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Modified H-shaped Antenna Design for Harmonic Suppression

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Abstract

In this paper, a modified H-shaped patch antenna was designed to remove the second and third harmonics generated by the diode of the rectifying circuit in the 2.45 GHz wireless power transmission system. The proposed antenna was designed using a commercial tool, HFSS, and manufactured/measured using an FR4 substrate. The partial ground plane technique was used in the design of the proposed antenna. Reflection loss was measured and the reflection loss characteristics, radiation patterns, and antenna gains were simulated due to changes in various antenna parameters. The measured reflection loss was in good agreement with the simulation results, and it was confirmed that the second and third harmonic components generated by the diode were well removed.

요 약

본 논문에서는 2.45GHz 무선전력 전송시스템에서 정류회로의 다이오드에 의해 발생하는 2차 및 3차 고조파를 제거하기 위하여, 변형된 H형태의 패치 안테나를 설계하였다. 제안하는 안테나의 설계에서 partial ground plane 기법을 이용하였다. 제안된 안테나는 상용 툴인 HFSS를 이용하여 설계하였고, FR4 기판을 사용하여 제작하였으며, 무반향 챔버에서 Anritsu VNA(37397C)를 사용하여 반사 손실을 측정하였다. 또한 안테나 구조 파라미터의 변화에 의한 특성과 복사 패턴, 안테나 이득을 시뮬레이션 하였다. 측정한 반사 손실은 시뮬레이션 결과와 잘 일치하였으며, 다이오드에 의해 발생하는 2차 및 3차의 고조파 성분이 잘 제거되었음을 확인하였다.

Keywords

wireless power transfer system, rectenna, harmonic suppression, H-shaped antenna, partial ground

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Ⅰ. Introduction

Wireless power transmission is a new concept of power transmission that transfers energy by converting power energy into microwaves that are advantageous for wireless transmission, and is an important core technology such as remote power supply, low-orbit satellite power supply, and space solar power generation[1]. The first thing to consider in the design of wireless power transmission systems is the selection of the frequency. Because frequencies near 10 MHz-300 MHz and 20 GHz-60 GHz are affected by the most severe noise due to the nature of noise in the atmosphere, the frequency for wireless power transmission uses frequencies in the 1 GHz-20 GHz band and mainly 2.45 GHz.

In particular, rectenna(Rectifying Antenna), a key element in wireless power transmission, is a power conversion device that receives microwaves and converts them into desired DC voltage power. The rectenna consists of an antenna, a band pass filter, and a rectifying circuit. A signal of 2.45 GHz is received from the antenna and inputted to the rectifying circuit through a band pass filter. The rectifying circuit is mainly composed of a diode and a low-pass filter, and since the diode is a nonlinear element, harmonics are generated, and these harmonics are re-radiated through the antenna again. This re-emission should be eliminated as a factor that reduces the efficiency of the rectenna. In [2], a rectenna design with a microstrip harmonic-rejecting circular sector antenna at 2.45 GHz is proposed. A microstrip patch antenna using the defected ground structure (DGS)[3] and novel microstrip-fed slot antenna[4] for harmonic suppression were proposed. Performance and efficiency of planar rectenna was presented in [5]. In [6], a harmonic rejection bandpass filter is proposed for the 2.4GHz rectenna.

In this paper, modified H-shaped antenna that can remove such re-radiation was proposed. In the proposed antenna design, partial ground technique[7] and H-shaped antenna[8]-[10] with harmonic removal characteristics were used. Although the H-shaped antenna basically has the characteristics of harmonic removal, it is not sufficient, so the partial grounding technique was utilized to increase the harmonic removal rate. The proposed antenna was optimally designed using Ansoft's HFSS, a commercial tool[11] and manufactured and measured using an FR4 substrate. As a result of the measurement, the second and third harmonics, which are unnecessary components, were almost removed, showing an efficiency of 93% or more in the desired frequency band. Reflection loss was measured and the reflection loss characteristics, radiation patterns, and antenna gain as a function of various antenna parameters were simulated.

Ⅱ. Antenna structure

Figure 1 shows the structure of the proposed antenna. The shape of the existing patch antenna was mostly a square shape. However, in this paper, the patch shape was designed as an H shape rather than a square shape. The modified H-shaped patch can reduce the size of the antenna compared to the existing square-shaped patch based on a stepped impedance resonator, reduce the radiation of unwanted harmonic components, and reduce electromagnetic interference.

The feeding part is one of the most important parts in designing the patch antenna. Microstrip line and CPW(Coplanar Waveguide) are often used as the feeding methods, and in this paper, microstrip line and the partial ground technique[7] were used for the design of the proposed antenna. For the 50Ω input impedance matching, the feeding line width was designed to be 1.526mm and FR-4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.025 and a thickness of 0.8mm was used, and the size of the substrate is 26.5mm×30mm. The harmonic components could not be sufficiently removed from an

H-shaped antenna that modified a regular square patch. Therefore we have used the modified H-shaped patch and the partial ground as shown in Figure 1.

III. Antenna simulation and measurement results

Figure 2 shows the simulation result when the end shape of stub1(W_1) is changed while W_2, L_2, W_3, and L_3 are fixed. We have changed the end shape of the stub1(W_1) as a square or a circular. Simulation results show that the impedance matching at 2.45 GHz was better when the end shape of W_1 was circular than the square, and that the 7.2 GHz harmonic component was better removed. Figure 3 shows the simulation of W_1 by fixing the shape of W_1 in a circular shape and changing the length of W_1 to 15mm, 20mm, and 25mm. As a result of the simulation, the efficiency at 2.45 GHz was not satisfactory when the length of W_1 was 15 mm, and the resonance point occurred at about 9 GHz when the length of W_1 was 25 mm, indicating that the harmonic component of 7.2 GHz was not sufficiently removed. Therefore, as a result of optimizing to 20mm, which is the middle length of 15mm and 25mm, impedance matching occurred well in the desired frequency band, and the second and third harmonic components were sufficiently removed.

The shape of W_1, which is the simulation optimization result, was circular, and the length of W_1 was fixed at 20mm and then simulated while changing W_2. Figure 4 (a) shows the simulation results when W_2 was changed to 0.4mm, 2.4mm, and 4.4mm, and even when W_2 was 0.4mm and 4.4mm, the harmonic component was removed, but it was optimized to 2.4mm because it did not satisfy the desired frequency band. The shape of W_1 was circular and fixed at 20mm, and W_2 was fixed at 2.4mm, and then simulated while changing the length of L_2. Figure 4 (b) shows the simulation results when the length of L_2 was changed to 5.5mm, 8.5mm, and 11.5mm, and even when L_2 was 5.5mm or 11.5mm, the harmonic components were removed, but it was optimized to 8.5mm to satisfy the desired frequency band.

It is difficult to obtain the desired efficiency only by changing the patch shape at a limited substrate size. As shown in Figure 1(b), the length of the ground was changed to induce impedance matching, which is called the partial ground technique[7].

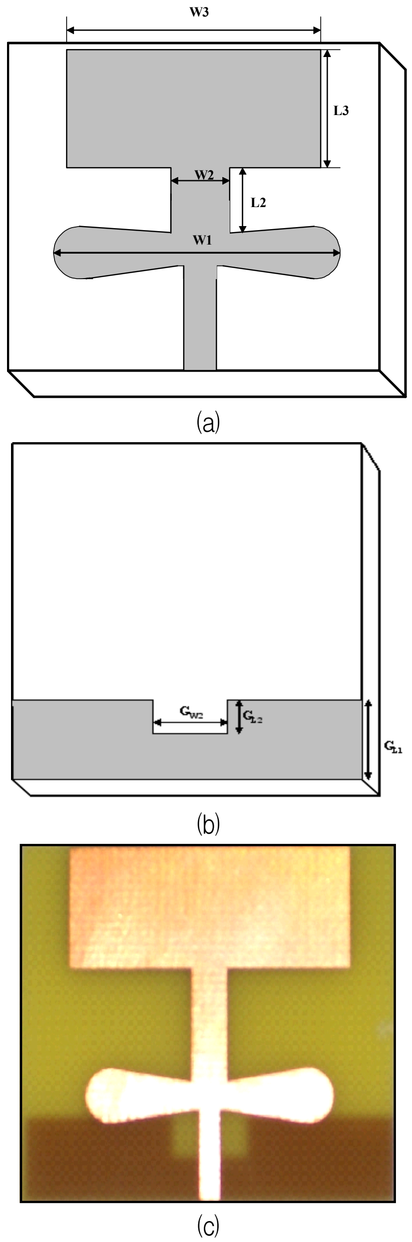


Fig. 1. Geometry of the proposed antenna
(a) Front-side view (b) Back-side view
(c) Photograph of the proposed antenna

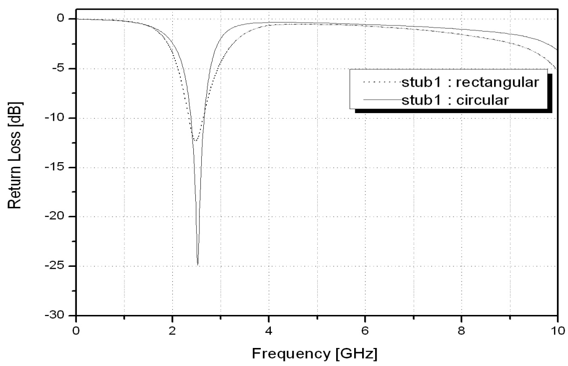


Fig. 2. Simulated results for the shape of stub1

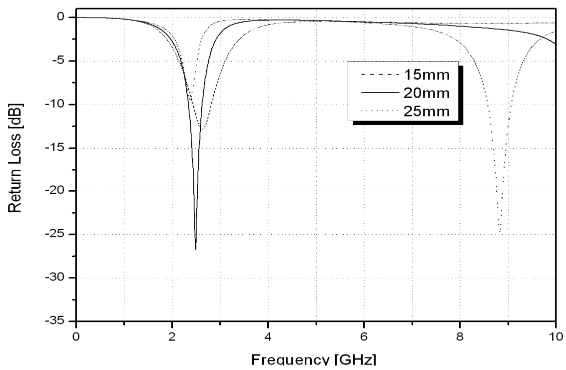
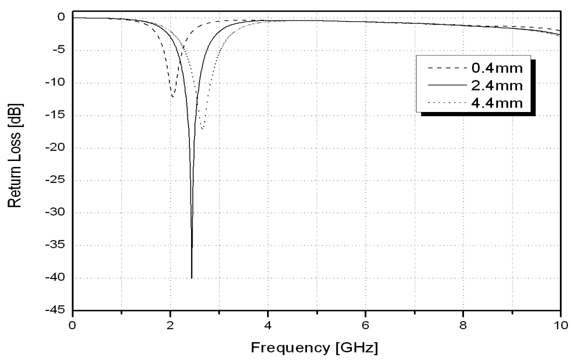
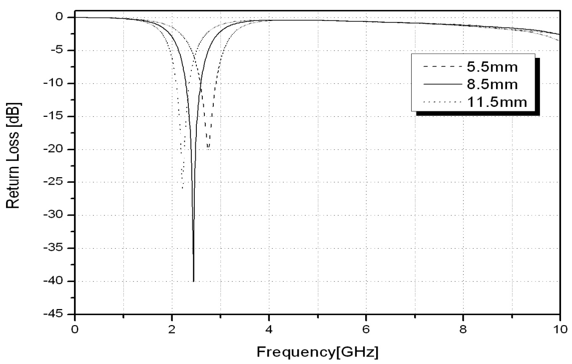


Fig. 3. Simulated return loss for different W_1



(a) W_2



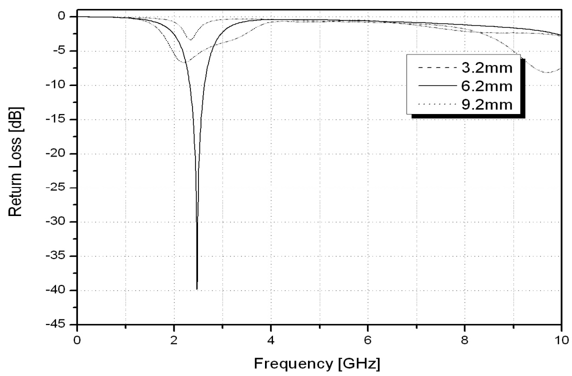
(b) L_2

Fig. 4. Simulated return loss for different W_2 and L_2

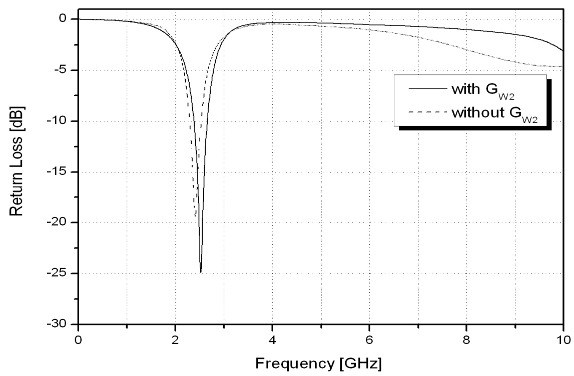
Figure 5 (a) shows the simulation result when the length of the ground G_{L1} is changed. When the length of the ground was 0.5mm smaller than the length of the feed line(6.7mm), the most optimized appearance could be seen. If it is longer than the feed line (9.2mm), it is not matched at 2.45GHz, and if it is shorter than the feed line, it is not matched at the desired frequency band. In addition, there is a limit to remove harmonic components as shown in the figure. In the partial ground plane, the rectangular slot(G_{W2}, G_{L2}) under the feed line was inserted to remove the harmonic components. Figure 5 (b) shows the simulation results when the width of the rectangular slot is changed. As shown in the figure, it can be seen that the harmonic component of 7.2 GHz was better removed in the presence of G_{W2}. It is of utmost importance for the proposed antenna to remove unnecessary second and third harmonic components. The reflection loss at 4.8 GHz was -0.34 dB, and the reflection loss at 7.2 GHz was -0.52 dB, indicating that the harmonic components were removed with less than 10% efficiency. Table 1 shows the final design parameters of the proposed antenna based on the HFSS simulation.

Figure 6 is the simulated radiation patterns (E-plane, H-plane) at 2.4 GHz, 4.8 GHz, and 7.2 GHz. As shown in the figure, it can be seen that the shape of the radiation pattern of the proposed antenna represents the omni-directional patterns that is transmitted and received in all directions. In addition, the magnitude of the radiation pattern at 4.8 GHz and 7.2 GHz is very smaller than that of 2.4 GHz, indicating that the radiation does not occur well in 4.8 GHz and 7.2 GHz, and that the harmonic components have been well removed. Table 2 shows the radiation efficiency and gain of the proposed antenna. As shown in the table, the radiation efficiency was about 93% or more at 2.45 GHz, which is the desired frequency band. In the second and third harmonic components of 4.8 GHz and 7.2 GHz, the radiation efficiency was less than 10%, and it can be seen that the harmonic components were well removed. The gain can be expressed as the product of the directivity and the radiation efficiency of the antenna. As shown in the table, at the desired frequency band (2.45 GHz), the gain showed good results of about 2 dBi.

Figure 7 is the result of measuring reflection loss by manufacturing the proposed antenna in Figure 1. As shown in the figure, it can be seen that the bandwidth of the antenna was about 410 MHz (2.15 GHz-2.56 GHz) at -10 dB, and the reflection loss was -20 dB at 2.45 GHz, indicating an efficiency of more than 90%.



(a)

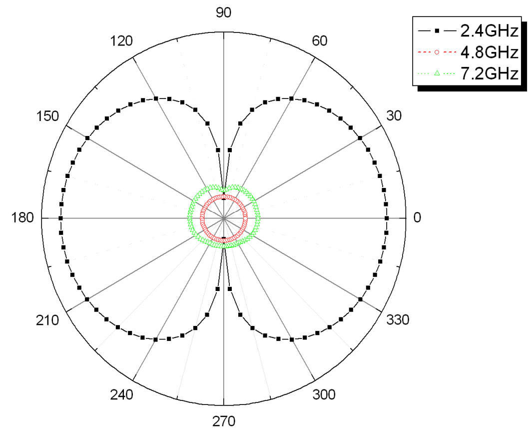


(b)

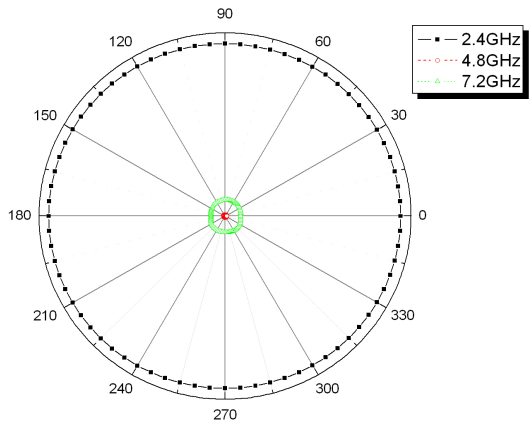
Fig. 5. Simulated return loss as a function of G_{L1} and G_{W2} (a) G_{L1} (b) G_{W2}

Table 1. Design parameters of the proposed antenna (unit:mm)

W_1	W_2	L_2	W_3	L_3	G_{L1}	G_{L2}	G_{W2}
20	2.4	8.5	22.8	9	6.2	5	6



(a) E-plane



(b) H-plane

Fig. 6. Radiation patterns

Table 2. Efficiency and gain of the proposed antenna

	2.4 GHz	4.8 GHz	7.2 GHz
Efficiency [%]	92	0.91	9
Gain [dBi]	1.9	-0.008	0.1

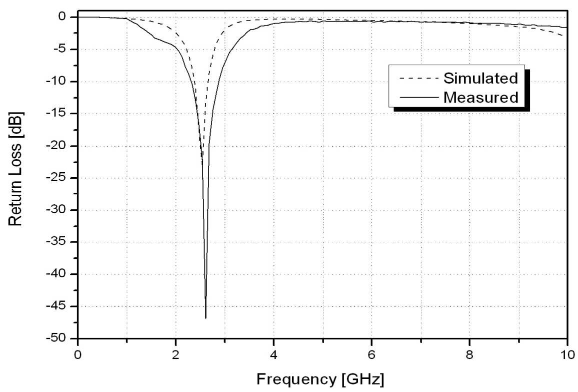


Fig. 7. Comparison of measured and simulated results

Ⅳ. Conclusion

In this paper, a modified H-shaped antenna for wireless power transmission was designed and manufactured using a partial ground plane. At the operating frequency of 2.45 GHz, the impedance bandwidth of the antenna was about 410 MHz (2.15 GHz-2.56 GHz) at -10 dB, the reflection loss at 4.8 GHz is about -0.34 dB, and the reflection loss at 7.2 GHz is about -0.52 dB, indicating that the harmonic components were removed. The radiation efficiency in the desired frequency band satisfied about 93% or more, and the gain was 2 dBi. In the proposed antenna design, the rectangular slot under the feed line is the most important to remove the second and third harmonic components.

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