Two Small Antenna Designs for Ultra-Wideband Wireless Systems

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Abstract This chapter focuses on designing small antennas used by Ultra Wideband (UWB) wireless systems. The study has been taken from the conventional rectangular manuscript patch antenna to miniaturize the size of used antenna to be more suitable for future 5G system applications. These applications are dealing with high data transmission rates over a very large spread spectrum frequency (3.1–10.6 GHz), so that, many challenges are provided in the antenna design. The main objective of this research is to design, and analyze two small manuscript patch antennas to satisfy UWB technology requirements. Several techniques were used to optimize the UWB bandwidth performance such as radiator dimensions, planar ground plane, and unprinted gaps between ground plane and radiators. Therefore, this work introduces two designs of microstrip-fed, small, and low profile which are called ax-shaped and socket-shaped patch antennas. It has

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been demonstrated numerically that the proposed antennas are suitable for UWB systems. They can provide satisfactory frequency domain performance (less than −10 dB return loss), including ultra-wide bandwidth with nearly omni-directional radiation patterns, and relatively good current density over the radiator parts of the proposed antenna designs.

1 Introduction

The wireless communication technology is very important in our daily lives and the people around the world use to have this technology especially in cellular phones and medical sensors. The wireless systems give us more freedom without geographical limitations. In 2002 the Federal Communications Commission (FCC) has been licensed the UWB frequency range (3.1–10.6 GHz) [1]. Then, it had a good attention in researches with considering as a promising technology. Because of low UWB transmission power (−41.3 dBm/MHz), the wireless system elements such as antenna need to be very sensitive in implementation [2]. A train of narrow pulses (less than 1 ns pulse duration) in the transmission and reception scenarios forced us to look for high sensitive antenna. This antenna is very important element for improving the UWB systems through daily several applications. In addition, lightweight, small size, low cost, and high performance are required in designing of wireless antennas. To achieve the previous requirements, microstrip planar antennas can be designed to radiate electromagnetic energy [3].

During the literature review, there are several published UWB antennas such as large monopole microstrip antenna of 40 × 38 mm^2 dimensions [4] use RF-4 substrate material and non uniform matching antenna of 30 × 35 mm^2 dimensions using FR-4 epoxy substrate material [5]. Also another two antenna schemes were implemented in [6] of 45 × 25 mm^2 dimensions and in [7] of 40 × 35 mm^2 dimensions to satisfy the operating frequency range. In addition, to these designs, slotted ground plane of manuscript planar antennas as deployed in [8] or rigged ground plane in [9] or U slot in the radiator as in [10] were implemented to cover the required band by maintain several resonance frequencies.

In this work, small size antenna designs with planar ground plane were proposed and curved edges of the patch are fed by microstrip feed line. These designs were used to achieve the frequency range of UWB to cover most of its applications. For organization of this work, Sect. 2 shows the configuration of designs and parametric study of antenna parameters. Section 3 detailed the CST simulation results for return loss with discussions for both designs. Section 4 presents current density on the radiators and omni-directional radiation patterns, while Sect. 5 concentrates with conclusions.

2 The Configuration of the Proposed Antenna Designs

The UWB wireless communication systems operate with train of very short pulses spread over the whole bandwidth which are suitable with high bit rate transmission [11, 12]. The propagation power is very low (−41.3 dBm/MHz) that leads to use sensitive and high gain antenna. The antenna should be designed to cover the UWB bandwidth and the antenna design based on developing the conventional rectangular patch antenna. Figure 1 shows the design elements which are including the antenna parameters and the steps of the proposed design methodology. First, the substrate material was chosen to be Taconic TLY-5 with relative dielectric constant (ε_r) of 2.2, loss tangent of 0.0009, and dimensions of 30 × 28 × 1.575 mm^3 for designs, ax-shaped patch antenna and socket-shaped patch antenna. Second, the radiated shape (patch of 14 × 16 mm^2) in Fig. 1a was selected to be two sided ax-shaped to extend the operating frequency range that can exhibit the UWB characteristics. In addition, the radiated shape with same dimensions in Fig. 1b was proposed to be socket shape to increase the surface current density at the edges. Third, microstrip transmission feed line was used in both antennas to feed the radiating areas with dimensions of 12 × 4.8 mm^2 and 12 × 5 mm^2. Forth, the ground planes on the back sides of the substrate material were proposed to be planar ground plane of 11.25 mm with gap of 0.75 mm for ax-shaped and of 11.75 mm with gap of 0.25 mm between the radiators and ground planes. Next, the parameter was used to optimize the impedance matching bandwidth is the feed gap height; also this parameter introduces the effects of changing the gap dimensions on radiation pattern characteristics.

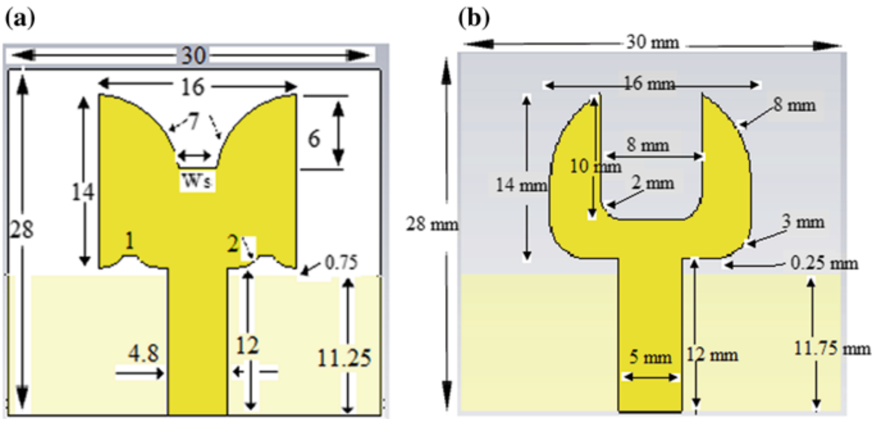

Fig. 1 The geometry of the proposed two antennas: **a** Ax-shaped patch, **b** socket-shaped patch

3 CST Simulation Results and Discussions

By using the CST microwave studio software, the simulation process was run to introduce the matching impedance bandwidth all over the UWB frequency range. The under −10 dB return loss curves are shown in Fig. 2 for two antenna designs. Ax-shaped antenna covers frequency range from 3.5 to 11.2 GHz, while socket-shaped antenna covers frequency range from 3.6 to 13.8 GHz. The coverage of both designs indicates that more than 90 % of incident power can be radiated by using these designs. The size of the conventional rectangular antenna substrate is reduced to be more suitable for future small UWB wireless systems. These reducing antenna sizes are maintained with improved antenna performance by keeping the radiation of desired signals over the UWB frequency range. To optimize the antenna performance, parametric study of feed gap was carried out to get the optimal gap depth in two designs. In Fig. 3, the study of feed gap depth is represented for socket-shaped antenna to show the suitable depth which is 1 mm to cover all UWB frequency range. In addition, the same parametric study was done for ax-shaped design as shown in Fig. 4 to get the optimal gap depth after adjusting the feed gap to 0.5 mm with high impedance matching can be achieved. From these figures, the effects of the feed gap between the radiator and the upper edge of the partial ground plane are affecting the entire frequency band but with higher sensitivity at high frequencies. Therefore, the feed gap is very crucial for the impedance matching since it can reduce the coupling between the currents at the bottom outer edge of the patch and the top edge of the ground plane. The feed gap thus has to be precisely tuned to achieve the desirable impedance matching. This tuning is noticed that when the feed gap is getting smaller as 1 mm in socket-shaped and 0.5 mm in ax-shaped patch antennas.

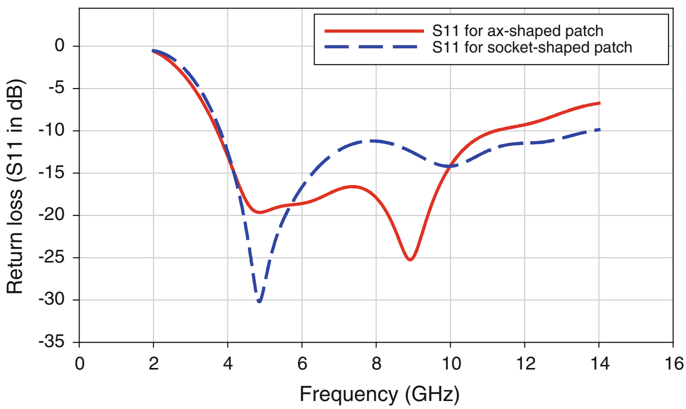

Fig. 2 Comparison between simulated S_{11} for ax-shaped and socked-shaped patch antennas

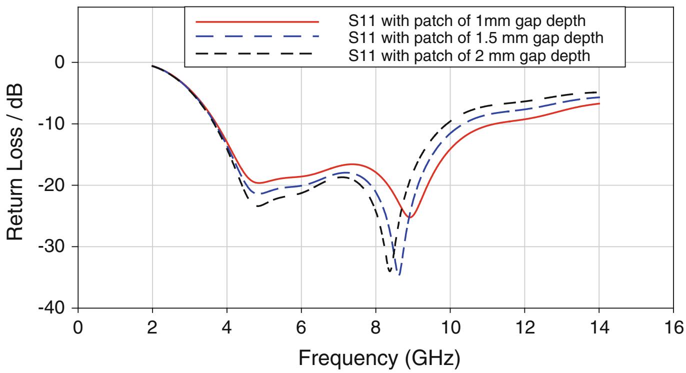

Fig. 3 The effects of feed gap depth on bandwidth for socket-shaped patch antenna

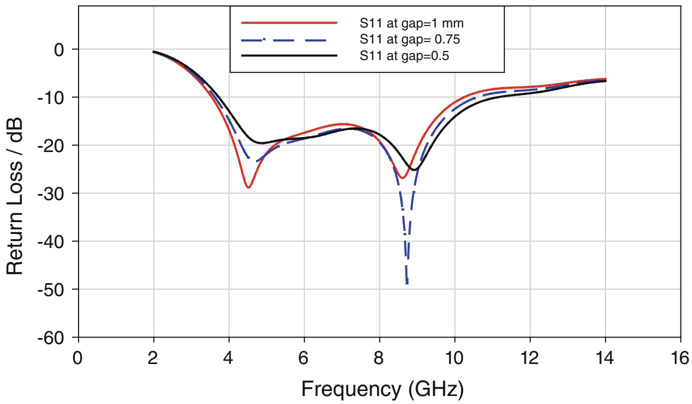

Fig. 4 The effects of feed gap depth on bandwidth for ax-shaped patch antenna

4 Current Density and Radiation Pattern for Two Designs

The simulated current densities of the proposed geometries are shown in Fig. 5a and b at frequency of 10 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 15.6 A/m^2 for Ax-shaped patch and 11 A/m^2 for socket-shaped patch. The current density is mainly concentrated on the bottom portion and the edges of the patch with low current density toward the patch center.

For Ax-shaped antenna design, Fig. 6a shows the two dimensional simulated radiation patterns were taken at resonant frequency of 5 GHz in E-plane and H-plane when Phi = 90° and Theta = 90°. Figure 6b shows the radiation patterns in

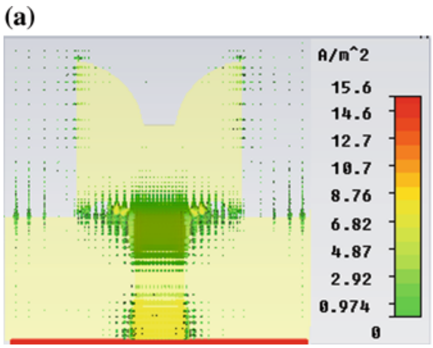

Fig. 5 Surface current density at frequency of 10 GHz for **a** ax-shaped patch and **b** socket-shaped patch

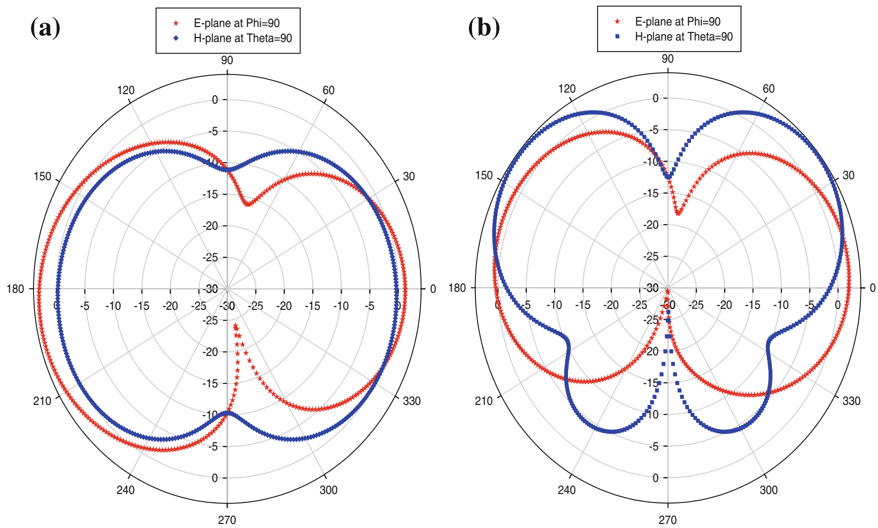

Fig. 6 Simulated radiation patterns for ax-shaped patch antenna in E-plane and H-plane at resonant frequencies of **a** 5 GHz, and **b** 9 GHz

E-plane and H-plane when Phi = 90° and Theta = 90° at resonance frequency of 9 GHz. While the simulated radiation patterns for socket-shaped antenna design are illustrated in Fig. 7a in H-plane and E-plane with Phi = 90° and Theta = 90° at resonant frequency of 5 GHz and are illustrated in Fig. 7b at resonant frequency of 9 GHz. However, the behavior and analysis of these radiation patterns shows that the proposed microstrip antennas are characterized by omni-directional radiation patterns in both planes across UWB bandwidth.

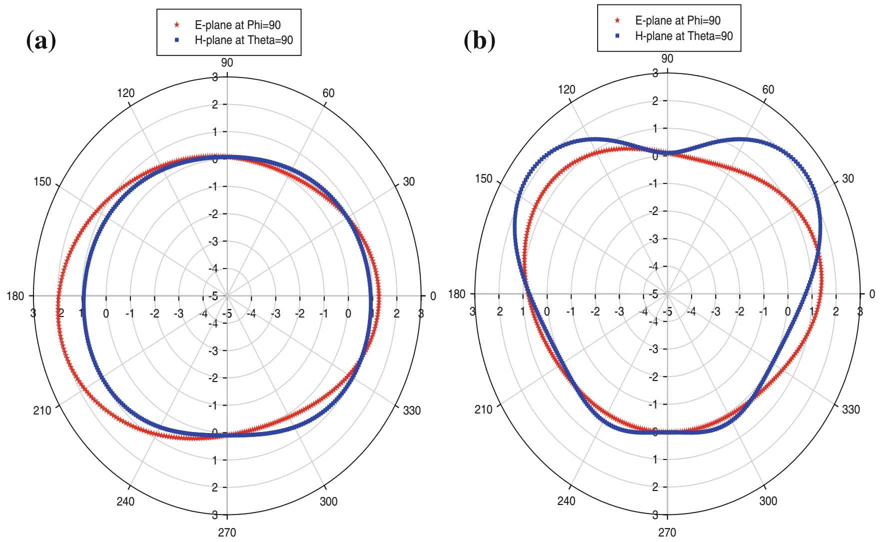

Fig. 7 Simulated radiation patterns for socket-shaped patch antenna in E-plane and H-plane at resonant frequencies of **a** 5 GHz, and **b** 9 GHz

5 Conclusions

In this work, two small and low-profile manuscript-fed simulated UWB antenna designs are studied and analyzed to satisfy UWB wireless technology requirements. The proposed antenna designs are covering the bandwidth of 7.5 GHz which are desired for UWB applications such as in indoor and outdoor propagation. These antennas are namely: the ax-shaped patch antenna and socket-shaped patch antenna. They are designed using different techniques to enhance the bandwidth in order to satisfy UWB frequency range. These techniques are: planar ground plane, adjust the gap between radiator and ground plane, and cutting notches in the radiating element. Cutting notches are used to miniaturize the size of printed patch. From the simulated results, ax-shaped antenna operates over a fractional bandwidth of 110 % and socket-shaped antenna operates over a fractional bandwidth of 138 %. In addition, the simulated radiations patterns are omni-directional to make both designs are suitable for indoor transmission and reception techniques.

References

1. Federal Communications Commission (FCC): Revision of Part 15 of the Commission's rules regarding ultra-wideband transmission systems. FCC first report and order 02-48 (2002)
2. Dotto, K.: Development of a novel ultra-wideband antenna and prototype scanner for detection and location of voids in wood. PHD thesis, The University of British Columbia (2005)

3. Bataller, M., Fabres, M., Daviu, E., Nogueira, A.: Overview of planar monopole antennas for UWB applications. In: Proceeding of EUCAP 2006, November (2006)
4. Tilanthe, P., Sharma, P.C., Bandopadhyay, T.K.: A Monopole microstrip antenna with enhanced dual band rejection for UWB applications. Prog. Electromagn. Res. B **38**, 315–331 (2012)
5. Hayouni, M., El Oualkadi, A., Choubani, F., Vuong, T.H., David, J.: Antenna ultra wideband enhancement by non-uniform matching. Prog. Electromagn. Res. Lett. **31**, 121–129 (2012)
6. Karmarkar, A., Verma, S., Pal, M., Ghatak, R.: An ultra wideband monopole antenna with multiple fractal slots with dual band rejection characteristics. Prog. Electromagn. Res. C **31**, 185–197 (2012)
7. Kasi, B., Chakrabarty, C.K.: Ultra-Wideband antenna array design for target detection. Prog. Electromagn. Res. C **25**, 67–78 (2012)
8. Sim, C.Y.D., Chung, W.T., Lee, C.H.: Compact slot antenna for UWB applications. In: Antenna and Wireless Propagation Letters, pp. 62–66 (2010)
9. Lin, C.C., Chuang, H.R.: A 3–12 GHz UWB planar triangular monopole antenna with ridged ground-plane. Prog. Electromagn. Res. **83**, 307–321 (2008)
10. Sze, J.Y., Wong, K.L.: Bandwidth enhancement of a microstripline-fed printed wide slot antenna. In: IEEE Transactions and Propagation, pp. 1020–1024 (2011, July)
11. Jia, Lu, Shu Lin, Yu., Tian, Liwen Jing, Liu, Mengqian, Zhao, Zhihua: The simulation and experiment of a UWB printed dipole antenna. Prog. Electromagn. Res. Lett. **36**, 21–30 (2013)
12. Srifi, M.N.: Ultra Wideband Communications: Novel Trends-Antennas and Propagation, Chapter 10, Ultra-Wideband Printed Antennas Design. ISBN:978-953-307-452-8, pp. 196–215 (2011)