An H-Plane Wide-Angle Rectenna Using an In-Phase/Anti-Phase Dual-Feed Antenna

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***Abstract* – A new H-plane wide-angle rectenna using an in-phase/anti-phase dual-feed antenna is proposed. Generally, high gain array antennas have a narrow beam width and its beam deviation from arrival waves seriously degrades the antenna gain. This is due to the phase difference of the waves received by multiple antenna elements. A magic-T used in the proposed dual-feed antenna divides the received waves into in-phase and anti-phase components, and these components are separately rectified by two diodes. As a result, wide-angle performance is obtained by combining the two rectified DC power. In this paper, a slot-T type magic-T is used to achieve an H-plane wide-angle rectenna. The basic concept of the proposed rectenna is experimentally confirmed and about two times of wider reception angle is obtained when compared to conventional rectennas using an array antenna.**

***Index Terms* — A wide-angle rectenna, In-phase/anti-phase antenna, Magic-T, H-plane.**

1. Introduction

Recently, energy harvesting has attracted much attention as a electric power source that can be used anywhere anytime without a battery, wire, and CO_2 [1]. Not only in the energy harvesting but also in the wireless power transfer, rectennas which convert RF power to DC power are one of the most essential key elements.

It is important for rectennas to increase the RF-to-DC conversion efficiency. Using a high-gain array antenna is one of the solutions to improve the efficiency. A rectenna array configuration has been presented for enhanced RF power harvesting [2]. Several other rectenna arrays which are suitable for low power density condition have been also presented [3]. However, the beam of the array antennas becomes sharp along with the improvement of the antenna gain. Consequently, the conversion efficiency decreases owing to the off axis of the arrival RF waves. This is because the anti-phase components of the RF waves received by two antennas cancel each other. To solve the issue, we have proposed an E-plane wide-angle rectenna using magic-Ts [4].

In this paper, a new high-gain and wide-angle rectenna in H-plane is proposed. The proposed rectenna employs an in-phase/anti-phase dual-feed array antenna to separately rectify the in-phase and anti-phase components of the RF waves. A new slot-T type magic-T is used in this rectenna to realize an H-plane wide-angle reception. The performance of the proposed rectenna is experimentally evaluated using a prototype rectenna.

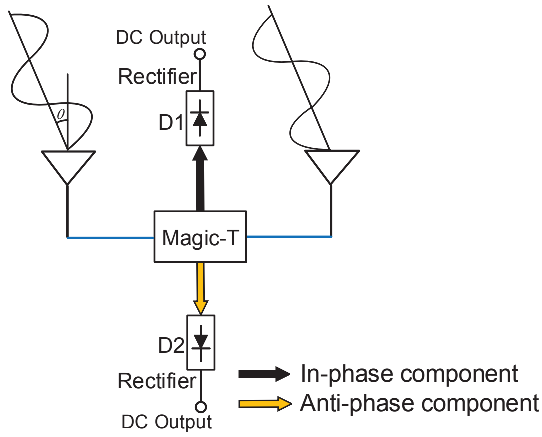

Fig. 1. Block diagram of the proposed rectenna.

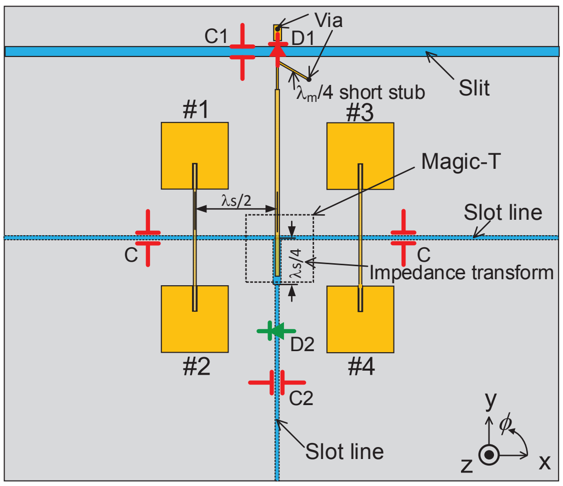

Fig. 2. Structure of the proposed rectenna.

2. Rectenna Design

(1) Basic Concept

Fig. 1 shows the block diagram of the proposed rectenna which consists of two pairs of antenna elements, a magic-T and two rectifying diodes. RF waves received by the antenna elements are divided into in-phase and anti-phase components by the magic-T. The in-phase and anti-phase components are separately rectified by the diodes D1 and D2, respectively. By combining the DC output rectified by the two diodes, wide-angle reception is realized.

(2) Structure

Fig. 2 shows the structure of the proposed rectenna. Four microstrip antenna elements are placed on a substrate. Antenna elements #1 and #2 are connected to a microstrip line and converted to a slot line on the bottom side at the middle of the microstrip line. Antenna elements #3 and #4 are the same. A magic-T constructed with a slot-line T junction and microstrip line-to-slot line T junction is located at the center of the substrate. An impedance transformer is employed to reduce the magic-T's insertion loss. A rectifying diode D1 is connected to the microstrip line of the magic-T and the other side of D1 is connected to the conductor on the bottom side by a via. A slit on the bottom side is formed for DC cut and the separated conductors are connected by a capacitor C1. A quarter-wavelength shorted stub is connected to D1 to suppress the even harmonics generated by the diode and form a circuit to charge the capacitor C1. A diode D2 is mounted on the bottom side across the slot line. A capacitor C2 is mounted to form a quarter-wavelength shorted slot line. C2 is also used to store the charge rectified by the diode D2. Two capacitors C are also mounted to form a quarter-wavelength shorted slot line.

(3) Operating Principle

RF waves received by two pairs of the antenna elements (#1, #2) and (#3, #4) are fed to the slot line of the magic-T. Thanks to the magic-T, the in-phase component of the RF waves goes to the diode D1 and the anti-phase component goes to the diode D2. Hence, the in-phase and anti-phase components of the RF waves are separately rectified by D1 and D2, respectively. By combining the rectified DC power in a series or parallel connection, both of the in-phase and anti-phase power can be effectively used.

3. Measured Results

Fig. 3 shows the open-circuit output DC voltage of the fabricated rectenna with respect to the reception angle θ in H-plane (*xz*-plane). The power density P_{PD} is 0.05 W/m^2 and the measured frequency is 5.92 GHz where the highest voltage is obtained. The peak of the voltage rectified by D1 is 263 mV at the angle 0° as shown in the yellow line. On the other hand, the voltage of D2 shown in the green line has two peaks at +/-28°. The blue and red lines show the voltages of a series and parallel connection of D1 and D2, respectively. Taking the peak voltage of D1 as a reference, the half-power angles of D1, parallel and series connection are 29°, 22° and 57°, respectively.

Fig. 4 shows the output DC power with respect to the load resistance R_L. The angles are chosen to provide the highest voltage in each connection. The optimum load resistances where the maximum power is obtained are 510 Ω and 470 Ω for D1 and the parallel connection, respectively. This means that the internal resistances are around 500 Ω. As shown in this figure, D1 and the parallel connection provide better power than those of D2 and the series connection. This is due to the high internal resistance of the series connection around 1200 Ω.

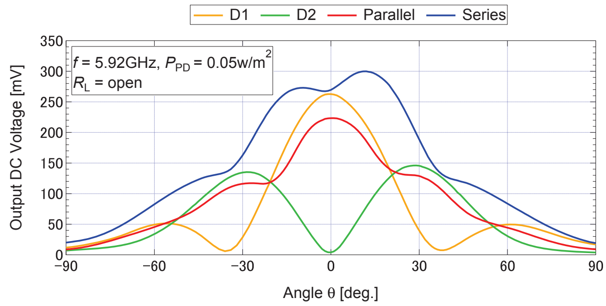

Fig. 3. Measured output DC voltage vs. angle (H-Plane).

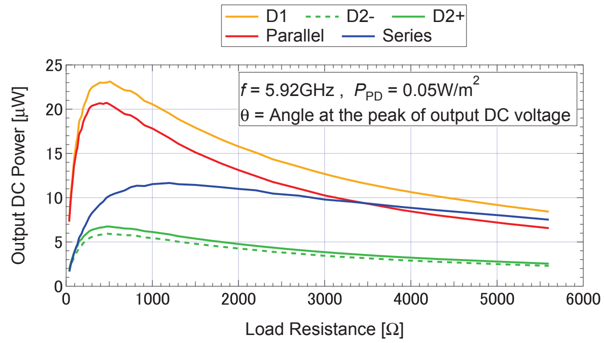

Fig. 4. Measured output DC power vs. load resistance.

Conclusion

An H-plane wide-angle rectenna using an in-phase/anti-phase dual-feed antenna has been proposed. In this rectenna, the in-phase and anti-phase components of the received RF waves are separately rectified by two diodes. A planar magic-T which is the combination of a slot-line T junction and microstrip line-to-slot line T junction is effectively used to obtain the in-phase and anti-phase components of the received RF waves in H-plane. From the measured results, both series and parallel connection provide wide-angle reception. The proposed rectenna can be used to enhance the reception capability of rectennas by integrating with an E-plane wide-angle rectenna using another type of the dual-feed network.

Acknowledgment

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