Journal of information and
communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 15(1): 1-6, Mar. 2017 Regular paper

Design of a Polygon Slot Antenna with a Polygon Tuning Stub for Ultra-Wideband Applications

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Abstract

In this study, we develop and experimentally evaluate an ultra-wideband (UWB) slot antenna with a polygon tuning stub. The proposed antenna consists of a polygon slot with a 50-Ω feed line. The effects of various parameters of the polygon-shaped slot and the polygon tuning stub on UWB applications are investigated. The optimum parameters were obtained using the Ansys HFSS software. The results of the studies on the surface current distributions of the operating frequency bands were discussed. The proposed antenna is fabricated on an inexpensive FR-4 substrate with the overall dimensions of 28.0 mm × 30.0 mm. The measured results confirm that the proposed antenna covers frequencies from 2.58 GHz to 13.27 GHz, which is the UWB frequency range. Further, the proposed UWB antenna also exhibited that omni-directionality in the H-plane gain varied from 1.185 to 7.246 dBi. The good antenna characteristics of the proposed antenna make it suitable for UWB system applications.

Index Terms: Polygon slot, Polygon tuning stub, Slot antenna, UWB

I. INTRODUCTION

Since its approval for use in communications by the Federal Communications Commission in 2002 [1], the ultra-wideband (UWB) has received substantial attention from both the academic and the industrial sectors. UWB applications have become the focus of short-range high-speed wireless communication because of advantages such as high-speed data transmission, high precision range, low power consumption, and considerable capacity. Research on UWB systems continues to grow rapidly, and many different prototypes of UWB antennas have been proposed and developed thus far [2-4].

An antenna plays an important role as a key component that determines the radio frequency (RF) performance of an end-product. Therefore, the increasing popularity of UWB communications has created a need for a UWB antenna with a low profile, low weight, low cost, easy fabrication, ability to be flush-mounted, and simple structure. Compared with microstrip patch antennas, slot antennas have the advantages of wider bandwidth, superior impedance matching, lower dispersion, lower radiation loss, and the possibility of obtaining omni-directional radiation patterns. Therefore, the slot antenna is one of the most promising candidates for UWB applications [5-8]. On the other hand, a number of polygon-shaped slot antennas are widely used in many applications because of their various advantages and have been introduced for wide bandwidths [9-14].

One effective way to enhance an antenna's impedance bandwidth is to change the feed shape. Antennas with

Received 12 August 2016, **Revised** 16 August 2016, **Accepted** 27 January 2017
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Open Access **http://doi.org/10.6109/jicce.2017.15.1.1** print ISSN: 2234-8255 online ISSN: 2234-8883

various microstrip feed line shapes and wide slots have been introduced for large impedance bandwidths. Although many microstrip-fed wide-slot antennas have been proposed for wideband applications, there have been few studies on polygon slot antennas with a polygon-shaped tuning stub for wideband applications.

In this article, we propose a polygon slot antenna with a polygon-shaped tuning stub for UWB applications. The wideband characteristics of the proposed polygon slot antenna are obtained by introducing a polygon-shaped tuning stub into the proposed design. The polygon-shaped tuning stub was positioned within the slot region opposite to the printed polygon slot. The selection of suitable parameters resulted in a significantly enhanced wideband impedance bandwidth. A prototype of the proposed polygon slot antenna with a polygon tuning stub was designed, simulated, and evaluated.

II. ANTENNA DESIGN

The geometrical configuration of the proposed antenna along with its dimensional parameters is presented in Fig. 1. The antenna was designed on a low-cost FR4 substrate with a dielectric constant of 4.4, dielectric loss tangent of 0.02, and thickness of 1.0 mm. The total size of the substrate and of the ground plane of the proposed antenna was 28.0 mm ×

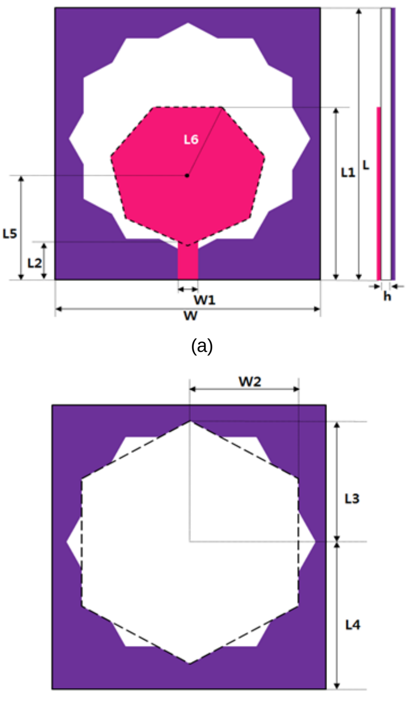


Fig. 1. Geometry of the proposed antenna: (a) front view and (b) polygon slot.

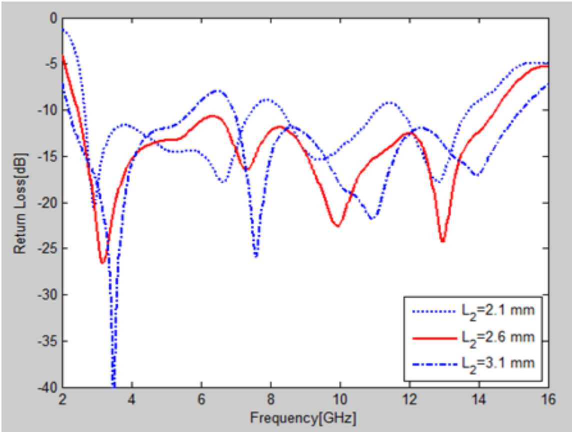


Fig. 2. Simulated return loss of the proposed antenna with different lengths of the microstrip-fed feed line.

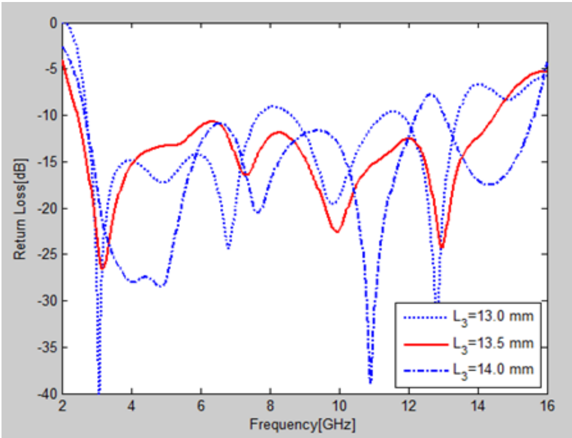


Fig. 3. Simulated return loss curves of the proposed antenna with different lengths from the starting point to the vertex.

40.0 mm (W × L). The proposed antenna consisted of a polygon-shaped radiating patch and ground plane. The radiating patch was composed of two hexagon shapes that lean 45°.

A 50-Ω microstrip feed line with a polygon-shaped tuning stub was adopted to excite the proposed polygon slot antenna. The radiating element was placed on the same side as the feeding strip, and the ground plane was placed on the other side of the substrate.

The design of the proposed antenna was in accordance with the described guidelines followed for optimization with the commercially available software Ansys HFSS (Ansys Inc., Canonsburg, PA, USA), a full-wave commercial electromagnetic (EM) software capable of simulating a finite substrate and a finite ground structure. Parametric studies were conducted to investigate the wideband characteristics of the proposed antenna.

The simulated results revealed that the length of the microstrip-fed feed line, the length from the starting point to

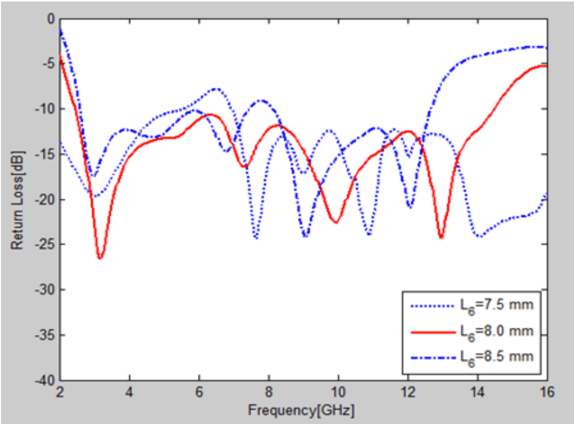


Fig. 4. Simulated return loss curves of the proposed antenna with different radii of the polygon-shaped radiating patch.

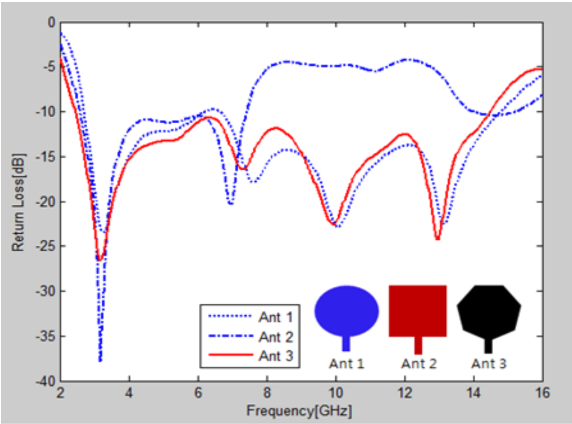


Fig. 5. Simulated return loss curves of the proposed antenna with various radiating elements.

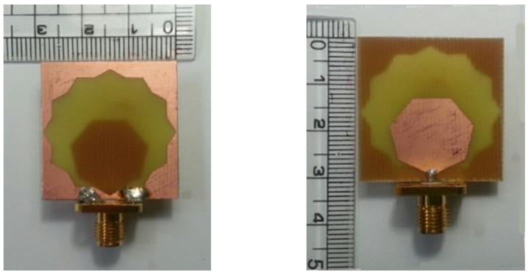
the vertex, and the radiating element significantly affected the impedance matching. Fig. 2 shows the simulated return loss curves for different lengths of the microstrip-fed feed line (L_2 = 2.1, 2.6, and 3.1 mm) when the other parameters remained optimal. The return loss curve varied with the variation of L_2. When L_2 was either too large or too small (in the cases of L_2 = 2.1 mm and L_2 = 3.1 mm), the impedance bandwidth deviated from the UWB band (3.1–10.6 GHz). The optimal length of the feed line was 2.6 mm.

Fig. 3 shows the simulated return loss curves with different values from the starting point to the vertex (L_3 = 13.0, 13.5, and 14.0 mm) when the other parameters remained optimal. The return loss curve varied substantially. When L_3 was 13.0 mm, the simulated lower band of the return loss characteristics deviated from the required UWB bandwidth (3.1–10.3 GHz). When W_5 was 14.0 mm, the simulated return loss performance was poor in the mid-UWB band. The optimal fork-like feed length was 13.5 mm.

Fig. 4 shows the simulated return loss curves with the radius of the polygon-shaped radiating patch (L_6 = 7.5, 8.0, and 8.5 mm) when the other parameters remained optimal. The return loss curve varied with the variation of L_6. When L_6 was either too large or too small (in the cases of L_6 = 7.5 mm and L_6 = 8.5 mm), the −10 dB impedance bandwidth deviated from the UWB band (3.1–10.6 GHz) in the 7-GHz band and the 8.5-GHz band, respectively. Therefore, the optimal radius of the polygon-shaped radiating patch was 8.0 mm.

Three radiating elements with different shapes were used in this antenna design. Fig. 5 shows the geometries of the differently shaped radiating elements used in the design. The radiating elements used were hexagonal, rectangular, and circular. Fig. 4 shows the simulated return loss for the proposed antenna with different radiating elements. A polygon slot monopole antenna with a rectangular radiating element resulted in a poor simulated return loss in the higher UWB frequency band. The simulated return loss of a polygon slot monopole antenna with a hexagonal radiating element gave better results than the polygon slot monopole antenna with a circular radiating element.

The values of the design parameters shown in Fig. 1 were calculated using the optimized Ansys HFSS. Thus, the dimensions of the proposed antenna were set as follows: L =



(a) (b)

Fig. 6. Prototype of the proposed triple-band antenna: (a) front view and (b) back view.

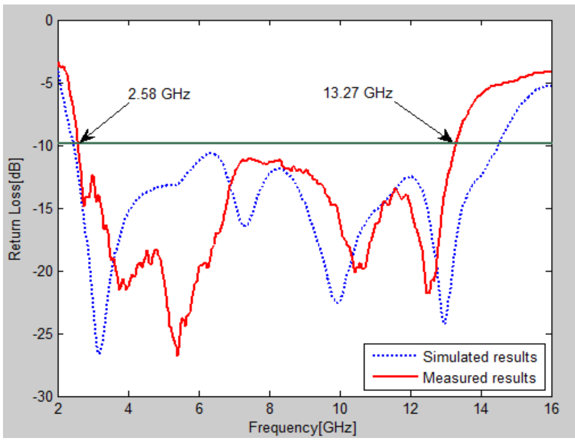


Fig. 7. Simulated and measured return losses vs. frequencies of the proposed antenna.

30.0 mm, L_1 = 17.4 mm, L_2 = 2.6 mm, L_3 = 13.5 mm, L_4 = 15.0 mm, L_5 = 10.0 mm, L_6 = 8.0 mm, W = 28.0 mm, W_1 = 1.5 mm, W_2 = 8.5 mm, and h = 1.0 mm. The simulation results revealed that the −10 dB impedance bandwidths ranged from 2.665 GHz to 14.53 GHz.

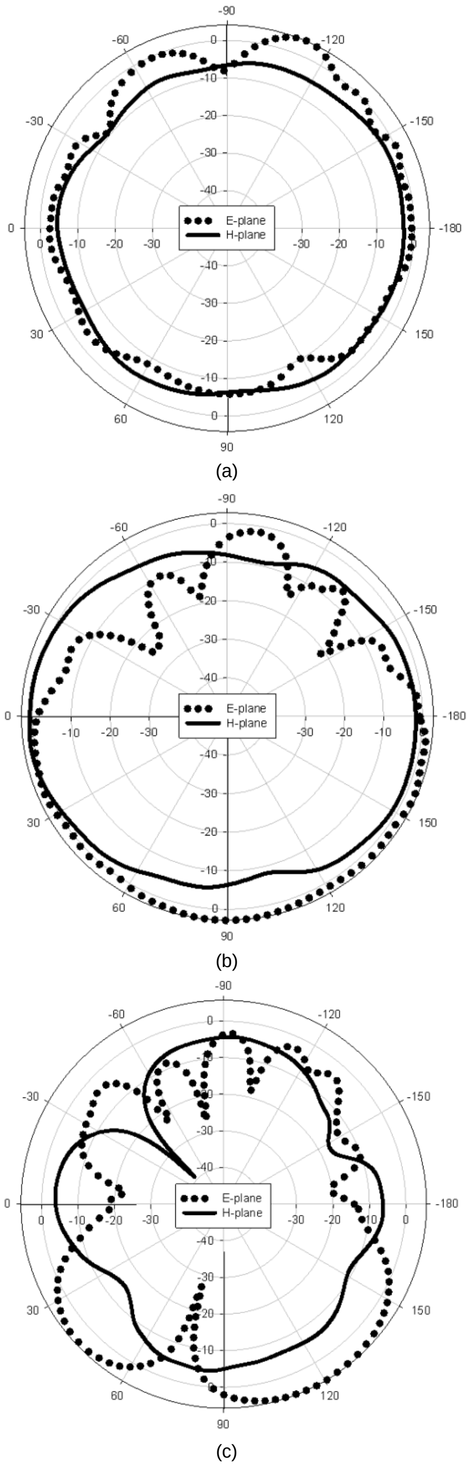


Fig. 8. Radiation patterns of the proposed antenna for the UWB operation frequencies of (a) 4, (b) 7, and (c) 10 GHz.

III. MEASUREMENTS

A prototype of the optimized antenna was fabricated, and its characteristics were investigated. Fig. 6 shows the top and bottom views of the fabricated prototype of the proposed UWB antenna. The vector network analyzer Anritsu MS4644A was used for the measurement. The simulated and measured return loss curves of the antenna are plotted in Fig. 7. Fig. 7 shows that the measured impedance bandwidth defined by a return loss of less than −10 dB, was approximately 10.69 GHz (2.58–13.27 GHz), which could be used for the UWB bands (3.1–10.3 GHz). The obtained results showed a good agreement between the measured and the simulated data, with an acceptable frequency discrepancy that might have been caused by the measurement environment and the fabrication error. In other words, the frequency discrepancy was probably due to the influence of the cable connected to the fabricated antenna in the measurement procedure. Moreover, the simulation used a lumped port, and an SMA connector was used for the measurement; therefore, a difference existed between the measurement and the simulation results. The accuracy of the return loss characteristics of the designed antenna should be confirmed by using more samples and more extensive measurements of this antenna.

The far-field radiation patterns and gains were measured using a far-field anechoic absorber. Fig. 8 illustrates the normalized measured radiation patterns in the E-plane (x–z plane) and the H plane (y–z plane). Fig. 8(a), (b), and (c) show the two-dimensional radiation patterns at 4, 7, and 10 GHz, respectively. The radiation pattern behavior was omnidirectional in the H-plane and had a monopole-like pattern in the E-plane at the operating frequencies.

The measured gain is presented in Fig. 9, which shows that an antenna peak gain level of approximately 1.185–7.246 dBi was achieved.

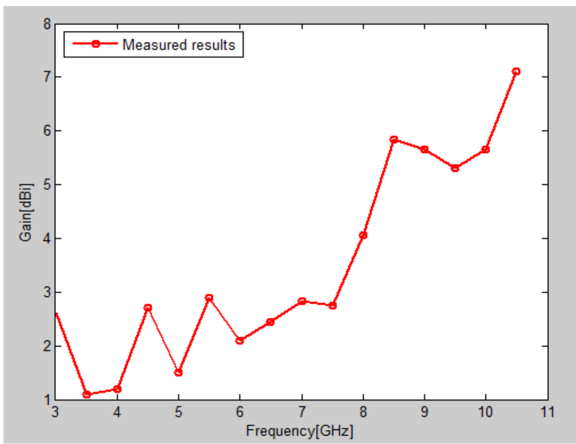


Fig. 9. Measured antenna peak gains for different operating frequencies.

IV. CONCLUSION

A polygon-shaped slot antenna with a polygon tuning stub was designed and investigated for UWB applications. The impedance matching was improved by introducing a polygon tuning stub to the opposite polygon slot. The optimum parameters were obtained using the Ansys HFSS software. The results of the studies on the surface current distributions of the operating frequency bands were discussed. The proposed antenna had an impedance bandwidth (return loss, −10 dB by definition) of approximately 10.69 GHz (2.58–13.27 GHz). The proposed UWB antenna also exhibited that omni-directionality in the H-plane gain varied from 1.185 to 7.246 dBi. The good antenna characteristics of the proposed antenna make it suitable for UWB system applications.

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