Study on Rectenna Harmonics Reradiation for Microwave Power Transfer with a Harmonics-Based Retrodirective System

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***Abstract* – A harmonics-based retrodirective system (HBRS) is proposed for microwave power transfer to an airplane for weight saving. Re-radiation of rectenna harmonics is adopted for the pilot signal in the HBRS. It is necessary for actualizing the HBRS to evaluate harmonic re-radiation from rectennas. In this paper, we fabricated rectennas which are on a thin and lightweight substrate, and conducted experiments. From measurements with a single rectenna, we obtained re-radiation patterns which agreed with the electromagnetic simulation. The re-radiation patterns from the array of two rectenna were consisted with the patterns which were calculated from the array factor.**

***Index Terms* — Rectennas, Re-radiation, Harmonics, Retrodirective.**

1. Introduction

A retrodirective system is a direction detection method, which can be used for microwave power transfer to a device such as a small airplane. The microwave power is radiated to the direction where a pilot signal arrives from the device. Typically, this pilot signal is generated by a signal generator mounted on the device. In a harmonics-based retrodirective system (HBRS), harmonics re-radiation from rectennas are adopted for the pilot signal[1]. Not requiring a signal generator, we can reduce the weight and the size of the device. In order to realize the HBRS, it is necessary to understand the characteristics of re-radiation from rectennas. In this paper, we show the results of the electromagnetic simulations and re-radiation experiments.

2. Harmonic Radiation Simulations

We fabricated rectennas which the antenna was a λ/2 dipole antenna and the rectifier was a double voltage rectifier. The antenna and the rectifier was integrated on a thin and lightweight substrate. The fundamental frequency was 2.45 GHz. The length of one side of dipole, *l*, was 28 mm, 29 mm, and 30 mm. Fig.1 shows the picture of this rectenna.

In order to investigate where and how the harmonics re-radiate from the rectenna, we conducted electromagnetic simulations by using HFSS (High Frequency Structural Simulation). We made the model of transmission lines and simulated at the 2nd and 3rd harmonics. Fig.2 shows the results. These patterns were normalized with maximum value.

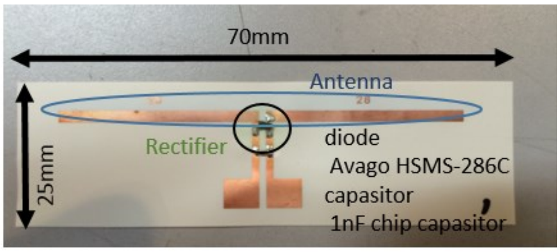

Fig.1 A photo of a double voltage rectenna with λ/2 dipole antenna

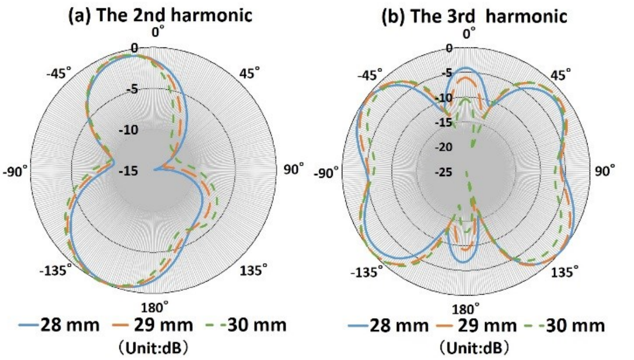

Fig.2 Harmonic radiation patterns by HFSS simulations

The 2nd harmonic pattern had null points at $\pm 90^{\circ}$. This is consistent with the radiation pattern of λ dipole antenna. The pattern became small around 150°. This is because of the asymmetric transmission lines of rectenna. There were little differences by *l*. The 3rd harmonic pattern had null points at $\pm 20^{\circ}, \pm 90^{\circ}$, and $\pm 160^{\circ}$. This is consistent with the radiation pattern of $3\lambda/2$ dipole antenna. Around $0^{\circ}, 180^{\circ}$, the shorter *l* was, the lager the radiation pattern became. Since the 3rd harmonic had shorter wavelength, the patterns were more affected by the change in *l*.

3. Re-radiation Measurement Experiments

We conducted harmonic measurement experiments. Fig.3 shows the block diagram of the experiments. The measuring antenna was rotated around the rectenna. The power density radiated from the horn antenna was set to $1\ \mathrm{mW/cm^2}$ at the rectenna. The load of rectenna was $1\ \mathrm{k\Omega}$ of a chip load. We obtain 43 % of RF-DC conversion efficiency in this condition. In this experiments, the re-radiation patterns of the 2nd and the 3rd harmonics were measured. The 4th and higher harmonics were less than measurement sensitivity. The fundamental re-radiation could not be evaluated because the power from of the horn antenna was too large to detect the re-radiation from the rectennas.

First, we set a single rectenna and measured the re-radiation patterns. Figs.4 and 5 show the measured patterns of 2nd and 3rd harmonics. The unit is power density at the measuring antenna. In both cases, the results of simulations and experiments were well matched on the directions of null points. The depths of null points were different from the simulations. This is because the HFSS model did not have electronic elements such as a diode and a capacitor.

Next, we set two rectennas in horizontal, and measured from -90° to $+90^{\circ}$. Fig 6 shows the measured results of the 2nd harmonics. Comparing to the single rectenna, the null points generated at $-30^{\circ}$and 25°, The value at 0° was 3 dB larger. In addition to the measured results, we calculated re-radiation patterns by multiplying the array factor and the patterns of the single rectenna. The array factors were determined by the number of elements and the phase difference δ. Assuming $\delta = 0$, the calculated pattern was well matched to the measured results. This indicates that the re-radiation from two rectennas were in-phase. With the 3rd harmonics, the measurement and the calculation were matched as well.

4. Conclusion

In this paper, we conducted electromagnetic simulations and experiments of the re-radiation harmonics from the rectennas. The result of experiments were agreed with the simulations, and the pattern of the rectenna array was matched with the calculation.

Increase the number of null points by aligning rectennas may cause insufficiency of the pilot signal power. In order to realize the HBRS, we will consider the optimum antenna geometry and the array.

Acknowledgment

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References

[1]M. Iwashimizu, T. Mitani, N. Shinohara, G. Sakaki, K. Hiraoka, K. Matsuzaki, and K. Yonemoto,"Study on Direction Detection in a Microwave Power Transmission System for a Mars Observation Airplane" IEEE Wireless Power Transfer Conference 2014, P-Th-2, Proceedings pp. 146-149, Korea, May 2014

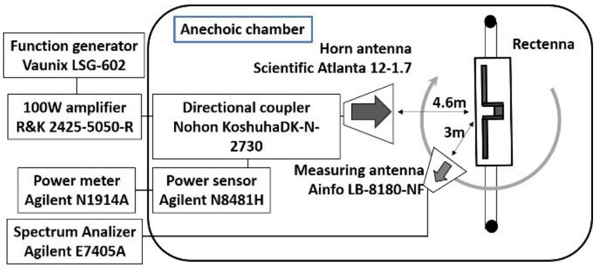

Fig.3 A block diagram of the harmonic re-radiation experiments

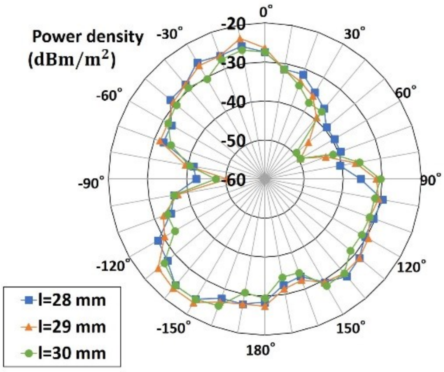

Fig.4 2nd harmonic re-radiation patterns from the experiments

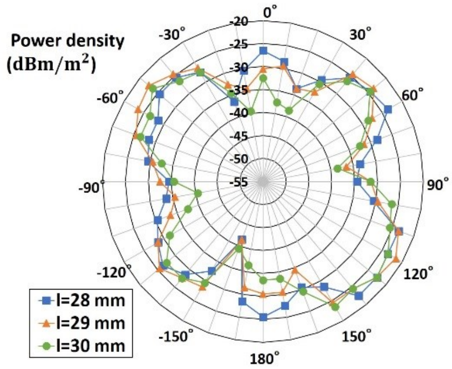

Fig.5 3rd harmonic re-radiation patterns from the experiments

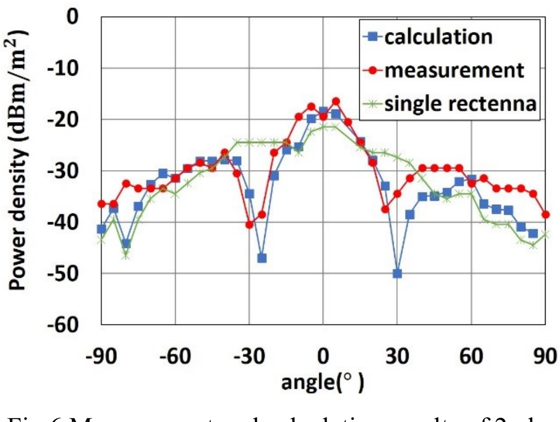

Fig.6 Measurement and calculation results of 2nd re-radiation patterns of the two rectennas array (Measurement results of a single rectenna are also plotted.)