Performance Evaluation of a 5.8-GHz Current Aggregation Type Multi-Polarization Rectenna

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Abstract – **In this paper a 5.8-GHz current aggregation type multi-polarization rectenna is proposed. The proposed rectenna is based on the previously reported 5.8-GHz multi-polarization rectenna integrating four dual-polarized antennas. The proposed new multi-polarization rectenna is experimentally examined and its performance is evaluated. The RF-DC conversion efficiency was better than 40% regardless of the polarization angle.**

Index Terms — **Rectenna, Current aggregation type, Multi-polarization, Energy harvesting, Wireless power transmission**

I. INTRODUCTION

Recently, energy harvesting and wireless power transmission (WPT) have become attractive applications of the microwave technologies [1], [2]. In these applications, high performance rectennas are required because the rectenna is one of the most essential elements.

We have proposed a multi-polarization rectenna integrating four dual-polarized antennas which receive an RF wave and divide it into two orthogonal components [3], [4]. However, the performance of the multi-polarization rectenna degrades for a certain polarization angle due to the diodes which do not work at the polarization angle. In this paper, a new current aggregation type multi-polarization rectenna is proposed and its performance is experimentally evaluated.

II. STRUCTURE AND OPERATION

Fig. 1 shows the structure of the newly proposed current aggregation type multi-polarization rectenna. This rectenna is based on the previously reported multi-polarization rectenna [3], [4]. Four diodes are mounted between dual-polarized antennas. However, the diodes D3 and D4 are mounted in the opposite direction when compared to the previously reported multi-polarization rectenna.

Fig. 2 shows the basic operation of the proposed current aggregation type rectenna. Generally, any polarized waves can be divided into two orthogonal components such as x- and y-components. The x- and y-components are converted to DC by the diode D1, D3 and D2, D4, respectively. When the RF wave with the polarization angle $\phi_P = 45$ deg. is received as shown in this figure, the diodes D2, D3 and D1, D4 alternately repeat ON and OFF states according to the RF phase. The DC current I_{DC} flows as shown in Fig. 2. However,
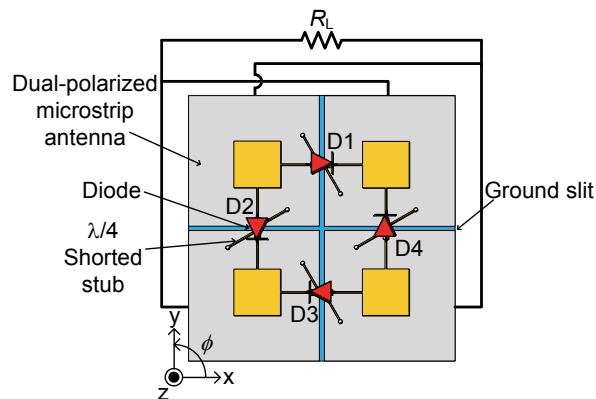

Figure 1. Structure of the current aggregation type multi-polarization rectenna.
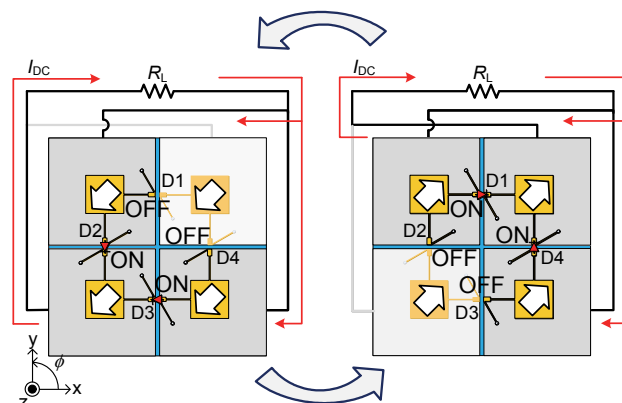

Figure 2. Operation of the proposed current aggregation type rectenna ($\phi_P = 45$ deg.).

only the diodes D2 and D4 work as a rectifier for the polarization angle $\phi_P = 90$ deg.

Fig. 3 shows the equivalent circuit of the proposed rectenna when the load resistance R_L is connected as shown in Fig. 1. In this connection, four rectifiers are connected in parallel. In the case of the previously reported multi-polarization rectenna, the rectifiers are connected in series and parallel. Hence the non-working diodes, i.e., diode D1 and D3 for the polarization of $\phi_P = 0$, 90, and 180 deg. act as a part of the load. This causes the performance degradation for the polarization angles. On the other hand, the newly proposed current aggregation type rectenna avoids the undesired voltage drop caused by the non-working diodes because all rectifiers are connected in parallel.

III. EXPERIMENTAL RESULTS

The RF-to-DC conversion efficiency η is defined in

$$\eta = \frac{P_{DC}}{P_{in}} = \frac{V_{DC}^2 / R_L}{P_{PD} \times A_{er}}, \tag{1}$$

where P_{DC} and P_{in} are the output DC power and received RF power, respectively. P_{DC} is derived from the output DC voltage V_{DC} and load resistance R_L. A_{er} is the effective antenna aperture. The RF power density P_{PD} is calibrated at the receiving plane using a standard horn antenna (10.2 dBi at 5.8 GHz).

Fig. 4 shows the measured performance of the RF-to-DC conversion efficiency vs. load resistance. Measurement was conducted under the very low input power of $P_{in} = 0.16$ mW (power density $P_{PD} = 0.05$ W/m^2) at 5.83 GHz where the maximum output DC voltage was obtained. The measured maximum conversion efficiency is approximately 40% at the polarization angle $\phi_P = 45$ deg. and 45% at $\phi_P = 90$ deg.

Fig. 5 shows the measured performance of the RF-to-DC conversion efficiency vs. polarization angle. In this figure, the proposed current aggregation type multi-polarization rectenna is compared with the previously reported multi-polarization rectenna. The load resistance is the average value of optimum load resistance for each polarization. The measurement frequency is the value where the maximum output DC voltage was obtained by each rectenna. The RF-to-DC conversion efficiency of the current aggregation type rectenna is better than 40% regardless of the polarization angle. The conversion efficiency of the previous rectenna is minimum at the polarization angles $\phi_P = 0$, 90, and 180 deg. due to the reason described above. On the other hand, the conversion efficiency of the proposed current aggregation type rectenna is maximum at the polarization angle $\phi_P = 0$, 90, and 180 deg. and the proposed rectenna has a higher conversion efficiency than the previous one. This is because the parallel connection effectively avoids the undesired voltage drop caused by the non-working diodes.

IV. CONCLUSION

In this paper, a novel multi-polarization rectenna has been proposed and demonstrated. This rectenna is configured to aggregate the rectified DC current. The RF-to-DC conversion efficiency was better than 40% regardless of the polarization angle under the very low input power of 0.16 mW. The novel current aggregation type multi-polarization rectenna can provide a higher conversion efficiency than the previously reported multi-polarization rectenna due to its parallel structure. The proposed rectenna can be used for many kinds of applications such as energy harvesting and wireless power transmission (WPT).
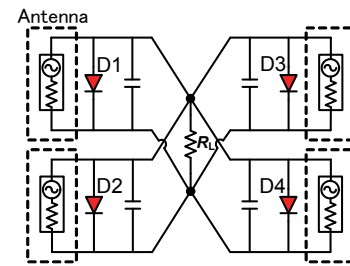

Figure 3. Equivalent circuit of the current aggregation type rectenna (All rectifiers are connected in parallel).
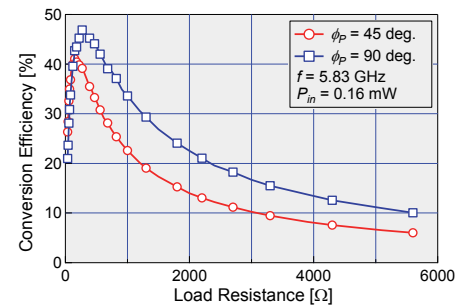

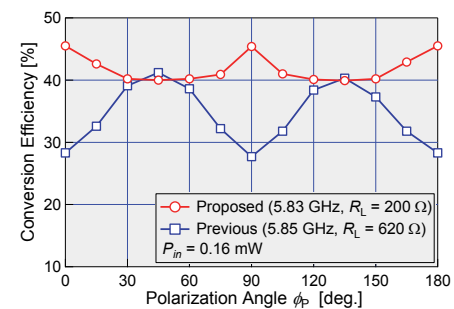Figure 4. Measured RF-DC conversion efficiency vs. load resistance ($f = 5.85$ GHz, $P_{in} = 0.16$ mW).

Figure 5. Measured RF-DC conversion efficiency vs. polarization angle ϕ_P. Optimum frequency and averaged optimum load resistance were chosen.

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