	1.5	4	18	11
Parameter	W_1	L_1	W_2	L_2	W_3	L_3	W_4	L_4	W_5
Value (mm)	0.5	0.5	1.25	5	4	1.5	1.25	0.5	5
Parameter	L_5	W_6	L_6	W_7	L_7	W_8	L_8	W_9	L_9
Value (mm)	1.75	0.5	0.5	4	2	1	2.25	1.5	1.5
Parameter	W_{10}	L_{10}	W_{11}	L_{11}	W_{12}	W_{13}	W_{14}	L_g	W_{15}
Value (mm)	1.5	5.5	1	0.5	1.5	0.5	6	6	0.5

W_S. The aperture width is approximate, where 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 width of the radiating patch W. This parameter is approximate, where is the guided wavelength in the microstrip line [3]. The optimized length of $L_{resonance}$ is set to resonate at 0.5λ where $L_{resonance} = W_{L1} + W_{L2} + L_L$ and $L_{resonance} = W_6 + L_7 + W_8 + L_9$ correspond to the extra resonance frequency (9.5 GHz). Also, the optimized length of L_{notch} is set to band-stop resonate where $L_{notch} = W_2 + L_3 + W_3 + L_5$ which corresponds the band-notch frequency (5.5 GHz).

In this study, to design a novel antenna, the modified protruded cross-shaped and T-shaped strips are placed inside rectangular slot in the ground plane and square-ring stub, respectively. Regarding defected ground structures (DGS) theory, the creating slots in the ground plane provide additional current paths. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth [4, 5]. Therefore, by cutting an extra rectangular slot with a pair of cross-shaped strips in the ground plane, much enhanced impedance bandwidth may be achieved. In addition, to create a desired band-stop characteristic, a pair of T-shaped strips are protruded inside square-ring radiating stub. At the notched frequency, the current flows are more dominant around the T-shaped strips, and they are oppositely directed between the parasitic element and radiating stub. As a result, the desired high attenuation near the notch frequency can be produced [7].

3. RESULTS AND DISCUSSIONS

In this section, the presented antenna with various design parameters was constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [12].

The configuration of the presented antenna is shown in Fig. 1. Voltage standing wave ratio (VSWR) for the ordinary slot antenna (Fig. 2(a)), the antenna with a pair of cross-shaped strips (Fig. 2(b)), and the proposed antenna (Fig. 2(c)) structures are compared in Fig. 3.

As shown in Fig. 3, by using a pair of cross-shaped strips protruded inside the extra rectangular slot in the ground plane, a new resonance at 9.5 GHz is generated, and the usable upper frequency of the antenna is extended from 9 GHz to 14.8 GHz. The protruded T-shaped strips at the square-ring radiating stub are used in order to obtain the WLAN frequency band-stop performance [13]. Also input impedance of the proposed antenna structure, which is shown in Fig. 1, on a Smith Chart is shown in Fig. 4.

To understand the phenomenon behind the bandwidth enhancement and band-notched performances, simulated current distributions for the proposed slot antenna in the ground plane at 9.5 GHz (new resonance frequency) and in the radiating stub at 5.5 GHz (notched frequency) are presented in Fig. 4. It can be observed in Fig. 4(a), at 9.5 GHz the current concentrated on the edges

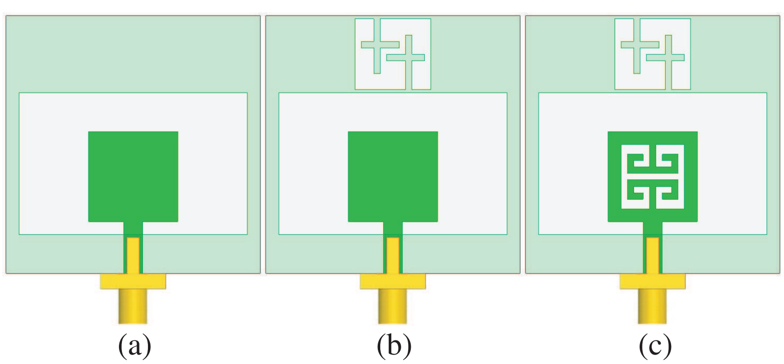

Figure 2. (a) Open-stub microstrip line, (b) open-stub microstrip line with minder-line strip, and (c) the proposed antenna structure.

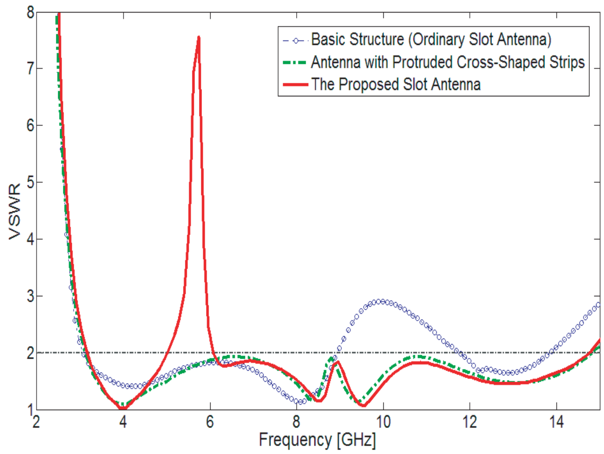

Figure 3. Simulated return loss characteristics for the various antenna structures shown in Fig. 2.

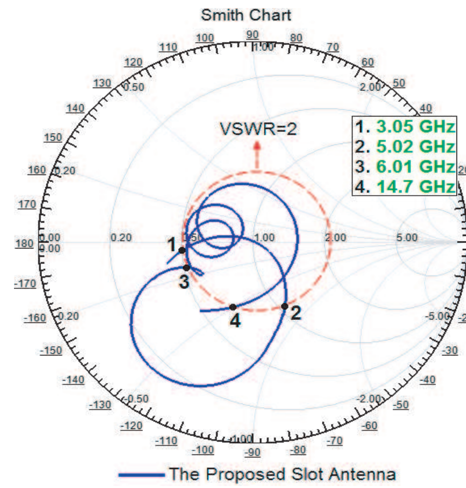

Figure 4. Smith chart demonstration of simulated input impedance for the proposed antenna.

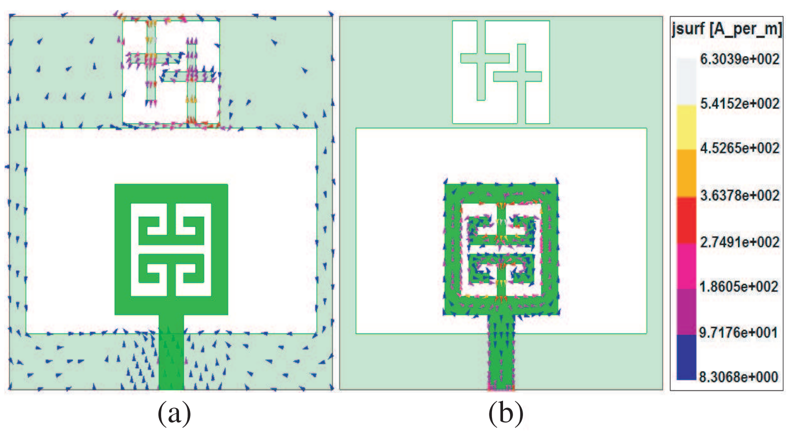

Figure 5. Simulated surface current distributions for the proposed antenna (a) at 2.45 GHz and (b) at 5.8 GHz.

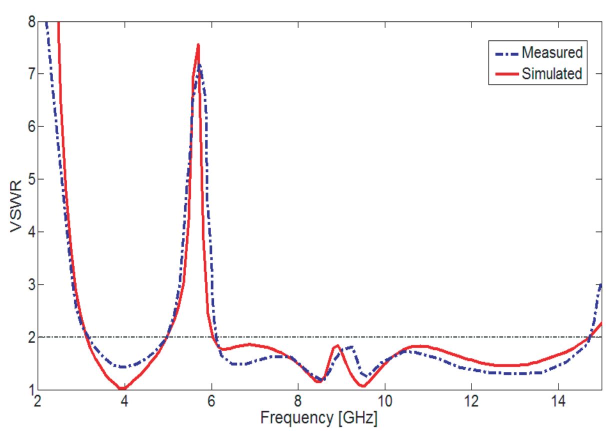

Figure 6. Measured and simulated VSWR characteristics of the proposed antenna.

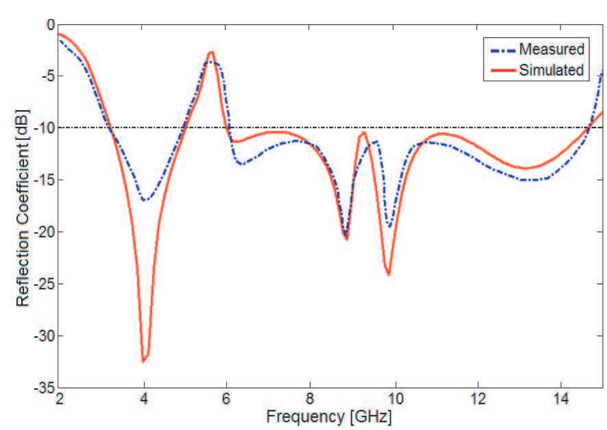

Figure 7. Measured and simulated reflection coefficient of the proposed antenna.

of the interior and exterior of the protruded cross-shaped strips. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the embedded structure in the ground plane [16]. As shown in Fig. 5(b), at the notched frequency the current flows are more dominant around the T-shaped strips inside the square-ring radiating stub. As a result, the desired high attenuation near the notched frequency can be produced [13, 14].

Figure 6 illustrates the measured and simulated VSWR characteristics for the proposed antenna. The fabricated antenna has the frequency band of 2.92 to over 13.5 GHz with a rejection band around of 5–6 GHz. Also, the measured and simulated reflection coefficients (S_{11}) of the proposed antenna are

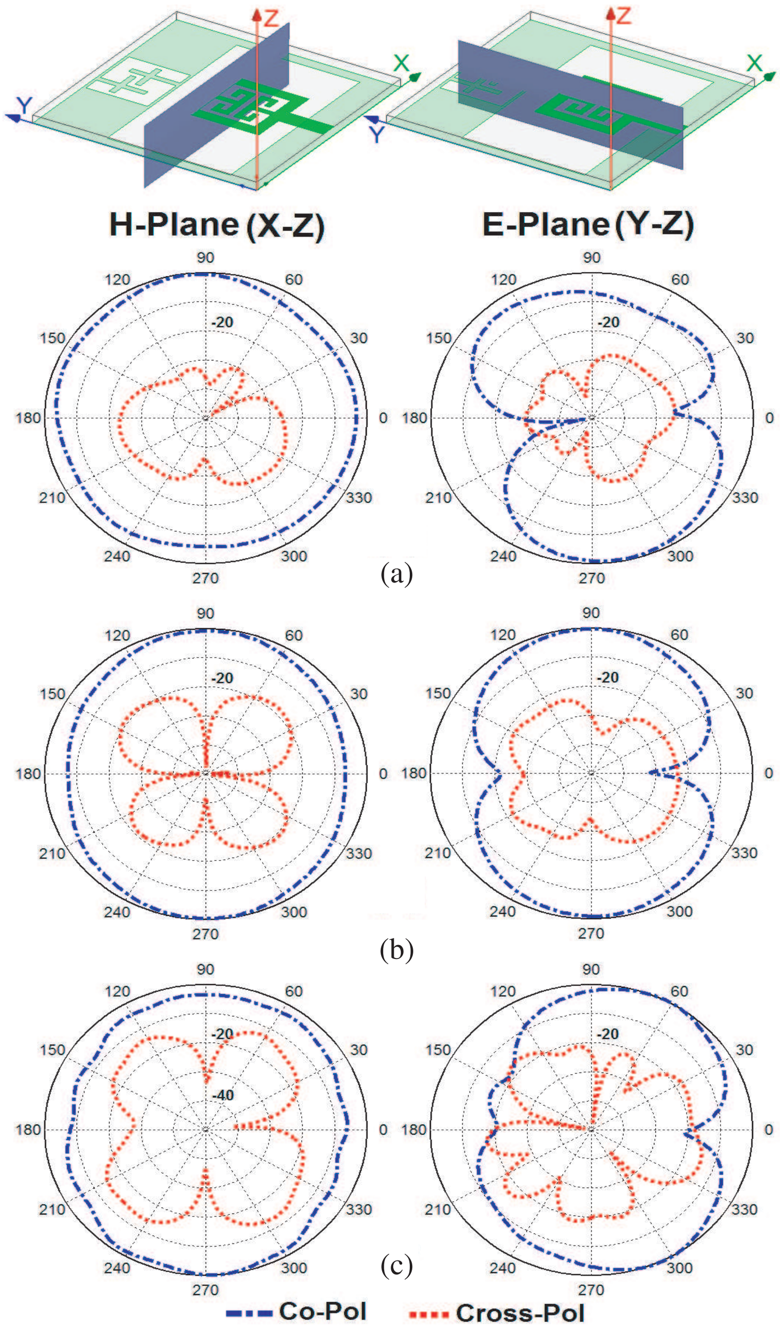

Figure 8. Measured radiation patterns of the proposed antenna at (a) 4 GHz, (b) 9 GHz and (c) 14 GHz.

presented in Fig. 7.

However, as seen, there exists a discrepancy between measured data and simulated results. This discrepancy is mostly due to a number of parameters such as the fabricated antenna dimensions, the thickness and dielectric constant of the substrate, on which the antenna is fabricated, and the wide range of simulation frequencies. 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), in which by default, the antenna is excited by a wave port which is renormalized to a 50-Ohm full port impedance at all frequencies. In order to confirm the accurate return loss characteristics for the designed antenna. It is recommended that the manufacturing and measurement processes need to be performed carefully. Moreover, SMA soldering accuracy and FR4 substrate quality need to be taken into consideration.

Figure 8 depicts the measured and simulated radiation patterns of the proposed antenna 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 quasi-omnidirectional radiation pattern can be observed on x-z plane over the whole UWB frequency range, especially at the low frequencies. The radiation pattern on the y-z plane displays a typical figure-of-eight, similar to that of a conventional dipole antenna. It should be noticed that the radiation patterns in E-plane become imbalanced as frequency increases because of the increasing effects of the cross polarization. The patterns indicate that at higher frequencies, more ripples can be observed in both E- and H-planes owing to the generation of higher-order modes. The cross-polarization component also increases at higher frequencies due to the increased horizontal surface currents [15].

Measured maximum gain of the proposed antenna is shown in Fig. 9. As illustrated, a sharp decrease of maximum gain in the notched frequency band at 5.5 GHz is shown in Fig. 9. For other frequencies outside the notched frequency band, the antenna gain with the filter is similar to the one without the filter. As seen, the proposed antenna has sufficient and acceptable gain level in the operation bands [16].

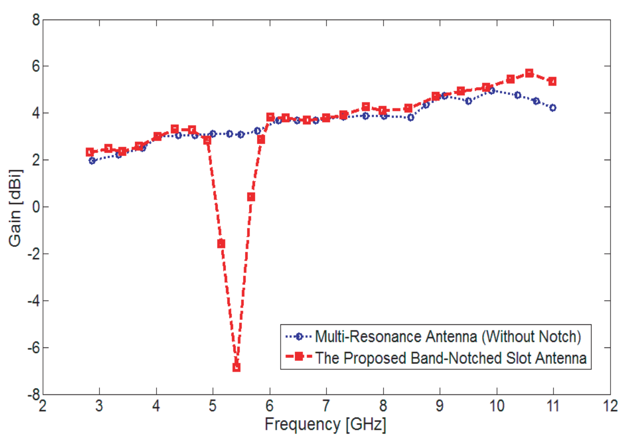

Figure 9. Measured maximum gain for the proposed antenna.

4. CONCLUSION

A novel small microstrip slot antenna with a band-stop property for UWB applications is proposed. In this design, the proposed antenna bandwidth is from 3.04 to 14.8 GHz with a rejection band around 5.1 to 6 GHz. The antenna structure consists of a square-ring radiating sub with a pair of T-shaped strips protruded inside the ring, a feed-line and a slotted ground plane with a pair of protruded cross-shaped strips inside the extra rectangular slot. The proposed antenna displays a good omnidirectional radiation pattern even at higher frequencies. The designed antenna has a small size. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications. The designed antenna has a compact size of $20 \times 20\,\mathrm{m}^2$.

ACKNOWLEDGMENT

The author is thankful to Microwave Technology (MWT) Company staff for their beneficial and professional help (www.microwave-technology.com).

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