Experimental Study on Load Resistance Design of a Differential Rectenna

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***Abstract*—In this paper, a new design concept of rectennas' load resistance is proposed and the feasibility is experimentally studied. The RF-to-DC conversion efficiency of rectennas depends on its load resistance. The load resistance characteristic of rectenna can be adjusted by changing the impedance matching between antennas and a rectifying diode. Three prototype differential rectennas designed for different load resistance are experimentally evaluated. It is found to be feasible to design the optimum load resistance using matching shorted stubs without harming RF-to-DC conversion performance.**

Keywords—wireless power transfer; rectenna; impedance matching; rectifying circuit

I. INTRODUCTION

Rectennas are the most important devices in wireless power transfer (WPT) systems. Many studies regarding the rectenna are carried out in various fields, for example, downsizing [1], broadband [2], high-efficiency [3-5] etc. We have also proposed a rectenna, which has better conversion efficiency under low power conditions and provides high design flexibility [6]. The output DC power of rectennas depends on load resistance. Then a study has been also conducted to adjust load resistance characteristic of rectennas [7]. In this study, the RF-to-DC conversion efficiency is considered for the load resistance values from 20 to 150 Ω under input power of 250 mW.

We have proposed a new differential rectenna using matching shorted stubs [8]. The matching shorted stubs are used to improve the impedance matching between antennas and a diode and high conversion efficiency is achieved at low received power. In the work of [8], it was also found that almost the same conversion efficiency was obtained with different load resistance by attaching the matching shorted stubs when enough power is received by the rectenna. This means that optimum load resistances can be designed by changing the matching circuit between antennas and a diode. In this paper, the feasibility of the load resistance design concept using the matching shorted stubs is experimentally investigated.

This paper is organized as follows. In Section II, the structure and operation of the differential rectenna are described. In Section III, measured results of three prototype rectennas are presented and discussed focusing on the load resistance design concept. Finally, Section IV concludes this paper.

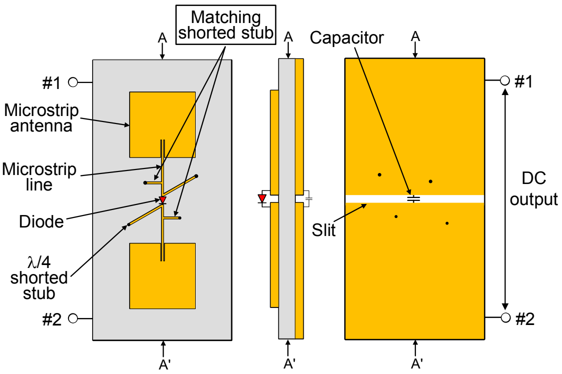

Fig.1. Structure of the proposed differential rectenna.

II. DIFFERENTIAL RECTENNA

A. Structure

Fig. 1 shows the structure of the proposed differential rectenna. Two microstrip antennas, two quarter-wavelength shorted stubs and two matching shorted stubs are connected to both sides of a rectifying diode. The matching shorted stubs and quarter-wavelength shorted stubs are attached to the microstrip lines which connect microstrip antennas and a rectifying diode. The quarter-wavelength shorted stubs suppress the even harmonics generated by the diode. The ground planes of the two microstrip antennas are separated by a slit. A capacitor mounted just under the diode connects the separated ground planes. The quarter-wavelength shorted stubs also act as a circuit to charge the capacitor. The rectified DC output power can be obtained between the two ground planes.

B. Rectenna Operation

The received RF wave by the two microstrip antennas are applied to a diode in anti-phase through the microstrip lines. Therefore, twice of RF voltage is applied to the diode because positive and negative voltages are simultaneously applied to the anode and cathode or cathode and anode, respectively. In case of ON state of the diode, current flows through the quarter-wavelength shorted stubs and the diode in conduction state. Then the capacitor is charged. In case of OFF state of the diode, current cannot flow through the diode because the circuit

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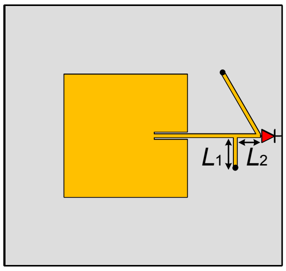


Fig.2. Length and position of the matching shorted stubs.

Table I. DESIGN PARAMETERS OF PROTOTYPE RECTENNAS

	Load Resistance [Ω]	Conversion Efficiency [%]	Stub Length L_1 [mm]	Stub Position L_2 [mm]
Design A	850	62.5	5.3	1.3
Design B	3000	72.4	2.7	3.4
Design C	3600	65.9	2.2	4.1

constructed with the quarter-wavelength shorted stubs and the diode becomes an open circuit. Hence, the differential rectenna acts as a half-wave rectifier.

C. Matching Shorted Stub

The main purpose of this paper is an experimental investigation of the relation between the matching circuit and optimum load resistance of the proposed differential rectenna. To do this, three prototype rectennas with different matching shorted stubs are designed and evaluated.

The two matching shorted stubs are attached to achieve the impedance matching between the antennas and the rectifying diode. The length L_1 and position L_2 of the matching shorted stubs shown in Fig. 2 are designed using Keysight Technologies's ADS.

Table I shows the design parameters of the three prototype rectennas with target load resistance and conversion efficiency values. Each design is optimized for different load resistance with better than 60% conversion efficiency.

III. EXPERIMENTAL RESULTS

Fig. 3 shows a picture of the prototype differential rectenna. It is fabricated on a Teflon glass fiber substrate whose dielectric constant and thickness are 2.15 and 0.8 mm, respectively. The design frequency is 5.8 GHz and the size is 37 × 74 mm.

The prototype rectennas are measured in an anechoic chamber using a standard horn antenna (10.2 dBi) with the distance of 0.8 m [6]. The output DC voltage is measured at the load resistor and the RF-to-DC conversion efficiency is defined as follows:

$$\eta = \frac{P_{\mathrm{DC}}}{P_{\mathrm{rec}}} \times 100 = \frac{P_{\mathrm{DC}}}{P_{\mathrm{PD}} \times G_{\mathrm{rec}} \times \frac{\lambda^2}{4\pi}} \times 100 \qquad (1)$$

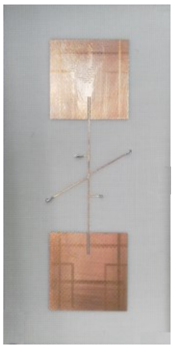


Fig.3. Picture of the prototype differential rectenna (37 × 74 mm).

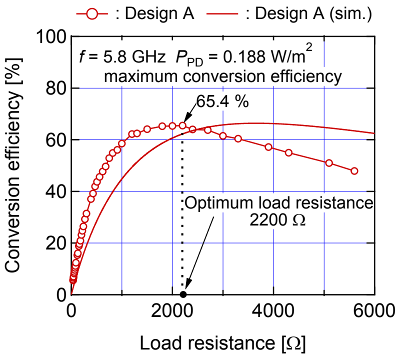


Fig. 4. Measured and simulated conversion efficiency vs. load resistance.

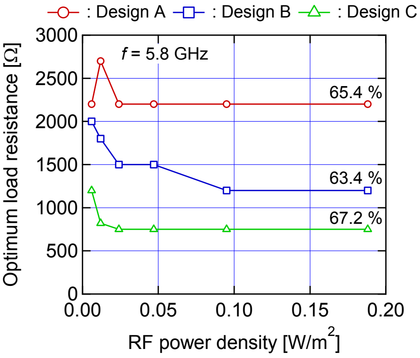
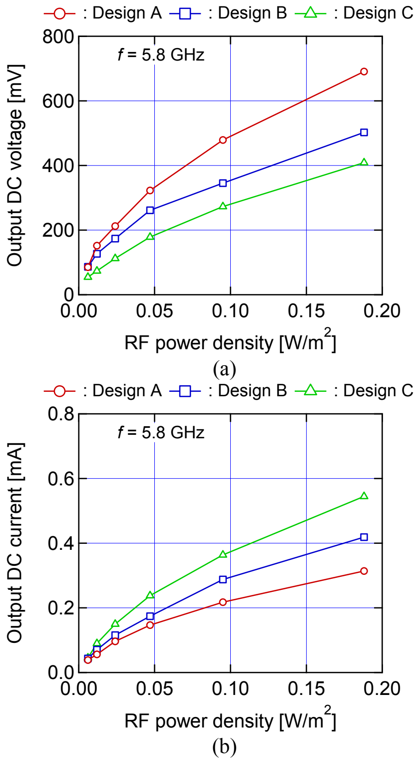


Fig. 5. Measured optimum load resistance vs. RF power density. The maximum conversion efficiency values of each design are also shown at 0.188 W/m^2.

where P_{DC}, P_{rec}, P_{PD} and G_{rec} are the output DC power, received RF power, RF power density and rectenna's gain, respectively.

Fig. 4 shows the measured and simulated conversion efficiency of Design A. The conversion efficiency changed from 5.5% to 65.4% according to the load resistance. Here, the measured frequency and RF power density are 5.8 GHz and 0.188 W/m^2, respectively. The maximum conversion efficiency is obtained at the load resistance of 2200 Ω. The resistance value where the maximum conversion efficiency is obtained is defined as an optimum load resistance in this paper.

Fig. 5 shows the measured optimum load resistance of the three prototypes at the RF power density from 0.006 to 0.188 W/m^2. The optimum load resistance strongly depends on the received RF power density under low power environment.



(a)

(b)

Fig. 6. Measured DC output vs. RF power density. (a) DC voltage, (b) DC current. The optimum load resistances of 2200 Ω, 1200 Ω and 750 Ω are used in the measurement for design A, B and C, respectively.

However, it becomes constant at high RF power density. The maximum conversion efficiency values at 0.188 W/m^2 are also shown in this figure, and they are 65.4%, 63.4% and 67.2% for Design A, B and C, respectively. Almost the same conversion efficiency is obtained regardless of the rectennas' design when enough power is received by the rectennas. Then, the optimum load resistance can be changed without harming the RF-to-DC conversion performance. The measured optimum load resistances are lower than those of the target load resistance shown in Table I. However, the conversion efficiency change is small around the optimum load resistance as shown in Fig. 4.

Figs. 6(a) and 6(b) show the measured output DC voltage and output DC current with respect to the RF power density, respectively. In these measurements, the optimum load resistances of 2200 Ω, 1200 Ω and 750 Ω are used for Design A, B and C, respectively. Higher output DC voltage is obtained in design A with the load resistance of 2200 Ω. On the other hand, its output DC current is less than those of other designs. This is because the conversion efficiency, i.e., output DC power is almost the same among the three prototypes.

IV. CONCLUSION

In this paper, load resistance characteristics of a differential rectenna have been experimentally examined to confirm the feasibility of a new load resistance design concept using matching shorted stubs. Almost the same conversion efficiency was obtained with different load resistances by adjusting the length and position of matching shorted stubs when enough RF power is applied to the diode. It was found to be feasible to design the load resistance of rectennas by using matching shorted stubs.

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