Bandwidth Enhancement of a Bell-shaped UWB Antenna for Indoor Localization Systems

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Abstract-In this paper, a simple method of enhancing the bandwidth of the Bell-shaped UWB Antenna for indoor localization systems is proposed. Therefore, a modified version of the bell-shaped Ultra-Wide Band (UWB) antenna for indoor localization systems is presented. The proposed antenna is printed on a low-cost FR-4 substrate of $21\times27\times1.6mm^3$ size. It is composed of a bell-shaped radiating patch and a multi-slotted ground plane. The measured results show that the proposed antenna has an impedance bandwidth of about 11.2GHz ranging from 3.16GHz to 14.36GHz at S11<−10dB. Compared to the original version, an enhancement of about 5.56GHz in the measured impedance bandwidth was observed.

Keywords-localization systems; printed monopole antennas; slotted ground plane; ultra wideband systems.

I. INTRODUCTION

During the last years, a large variety of antennas have been implemented for indoor localization systems. The selection of the appropriate antenna depends on many parameters and has considerable effects on the performance of the system. The study presented in [1] sums up the antenna requirements for indoor localization systems and more particularly for reference nodes. These requirements are more or less stringent, depending on the localization technique, the localization model, the metric being used during localization process and the nature of the signal being processed. As Impulse Radio Ultra Wide Band (IR-UWB) -based localization systems are commonly characterized by the transmission of ultra-short pulses over a large bandwidth, the smallest distortions introduced by the antennas lead to large localization errors. To reduce the effect of the antenna on localization accuracy, the designed antenna should respect these characteristics [1, 2]:

- Large bandwidth; ideally from 3.1GHz to 10.6GHz
- Linear phase and constant group delay over the entire bandwidth
- High radiation efficiency, typically > 70 %
- Omni-directional and stable radiation pattern
- Flat gain over the entire bandwidth
- Small size and low cost

The implementation of antennas with circular polarization over the entire bandwidth is another important characteristic for UWB antennas used for reference unit. This parameter enables the detection of targets with unknown polarization [3]. To achieve all these requirements, several antenna structures have been proposed, including 3D and planar forms. The microstrip patch antennas have gained more attention, due to their low profile, low cost, ease of fabrication, and good radiation properties. Unfortunately, they suffer from limited bandwidth. To improve their bandwidth, antenna designers have used several techniques including [2, 4-7]:

- Various feeding techniques
- Slot antenna geometry
- Addition of a slot on the radiating patch
- Insertion of an additional stub on the patch
- Addition of steps to the lower edge of the patch
- Insertion of multiple slots in the ground plane

In this study, a compact microstrip line-fed UWB antenna with partial ground plane is presented. Three slots with the same dimensions were inserted in the top edge of the ground

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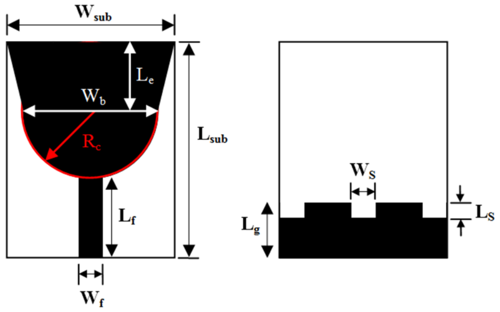
plane. With this technique, an enhancement of 5.56GHz in the measured impedance bandwidth of the antenna was achieved.

II. ANTENNA CONFIGURATION

The proposed antenna is realized on an FR-4 substrate of size (W_{sub} = 21mm × L_{sub} = 27mm) with height h = 1.6mm, relative permittivity ε_r = 4.4, and loss tangent tan δ = 0.02.



(a) (b)

Fig. 1. Geometry of the proposed antenna: (a) front view, (b) back view.

As shown in Figure 1, the front view is composed of a bell-shaped radiating patch fed by a 50Ω microstrip feed line with width W_f = 3mm and length L_f = 10mm. The radiating patch has the same shape and dimensions as the antenna presented in [8]. It is formed by the association of a trapezoid with dimensions W_b = 17mm, W_{sub} = 21mm, L_e =8.5mm and a semicircle of radius R_C = 8.5 mm. The back view of the structure consists of a partial ground plane with length L_g = 7mm. Three rectangular slots with size of W_s = 3mm × L_s = 2mm are added in the upper edge of the ground plane to enhance the impedance bandwidth of the antenna.

III. PARAMETRIC STUDY

To meet the UWB antenna requirements, a parametric study was carried out using the High Frequency Simulation Software (HFSS) v.13. To achieve the largest impedance bandwidth and to find the optimal antenna parameters, the effects of varying slot number, slot dimension, and slot positions were analyzed. During the simulations, an SMA coaxial connector was connected to the feed line to obtain more realistic results. The ground plane shape and dimensions are sensitive parameters in UWB antenna design [9-12]. Actually, the distance between the ground plane and the feed line changes the input impedance and hence the operating bandwidth of the antenna giving a better or a worst return loss. By inserting first a slot in the upper edge of the ground plane, the gap between the feed line and the ground plane is enlarged resulting in a change on the impedance bandwidth. The tuning results of slot size and position are presented in Figures 2 and 3 respectively. It can be seen from the figures, that a slot of dimensions W_S = 3mm × L_S = 2mm placed in the middle of the ground plane gives the largest impedance bandwidth. According to the simulated results, the -10dB return loss bandwidth of the antenna is about 7.89GHz ranging from 3.16GHz to 11.05GHz. To further enhance the impedance bandwidth of the antenna and to cover the entire UWB frequency band, more slots were inserted in the upper edge of the ground plane. The simulation results of S11 as a function of the number of slots are shown in Figure 4.

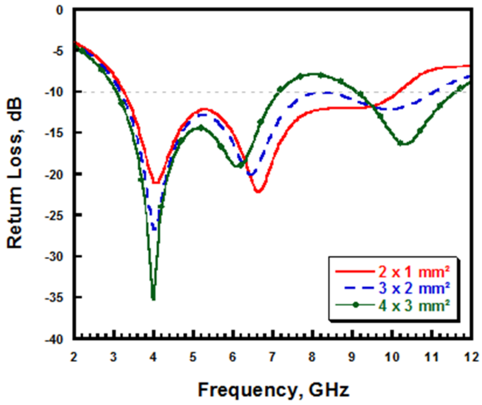


Fig. 2. Variation of the S11 for different slot dimensions.

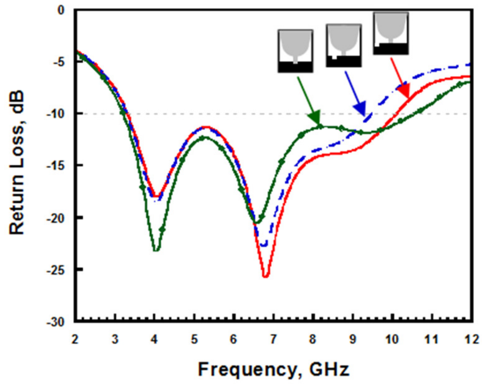


Fig. 3. Variation of the S11 for different slot positions.

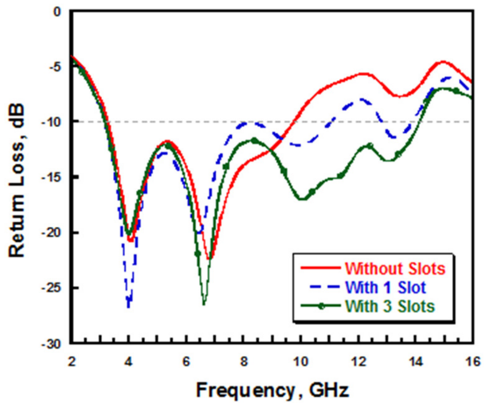


Fig. 4. Variation of the S11 as a function of the number of slots.

It can be observed from Figure 4 that the impedance bandwidth of the proposed antenna is getting larger as the number of slots increases. Actually, with the insertion of three slots in the ground plane, an enhancement of 4.47GHz in the simulated impedance bandwidth is noticed. The proposed antenna covers the frequency band from 3.16GHz to 14.11GHz, thus ensuring the coverage of almost the entire UWB frequency band. These results confirm the effect of ground plane on impedance bandwidth and prove the effectiveness of slot insertion on impedance bandwidth enhancement.

IV. RESULTS AND DISCUSSION

The prototype of the proposed antenna was fabricated on a low cost FR-4 substrate of compact size (Figure 5). All the antenna parameters were measured in the IMEP-LAHC research laboratory (Grenoble, France). The impedance characteristics were measured using The ANRITSU 37369A (40MHz – 40GHz) vector network analyzer while the gain and the radiation pattern were measured using an SATIMO anechoic chamber.

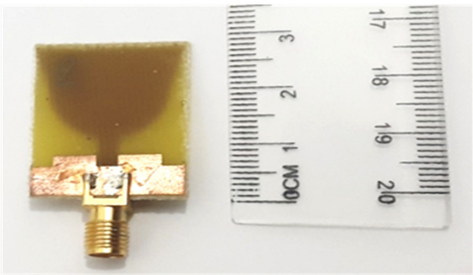


Fig. 5. Picture of the realized antenna.

A. Impedance Bandwidth

The simulated and measured return losses of the proposed antenna are presented in Figure 6. As shown in the Figure, the measured impedance bandwidth of the proposed antenna is about 11.2GHz ranging from 3.16GHz to 14.36GHz while the simulated impedance bandwidth is about 10.95GHz ranging from 3.16GHz to 14.11GHz. There is a good agreement between the simulation and the measurement results with a slight offset at the resonant frequencies and the high frequency. These discrepancies are mainly caused by the connector soldering, the fabrication process, and the nature of the substrate.

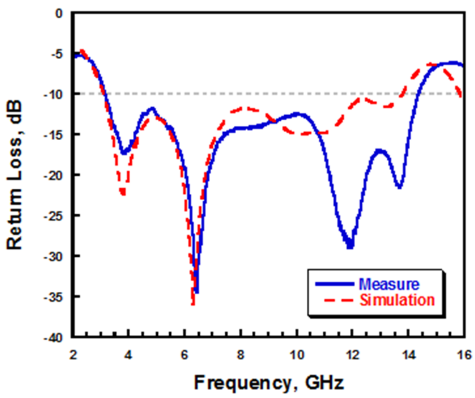


Fig. 6. Simulated and measured return loss.

B. Group Delay

The simulated group delay of the proposed antenna over the frequency band from 2GHz to 16GHz is presented in Figure 7. The simulation results show that the antenna has a group delay less than 0.5ns over the UWB frequency band and greater than 1ns outside this band. These results prove that the antenna introduces a low distortion on the transmitted UWB signal.

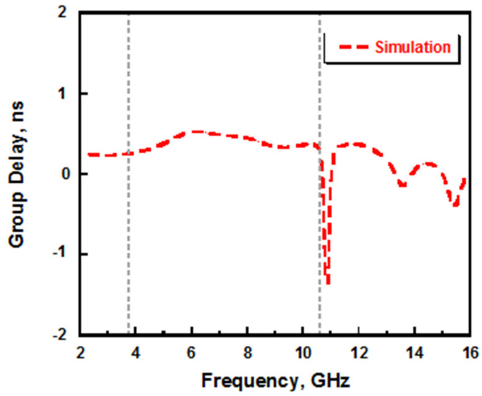


Fig. 7. Simulated group delay.

C. Peak Gain

The simulated and measured peak gains of the proposed antenna in the frequency band from 2GHz to 16GHz are presented in Figure 8. We see that the gains are larger than 1.8dBi for frequencies above 3GHz. The measured gain varies from 1.82dBi to 4dBi in the UWB band with a peak of 4.1dBi at 6.9GHz while the simulated gain varies from 0dBi to 4.38dBi with a peak of 4.38dBi at 10.3GHz. Actually, there is a slight difference between simulation and measurement results. This offset is due to the difference in the number of frequency points and the number of cuts taken during measurements.

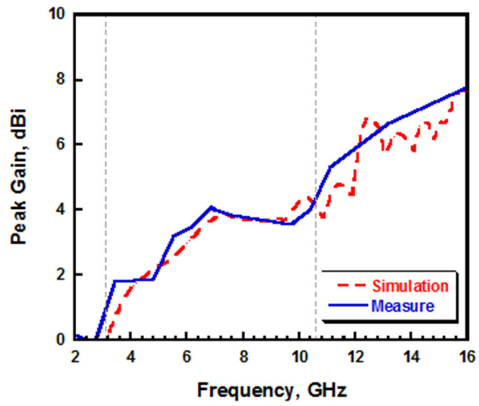


Fig. 8. Simulated and measured peak gain.

D. Radiation Pattern

Figure 9 illustrates the simulated and measured radiation patterns of the antenna in the E-plane and the H-plane at different frequencies (4.1GHz, 7GHz, 10GHz and 13GHz). The radiation pattern results show a good match between simulation and measurements with a visible offset especially at 4.1GHz and 10GHz frequencies. As shown in Figure 9, the radiation patterns of the proposed antenna are nearly omnidirectional and stable in both planes.

E. Radiation Efficiency

The simulated radiation efficiency of the proposed antenna is depicted in Figure 10. It can be seen that the proposed antenna has a maximum radiation efficiency of 98.44% at 8.6GHz with an average of 95.78%.

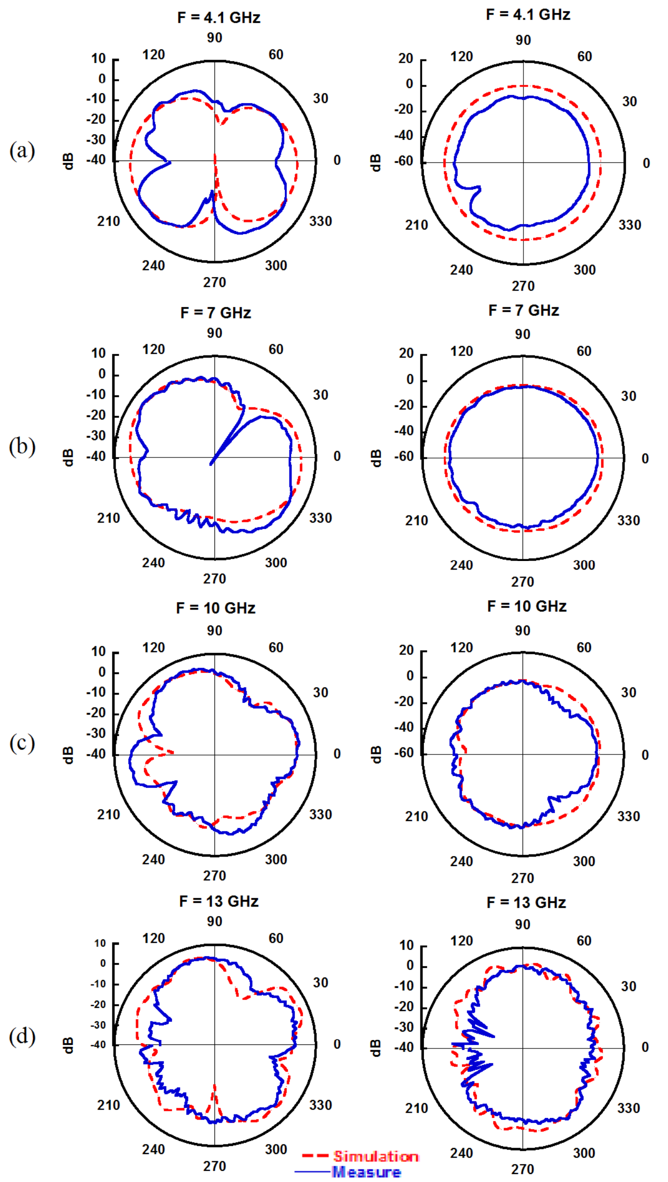


Fig. 9. Simulated and measured radiation patterns (left: E-plane, right: H-plane) at: (a) 4.1GHz, (b) 7GHz, (c) 10GHz, and (d) 13GHz.

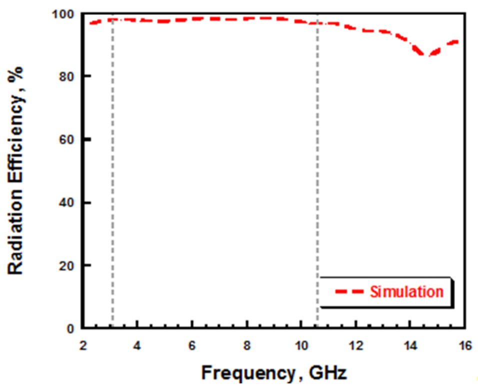


Fig. 10. Simulated radiation efficiency.

V. Comparative Study

A comparative study between antennas with slotted ground plane referenced in the literature and the proposed antenna is shown in Table I. The comparative parameters are impedance bandwidth, antenna dimensions, fractional bandwidth and maximum gain. The proposed antenna has the most compact size, a large impedance bandwidth, a high fractional bandwidth but a low gain. It is a good compromise between bandwidth and size. Fortunately, it covers the entire UWB frequency band, but in comparison with other structures, the antenna presented in [2] has larger bandwidth and gain.

TABLE I. BANDWIDTH, DIMENSIONS, FRACTIONAL BANDWIDTH AND GAIN COMPARISON

Antenna	-10dB Bandwidth (GHz)	Dimensions (mm^2)	FBW (%)	Max gain (dBi)
[2]	2.57–16.72	30×22	146.7	6.27
[4]	2.6–12.3	39×40	130.2	5.52
[13]	3.66–14	24×36	117.1	-
[14]	3.8–12	28×29	103.79	4.5
[15]	3.09–10.85	30×30	111.33	-
[16]	3.1–10.6	32×40.57	109.49	-
Proposed	3.16–14.36	27×21	127.85	4.1

VI. Conclusion

In this study, a compact and low cost microstrip bell-shaped patch antenna with three slots in the ground plane has been designed and fabricated. The return loss results prove that the insertion of rectangular slots on the upper edge of the ground plane improves the impedance bandwidth of the antenna. Indeed, compared to the original version, the measurement results show a bandwidth enhancement of about 5.56GHz, thus reaching 11.2GHz. The proposed antenna has a large impedance bandwidth ranging from 3.16GHz to 14.36GHz, which covers the entire UWB frequency band. Consequently, it remains suitable for being used in UWB localization systems with its stable gain, its low group delay and its nearly omnidirectional radiation patterns in both planes.

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