LED Illumination Experiment through Energy Harvesting using Novel Capacitance Loaded Loop Rectenna

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Abstract In this study, we propose a capacitance-loaded loop rectenna as a method for illuminating LEDs while preserving the electromagnetic field characteristics of a typical loop-type rectenna and preventing short-circuiting issues associated with its loop shape. Through electromagnetic field analysis, we discovered that the resonance frequency of the capacitance-loaded loop antenna closely matches the *S*-parameter characteristics of a conventional loop antenna (rectenna), whereas this frequency shifts when using a loop rectenna with notch. Subsequently, we constructed a capacitance-loaded rectenna and conducted an LED lighting experiment, using slight electromagnetic wave leakage from a microwave oven as the radiation source. The results of the experiment demonstrate the successful illumination of LEDs using the capacitance-loaded rectenna, which possesses electromagnetic field characteristics equivalent to those of a standard loop rectenna, without compromising the integrity of the power-feeding circuit.

Keyword Loop antenna, Rectenna, Energy harvest, WPT, Wireless power transmission, Capacitance Load

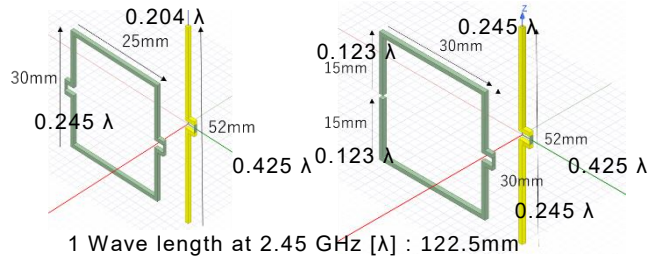
1. Introduction

The principle of the Yagi-Uda structure's waveguide, which utilizes the phenomenon of the magnetic field generated by the current flowing through the feeding elements, inducing a current in adjacent non-feeding elements, has been applied to create an array of rectennas where LEDs illuminate, propagating power to distant rectennas [1], [2]. However, there are constraints regarding the shapes, sizes, and spacing of the elements in the case of the Yagi-Uda structure, making it difficult to achieve a freeform or flexible arrangement. On the other hand, loop-type Yagi-Uda antennas with loop-shaped elements are commonly used in amateur radio and similar applications. Therefore, it is possible to consider applying this concept to create a rectenna array [3]. However, in practice, a problem arose where the circuit would short-circuit in the loop section when constructing rectennas with loop antennas, and it does not function as a rectifying circuit. The authors, thus, have proposed a solution to this problem by introducing notches into the elements, creating a C-shaped loop rectenna array [4]. However, in this case, it is not possible to obtain characteristics similar to loop-type Yagi-Uda antennas as the shape of the elements change from a loop-type to a C-type. In this study, a new rectenna design is proposed, where notches are incorporated into the loop-type rectenna, and capacitance is loaded onto these notches. The characteristics of this design were analyzed through electromagnetic field analysis using HFSS, and an LED lighting experiment was conducted using faintly leaking electromagnetic waves from a microwave oven as the radiation source.

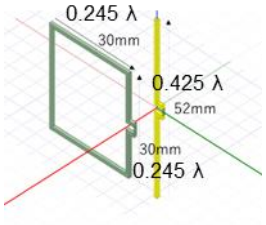
2. Analysis

The analysis model is depicted in Fig. 1. Here, the operating frequency is set to 2.4 GHz, the same frequency as that of a microwave oven. Fig. 1(a) represents the proposed capacitance-loaded loop rectenna. In this case, the capacitance value was chosen to not interfere with the self-resonance frequency, and it was set to 30 pF. The capacitance is loaded on the opposite side of the feeding point, as shown in Fig. 1(a). Fig. 1(b) depicts a C-shaped loop antenna with notches incorporated into the loop antenna for comparison. Fig.1(c) serves as a reference, representing a loop rectenna for comparison, without capacitance or notches loaded.

Fig. 2(a), Fig. 2(b), and Fig. 2(c) illustrate the analysis results for the capacitance-loaded rectenna, those for the loop rectenna with notch, and those for the reference normal loop rectenna, respectively.

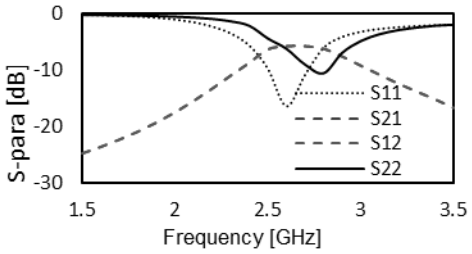


(a) Capacitance load (b) Loop rectenna with notch

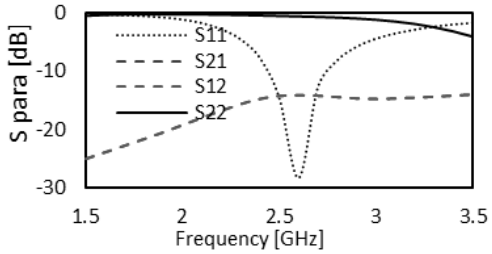


(c) Normal loop type

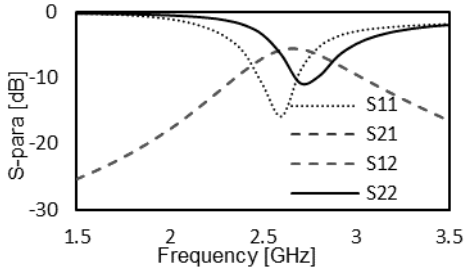
Fig.1. Three Types of Analysis Models for Loop Rectennas



(a) Capacitance load loop rectenna



(b) loop rectenna with notch



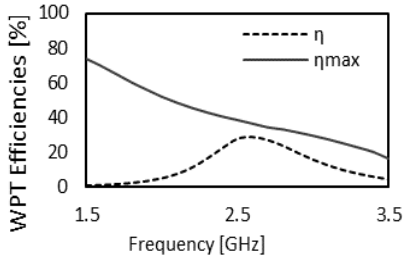
(c) Loop rectenna

Figure 2: Frequency Characteristics of S-Parameters for various loop rectennas.

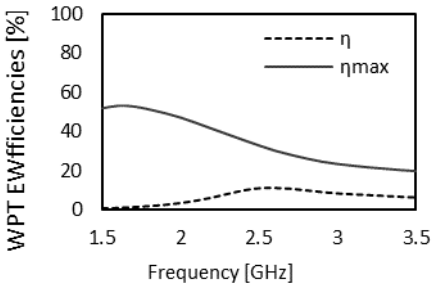
As evident from Fig. 2(a) and Fig. 2(c), loading capacitance has a minimal impact on the *S*-parameters. In contrast, the loop antenna with notch exhibits a significant shift in resonance frequency, over 1 GHz higher, indicating a notable change in its characteristics.

3. Wireless Power Transmission Efficiency

Using the results of electromagnetic field analysis obtained with HFSS, calculations for wireless power transmission efficiency [5], [6] were conducted, as detailed in Chapter 2. The results are presented in Fig. 3. It can be observed that the efficiency of the capacitance-loaded loop-type rectenna is higher than the loop rectenna with notch with notches, as demonstrated in the figure.



(a) Capacitance load loop rectenna



(b) loop rectenna with notch

Fig.3. Wireless power efficiencies vs. Frequency [GHz] of loop rectenna

4. The Experiment of LED Illumination Using Capacitance Load Loop Rectenna

The capacitance-loaded rectenna shown in Fig. 1(a) was prototyped, and an LED lighting experiment was conducted. Figure 4 depicts the experimental setup when each prototype rectenna was placed near the door of a microwave oven. In this experiment, the microwave oven had a power output of 500W, and a cup of water was placed inside it to prevent operation without items to be heated. It can be observed that the LEDs are illuminated due to the leaked waves from the microwave oven.

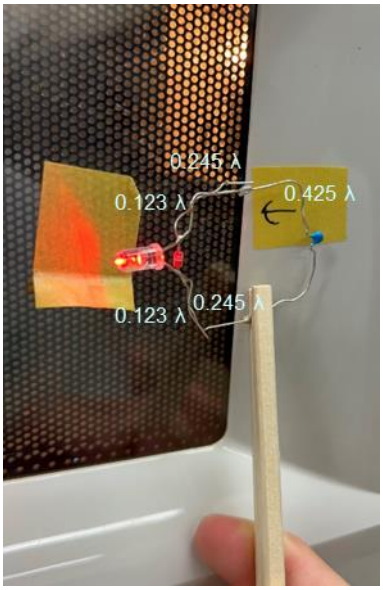


Fig.4. LED Illumination Experiment Using Capacitance-Loaded Loop Rectennas and Microwave Oven Leakage Waves.

5. Conclusion

We proposed the capacitance-loaded loop rectenna as a method to illuminate LEDs while maintaining the electromagnetic field characteristics of loop-type rectennas and avoiding short-circuiting issues caused by the loop shape. The analysis results revealed that a loop antenna loaded with 30 pF of capacitance exhibits characteristics where the resonance frequency position remains almost unchanged compared to an unloaded loop antenna at 2-GHz band. On the other hand, a loop antenna with notches of the same size showed a shift in the resonance frequency position towards higher frequencies.

We fabricated prototypes of capacitance-loaded rectennas and a loop rectenna with notch and conducted LED lighting experiments using faint electromagnetic waves leaking from a microwave oven as the radiation source. The results demonstrated the successful LED lighting experiment with the capacitance-loaded rectenna. In other words, the capacitance-loaded antenna exhibited the same electromagnetic field characteristics as the loop rectenna and was capable of illuminating LEDs without short-circuiting the power-feeding circuit. In the future, we plan to construct an array using capacitance-loaded loop rectennas and conduct experiments to illuminate multiple LEDs at a distance from the radiation source.

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