Small Design for Wireless Antenna Used by Ultra-wideband Systems

Rashid A. Fayadh[1], **F. Malek**[2], **Hilal A. Fadhil**[1], **Farah Salwani Abdullah**[2], **Sameer A. Dawood**[1], **and Ihsan Jabar Hasan**[3]

[1]School of Computer and Communication Engineering
Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia
[2]School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia
[3]Faculty of Electrical Engineering, Universiti Teknikal Malaysia (UTeM), Melaka, Malaysia

Abstract— This work focuses on ultra-wideband (UWB) antenna analysis and design. The proposed design has been undertaken to cover the area of UWB frequency range to be suitable for application of wireless UWB communication systems. UWB of 7.5 GHz is very large spectrum of frequencies which is able to achieve high transmission bit rates. As there are many challenges in indoor and outdoor wireless propagation, high gain and sensitive antenna design plays crucial role in UWB small size systems. The main object of this research is to design and implement small size UWB antenna that satisfy the ultra wide bandwidth technology requirements. The proposed antenna design has been simulated using CST microwave studio software to provide results of return loss, gain, radiation efficiency, surface current distribution, and radiation patterns. These results make the design is very useful for UWB technology applications.

1. INTRODUCTION

The wireless technology is very important in our daily lives and the people around the world use to have this technology especially in cellular phones. The wireless systems give us more free reliable to communicate to each other without position limitations. In 2002 the Federal Communications Commission (FCC) has been licensed the UWB frequency range (3.1 GHz to 10.6 GHz) [1]. Since then, it had a good attention in researches with considering as a promising technology. Because of very low transmission power (−41.3 dBm/MHz), the system elements need to be sensitive in implementation [2]. A train of short time pulses (less than 1 ns) in the transmission and reception scenarios forced us to look for high gain antennas. These antennas are very important elements for UWB systems through private and military applications. Also the lightweight, small size, low cost, high performance, easy to fabricate and integrate with other circuits is required in designing of wireless antennas. To meet the above requirements, microstrip planar antenna is achieved for design to radiate electromagnetic energy [3].

During the literature review, there are several published samples of UWB antennas such as large rectangular patch antennas of $47\,\mathrm{mm} \times 36\,\mathrm{mm}$ dimensions [4] use RF-4 substrate material and of $36\,\mathrm{mm} \times 46\,\mathrm{mm}$ dimensions using FR-4 epoxy substrate material [5]. A diamond patch shape of $30 \times 26\,\mathrm{mm}^2$ in [6] was simulated and printed on FR4 substrate to cover 95% of UWB starting from 3.39 GHz and has not got omni-directional radiation patterns. Also another antenna scheme of multiple fractal slots was implemented in [7] of $45\,\mathrm{mm} \times 25\,\mathrm{mm}$ dimensions with unstable radiation patterns. In addition, a compact microstrip patch antenna was proposed in [8] with total size of $40 \times 35 \times 1.575\,\mathrm{mm}^3$ and from the simulation results, the gain reduces at higher frequencies due to increasing the losses in the feed line.

In this work, small size antenna design with planar ground plane is proposed and curved edges of the patch are fed by microstrip feed line. This design is used to achieve the frequency range of UWB to cover most of its applications. Section 2 shows the parametric study and the dimensions of the design parameters. Sections 3 detailed the simulated results and discussions for return loss. Section 4 presents surface current distribution, and radiation patterns, while Section 5 concentrates with conclusions.

2. TWO SIDED AX-SHAPED PATCH ANTENNA CONFIGURATION AND DESIGN

The UWB digital wireless communication systems operate with narrow pulses that lead to low power and high capacity of bit rate [9]. The antenna was designed to develop the conventional rectangular patch antenna. Fig. 1 shows the design element which is including the antenna parameters and the steps of the proposed design methodology. First, the substrate material was chosen to be Taconic TLY5 with relative dielectric constant (ε_r) of 2.2, loss tangent of 0.0009, and dimensions of $30 \times 28 \times 1.575\,\mathrm{mm}^3$. Second, the radiated shape was selected to be two sided ax-shaped to extend the operating frequency range that can exhibit the UWB characteristics. Third, microstrip transmission feed line was used to feed the radiating area with dimensions of $12 \times 4.8\,\text{mm}^2$. Forth, the ground plane on the opposite side of the substrate was proposed to be planar plane of 11.25 mm with gap of 0.75 mm between the radiator and ground plane. Next, three parameters were used to optimize the impedance matching bandwidth, feed gap, upper slot width (W_s), and lower slot depth dimension. These parameters were adjusted to show the effects of their dimensions on the impedance bandwidth stability.

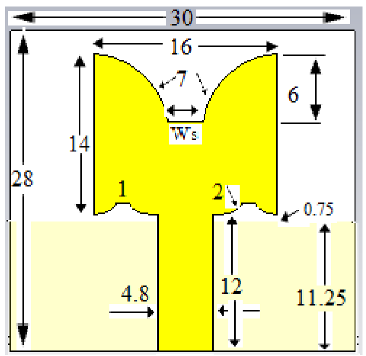

Figure 1: The geometry of the proposed two sided as-shaped patch antenna.

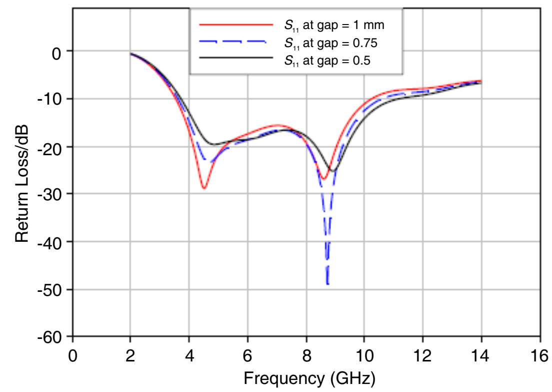

Figure 2: Effects of feed gap on S_{11}.

3. SIMULATION RESULTS AND DISCUSSION

By using the CST microwave studio software, the simulation was run to display the impedance bandwidth across the UWB range. To reduce the conventional overall antenna size, parametric study was carried out to get the optimized dimension for antenna parameters. Essentially, the antenna performance was affected by the geometrical shape and after that three parameters were proposed to achieve the optimal design. Firstly, the feed gap size and its effect is illustrated in Fig. 2 and the wider bandwidth can be shown at gap of 0.5 mm but the best resonance frequency of 8.7 GHz is applied at gap of 0.75 mm. Secondly, the effect of the lower slot depth is shown in Fig. 3 of three different values of the depth to have better matching impedance over the required bandwidth. The studying of this parameter is to present the best depth size for frequency range. The entire band is provided when the lower slot depth in the patch is 1 mm and the band is highly affected when the depth is 2 mm. Next, the effects of upper slot width are shown in Fig. 4 for three values of 3 mm, 4 mm, and 5 mm. Better impedance matching at $W_s = 3$ mm while no change when the width value increases to 4 or 5 mm but getting extended impedance bandwidth to cover most of UWB range. In general all the above parameters introduce the effects on antenna performance in order to optimize the antenna patch shape for wireless UWB applications.

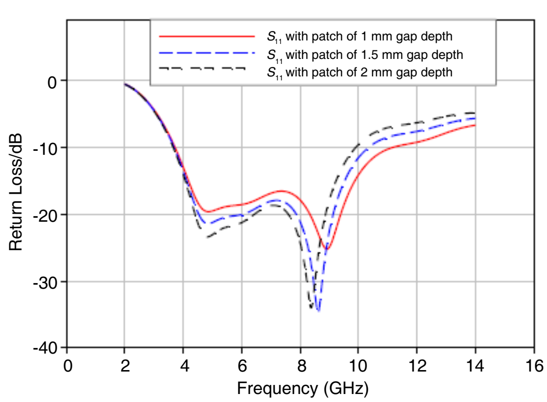

Figure 3: Effects of lower slot depth on S_{11}.

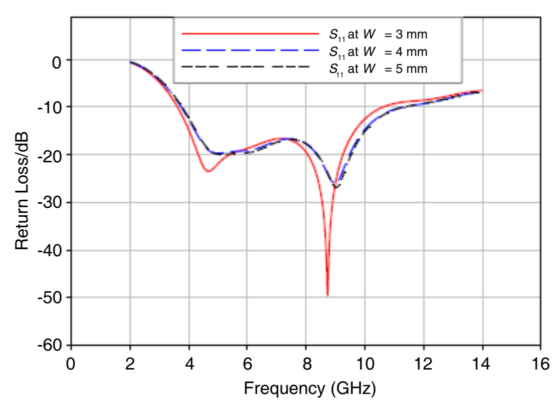

Figure 4: Effects of upper slot width on matching impedance bandwidth.

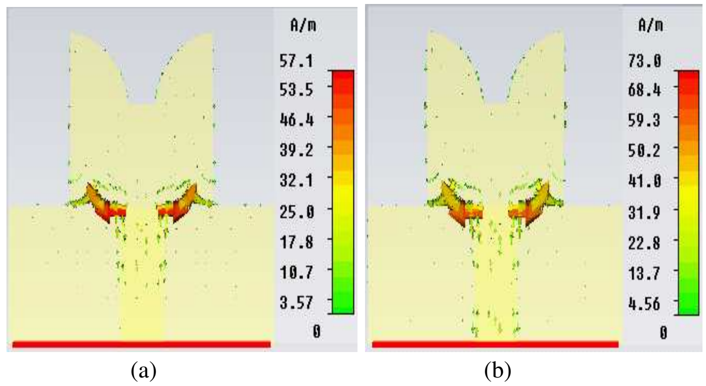

Figure 5: Surface current distribution at resonance frequencies of (a) 5 GHz and (b) 9 GHz.

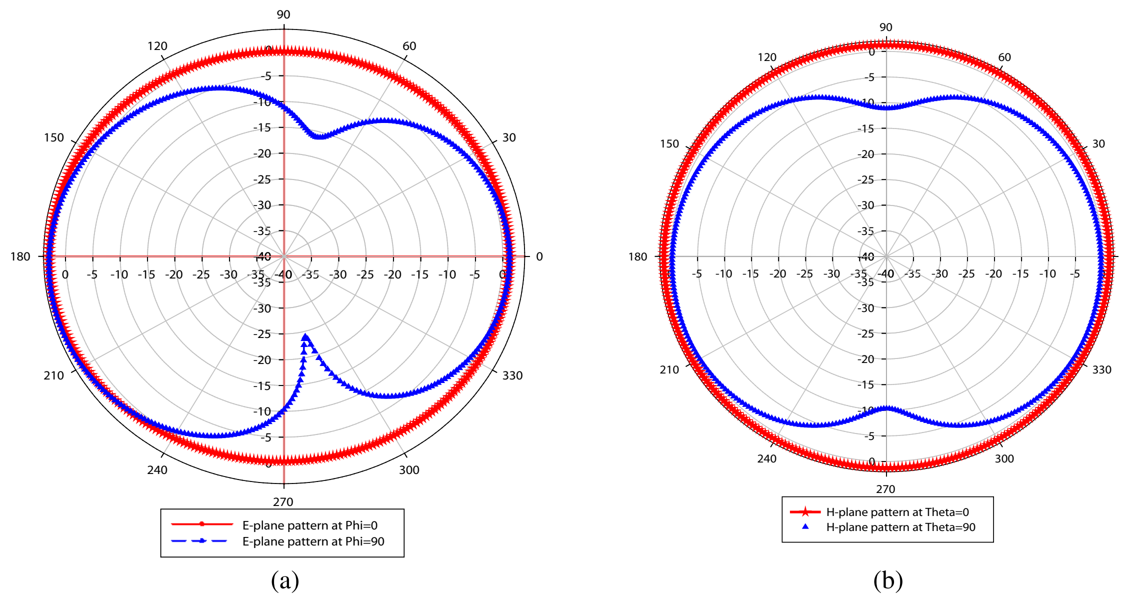

Figure 6: Simulated radiation patterns for designed antenna at frequency of 5 GHz with Phi and Theta equal to 0° and 90°, (a) E-plane, (b) H-plane.

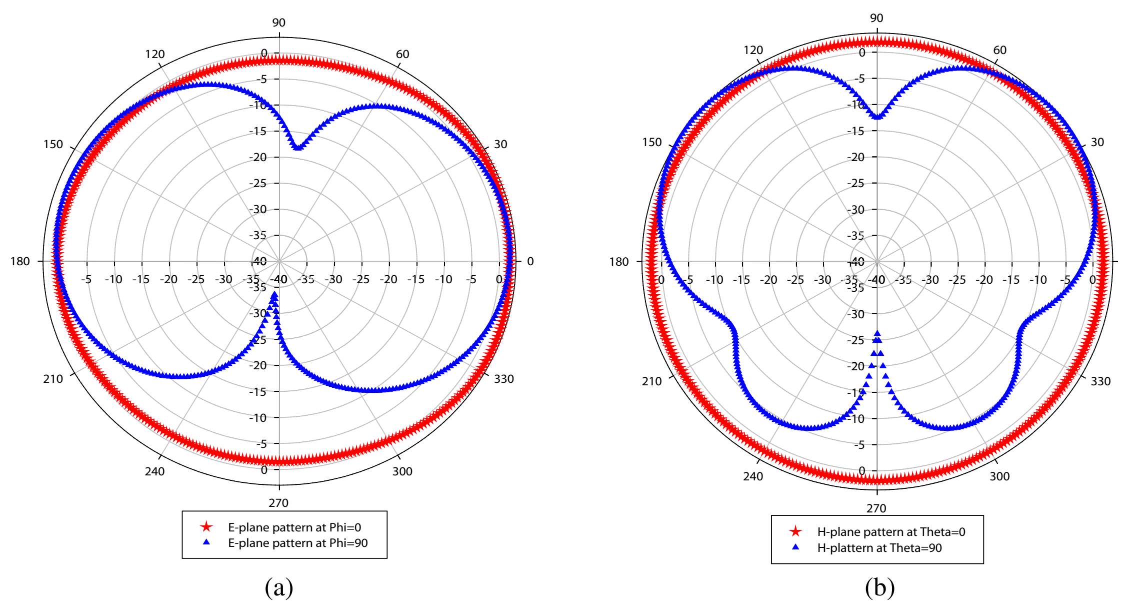

Figure 7: Simulated radiation patterns for designed antenna at frequency of 9 GHz with Phi and Theta equal to 0° and 90°, (a) E-plane, (b) H-plane.

4. ANTENNA CURRENT DISTRIBUTION AND RADIATION PATTERNS

The simulated surface current distributions are shown in Fig. 5 at resonant frequencies of 5 GHz and 9 GHz. It is absorbed that the most of current field is concentrated near the slots of low patch edge and on the other radiated area; the current is distributed in different densities. The maximum surface current density is 57 A/m at 5 GHz and 73 A/m at 9 GHz which are higher than that in [10] of no more than 10 A/m.

Figure 6(a) shows the two dimensional simulated radiation patterns were taken at resonant frequency of 5 GHz in E-plane when Phi = 0° and Phi = 90°. Fig. 6(b) shows the radiation patterns in H-plane when Theta = 0° and Theta = 90°. Fig. 7 illustrates the simulated H-plane and E-plane radiation patterns at resonant frequency of 9 GHz. However, the analysis of these patterns results shows that the proposed microstrip antenna is characterized by omni-directional radiation patterns in both planes.

5. CONCLUSIONS

In this research, an UWB antenna design of small dimensions was implemented using low cost and lightweight substrate material. The design was improved by using three parameter techniques to enhance the impedance bandwidth. These parameters are feed gap, upper patch slot, and lower patch slot depth. From the simulation results, the design is covering the UWB frequency range to be more suitable for wireless system applications. Radiation patterns are provided omni-directional patterns in E-plane and H-plane over the required band.

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