An UWB Microstrip-Fed Slot Antenna with Enhanced Bandwidth and WLAN Band-Notched Characteristics

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Abstract ─ In this paper, a compact Ultra-Wideband (UWB) slot antenna with band-notched performance is presented. In order to increase the impedance bandwidth of an ordinary slot antenna, we use a pair of S-shaped slots in the ground plane that with this structure, a new resonance at the higher frequencies can be achieved and a wide usable fractional bandwidth of more than 130% is provided. Additionally, by using a protruded E-shaped strip inside the square-ring radiating patch, a frequency band-notched function 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 3.13 to over 14.3 GHz, with a band rejection performance in the frequency band of 5 to 6 GHz. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

Index Terms ─ Band-notched function, microstrip-fed slot antenna, UWB systems.

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of an antenna while providing wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized [1-2]. Moreover, other strategies to improve the impedance bandwidth have been investigated [3-5].

The frequency range for UWB systems between 3.1-10.6 GHz will cause interference to the existing wireless communication systems, for example the Wireless Local Area Network (WLAN) for IEEE 802.11a operating in 5.15-5.35 GHz and 5.725-5.825 GHz bands, so the UWB antenna with band-notched function is required [6-9].

In this paper, a compact microstrip-fed slot antenna with band-notched characteristic for UWB applications has been designed and manufactured. In the proposed design, by cutting a pair of S-shaped slots in the ground plane, an additional resonance at middle frequencies was excited. By obtaining this resonance, the usable upper frequency of the antenna is extended from 9.3 GHz to 14.3 GHz. To generate a frequency band-notched function, we use a square-ring stub with rotated E-shaped strip protruded inside the square ring [6]. The designed antenna has a small size of 20×20×0.8 mm^3, and the impedance bandwidth of the designed slot antenna is higher than the UWB antennas reported recently [1-3].

II. ANTENNA DESIGN

The proposed slot antenna fed by a 50-Ω microstrip line is shown in Fig. 1, which is printed on an *FR4* substrate of thickness 0.8 mm and permittivity of 4.4. The width of the microstrip feed line is fixed at 1.5 mm. The basic antenna structure consists of square radiating stub, feed line, and slotted ground plane.

In the proposed antenna, the square-ring stub with a protruded E-shaped strip inside the ring is connected to a feed line, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane with a pair of S-shaped slots is placed. The proposed antenna is connected to a

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50-Ω SMA connector for signal transmission. Final dimensions of the designed antenna are shown in Table 1.

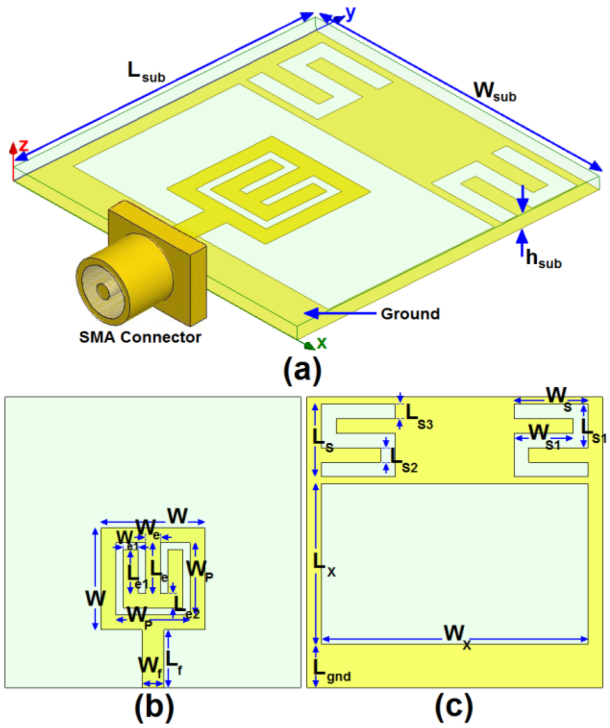

Fig. 1. Geometry of the proposed microstrip-fed slot antenna: (a) side view, (b) top layer, and (c) bottom layer.

Table 1: The final dimensions of the antenna

Param.	mm	Param.	mm	Param.	mm
W_{sub}	20	L_{sub}	20	W	7
W_S	5	W_P	4.5	W_X	18
L_X	11	W_f	1.5	L_f	4
W_{S1}	4	L_{S1}	3.25	W_{S2}	1
L_{S2}	0.5	L_{S3}	1.25	L_{S4}	0.5
W_e	1	L_e	3	W_{e1}	0.75
L_{e1}	2.5	L_{e2}	0.75	L_{gnd}	3

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 W_S. The aperture width is approximate, whereas 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 following step in the design is to choose the width of the radiating patch *W*. This parameter is approximate, whereas the guided wavelength is the microstrip line [3]. The last and final step in the design is to choose the length of the resonator and the band-stop filter elements. In this design, the optimized length $L_{resonance}$ is set to resonate at $0.25\lambda_{resonance}$, where $L_{resonance}=L_{S1}+L_{S2}+L_{S2}+0.5\ W_{S1}$. Also, the optimized length L_{notch} is set to band-stop resonate at $0.5\lambda_{notch}$, where $L_{notch}=L_e+0.5(W_{e1}+L_{e1})+W_P-W_e$. λ_{notch} corresponds to band-notched frequency (5.5 GHz).

In this study, to design a novel antenna, the modified S-shaped Defected Ground Structures (DGSs) is placed inside the ground plane. Regarding ECT, by inserting these structures in the substrate backside, additional coupling is introduced between the radiating stub and the ground plane, and the antenna impedance bandwidth is improved without any cost of size or expense. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth [4-6]. In addition, to create a desired frequency band-stop characteristic, an inverted E-shaped strip which protruded inside square-ring radiating stub is used. At the notched frequencies, the current flows are more dominant around the E-shaped structure, and they are oppositely directed between the embedded structure and the radiating stub. As a result, the desired high attenuation near the notched frequency can be produced [10-11].

III. RESULTS AND DISCUSSIONS

The proposed microstrip-fed slot 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 Ansoft simulation software High-Frequency Structure Simulator (HFSS) [12] is used to optimize the design.

The configuration of the presented slot antenna is shown in Fig. 1. Configuration of the ordinary slot antenna [Fig. 2 (a)], the antenna with a pair of S-shaped slots in the ground plane [Fig. 2 (b)], and the proposed antenna [Fig. 2 (c)] are shown in Fig. 2. Return loss characteristics for the structures shown in Fig. 2 are compared in Fig. 3. As illustrated, it is observed that the upper frequency bandwidth is affected by using the pair of S-shaped slots in the ground plane, and the notched frequency bandwidth is sensitive to the rotated E-shaped strip inside the square-ring radiating stub.

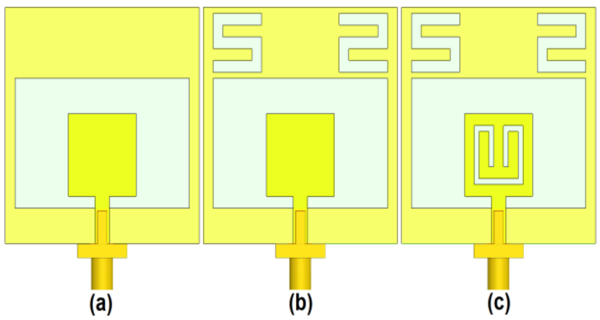

Fig. 2. (a) Ordinary slot antenna, (b) antenna with a pair of S-shaped slots in the ground plane, and (c) the proposed slot antenna.

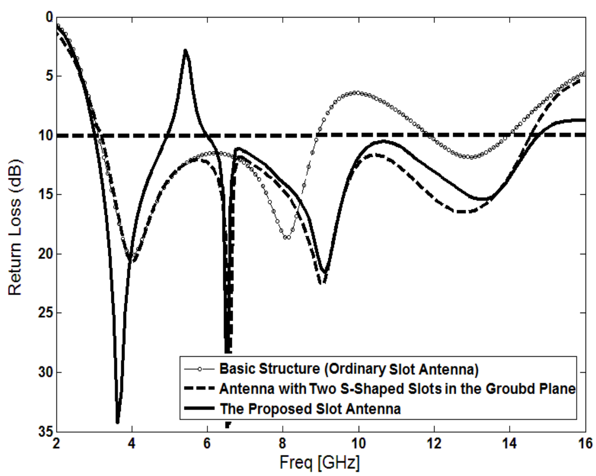

Fig. 3. Simulated return loss characteristics for the various antennas shown in Fig. 2.

To understand the phenomenon behind the additional resonance performance, the simulated current distributions in the ground plane for the proposed antenna at 6.7 GHz is presented in Fig. 4 (a). It is found that by using the S-shaped slots, a new resonance at 6.7 GHz can be achieved. Another important design parameter of this structure is the rotated E-shaped strip inside the square ring stub. Figure 4 (b) presents the simulated current distributions on the radiating stub at the notched frequency (5.5 GHz). As seen, at the notched frequency, the current flows are more dominant around of the rotated E-shaped strip [13-15]. Simulated input impedance results of the proposed antenna on a Smith Chart is shown in Fig. 5.

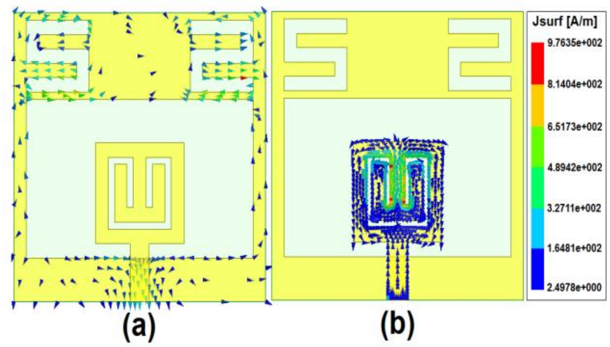

Fig. 4. Simulated surface current distributions for the proposed antenna: (a) in the ground plane at 6.7 GHz, and (b) on the radiating stub at 5.5 GHz.

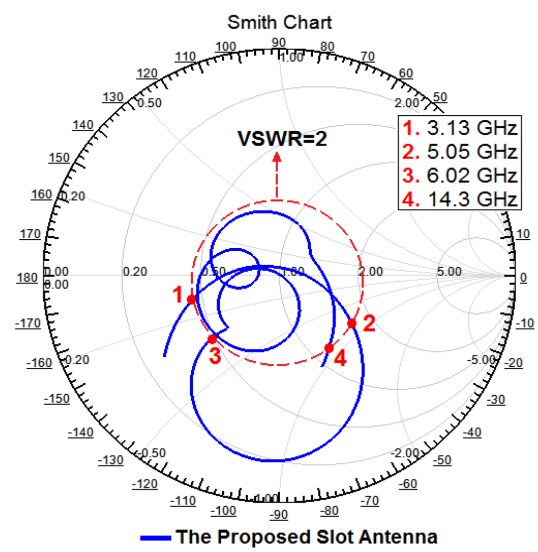

Fig. 5. Simulated Smith Chart results of proposed slot antenna.

In this study, a rotated E-shaped strip protruded inside the square ring stub with variable dimensions is used to generate the frequency band-stop performance [16-18]. The simulated VSWR curves with different values of Le are plotted in Fig. 5. As shown in Fig. 6, when the length of the rotated E-shaped strip increases from 0.75 to 2 mm, the center of notched frequency is decreased from 7.2 to 5.1 GHz. From this result, we can conclude that the notched frequency is controllable by changing the length of Le.

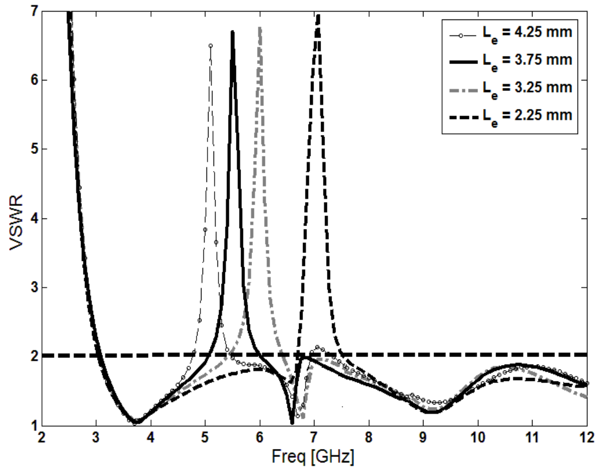

Fig. 6. Simulated VSWR characteristics for the proposed antenna with different values of Le.

Another main effect of the rotated E-shaped strip occurs on the filter bandwidth. In the presented structure, the width of We1 is the critical parameter to control the filter bandwidth. Figure 7 illustrates the simulated VSWRs with different values of We1. As the exterior width of the We1 increases from 0.25 to 1 mm, the notched frequency bandwidth is varied from 0.73 to 1.5 GHz. Therefore, the bandwidth of notched frequency is controllable by changing the width of We1.

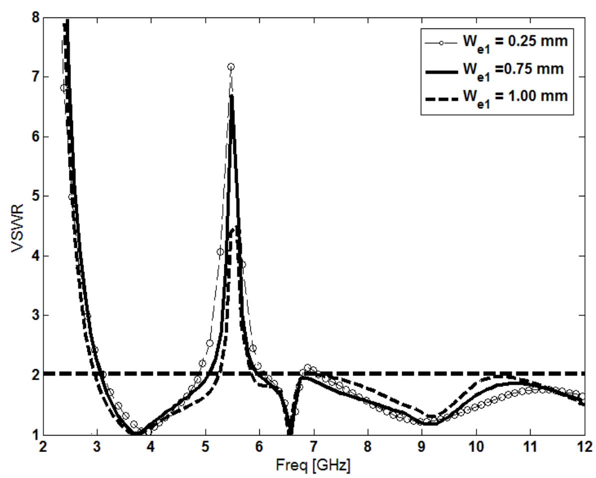

Fig. 7. Simulated VSWR characteristics for the proposed antenna with different values of We1.

The proposed antenna with final design as shown in Fig. 8, was built and tested. The VSWR characteristic of the antenna was measured using the HP 8720ES network analyzer.

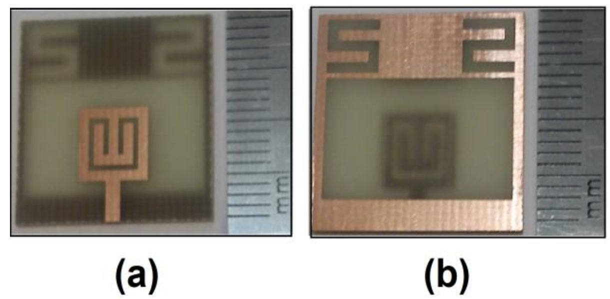

Fig. 8. Fabricated antenna: (a) top view, and (b) bottom view.

The radiation patterns have been measured inside an anechoic chamber using a double-ridged horn antenna as a reference antenna placed at a distance of 2 m. Also, two-antenna technique using an Agilent E4440A spectrum analyzer and a double-ridged horn antenna as a reference antenna placed at a distance of 2 m, is used to measure the radiation gain in the z axis direction (x-z plane). Measurement set-up of the proposed antenna for the VSWR, antenna gain and radiation pattern characteristics are shown in Fig. 9.

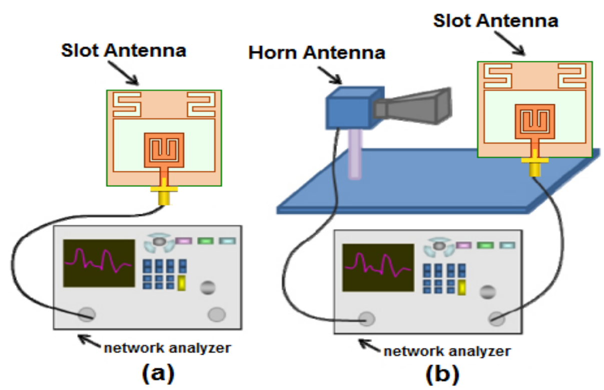

Fig. 9. Measurement set-up of the proposed antenna: (a) VSWR, and (b) antenna gain and radiation patterns.

The measured and simulated VSWR characteristic of the proposed antenna was shown in Fig. 10. The fabricated antenna has the frequency band of 3.13 to over 14.31 GHz with a rejection band around 5 to 6 GHz. However, as seen, there exists a discrepancy between the measured data and simulated results. This discrepancy is mostly due to a number of parameters, such as the fabricated antenna dimensions as well as 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); 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. 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.

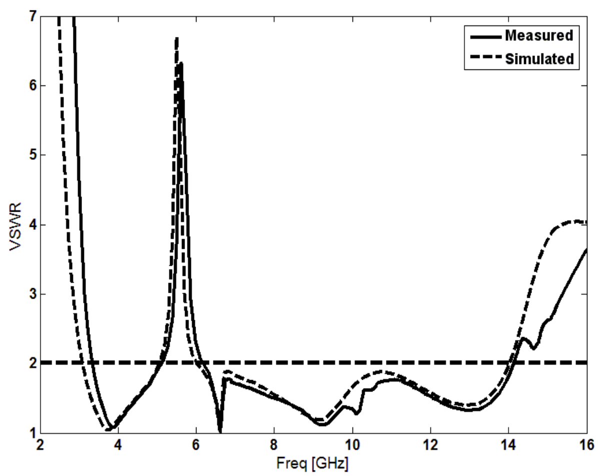

Fig. 10. Measured and simulated VSWR characteristics of the proposed antenna.

Figure 11 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 at higher frequencies; more ripples can be observed in both E- and H-planes owing to the generation of higher-order modes [19-20].

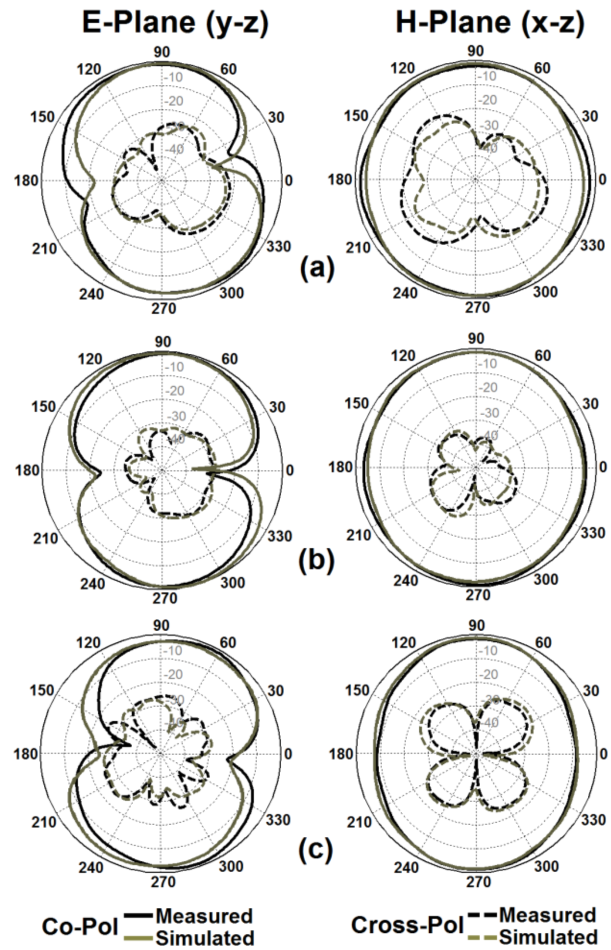

Fig. 11. Measured and simulated radiation patterns of the proposed antenna: (a) 3.5 GHz, (b) 7 GHz, and (c) 10 GHz.

Measured and simulated maximum gains of the proposed antenna w/o band-notched function were shown in Fig. 12. As illustrated, a sharp decrease of measured 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 (measured) is similar to this without it (simulated). As seen, the proposed antenna has sufficient and acceptable gain levels in the operation bands [21-22].

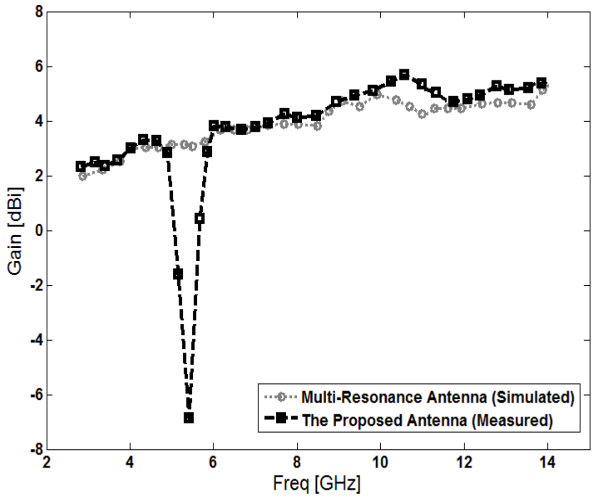

Fig. 12. Measured and simulated maximum gains for the proposed antenna.

Table 2 summarizes the previous UWB microstrip slot designs and the proposed antenna [23-30]. As seen, the proposed antenna has a compact size with very wide bandwidth, compared with the pervious works. In addition, in comparison with previous band-notched antennas, the proposed antenna displays a good omnidirectional radiation pattern, even at lower and higher frequencies. Also, the proposed microstrip-fed slot antenna has sufficient and acceptable antenna gain, co- and cross-polarization levels in the operation bands.

Table 2: Comparison of previous UWB microstrip slot antennas with the proposed design

Ref.	Size (mm^2)	Bandwidth (VSWR<2)	Gain (dBi)
[23]	22×8.5	3.1-10.6 GHz	1.5~3.5
[24]	45×50	2.9-10.8 GHz	4-7
[25]	100×100	3.1-12.0 GHz	2-8
[26]	60×60	1.5-11.1 GHz	3-8
[27]	24×24	2.8-12.0 GHz	2.5-6.5
[28]	32×24	2.9-12.5 GHz	2~6
[29]	30×30	1.8-12.4 GHz	2.5-5.5
[30]	25×25	2.6-13.0 GHz	not reported
This work	*20×20*	*3.1-14.3 GHz*	*2.2~5.7*

IV. CONCLUSION

In this paper, a novel design of ultra-wideband slot antenna with variable band-notched function is proposed. The presented slot antenna can operate from 3.13 to over 14.31 GHz with VSWR < 2, and with a rejection band around 5 to 6 GHz. By using a pair of S-shaped slots in the ground plane, additional resonance at the higher frequencies is excited and much wider impedance bandwidth can be produced. In order to generate a frequency band-stop performance, we use the square ring radiating stub with a rotated E-shaped strip inside the stub. The measured results show good agreement with the simulated and measured results. Experimental results show that the presented slot antenna could be a good candidate for UWB applications.

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