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An Investigation for Optimum Design of Matching Circuit in Highly Efficient RF-DC Conversion Circuit by Genetic Algorithm

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Abstract— **RF-DC conversion circuit is one of the most important components in the wireless power transmission technologies and design method of the circuit is actively investigating. However, it is difficult to formulate the principle of operation of RF-DC conversion circuit because the diode which has non-linear characteristic is used and its operating point is not fixed.**

In this paper, we investigate the optimal design of RF-DC conversion circuit by using the genetic algorithm, And, for clarifying the optimal operation of the diode, we also discuss characteristics of the matching circuit used in RF-DC conversion circuit obtained by the automatic design.

1. INTRODUCTION

Recently years, microwave and millimeter-wave are used for not only the radio communication but also the wireless power transmission. For example, there are the Space Solar Power System(SSPS)[1],, the charging system to electric vehicles[2][3] and so on. In these wireless power transmission systems, one of the most important components is the rectifying antenna (Rectenna)[4]. The rectenna is composed with the circuit to convert the microwave power(RF) to the direct power(DC) and the antenna. For realizing highly efficient wireless power transmission system, the rectenna must be designed with high RF-DC conversion efficiency. However, it is difficult to formulate the optimum design and the operation of the rectenna because the diode has non-linear characteristic and parasitic reactances, and its operating point depends on input power and load resistance.

On the other hand, the method of applying the genetic algorithm to the optimum design of the antenna and the circuit is reported[5]. This method has the advantage that a structure not easy to create can be theoretically discovered though it is known to be not practicable if the speed of the solver is not so high.

In this paper, we investigate the optimum design of RF-DC conversion circuit by using the Lumped Element Finite Difference Time Domain(LE-FDTD) method[6] that can consider mounted devices and GA technique. The LE-FDTD solver is implemented on the GPGPU to overcome the difficulty of GA, and the speed-up of the solver is achieved. We also discuss characteristics of the matching circuit of the obtained optimum RF-DC conversion circuit by this technique.

2. RF-DC CONVERSION CIRCUIT

The rectenna is composed of the receiving antenna, the diode as the rectifying device, the filter, and the load resistance. Microwave received with the antenna is rectified by the diode. The RF stop filter such as the band eliminate filter or the low pass filter is necessary for the output filter because the input wave and its higher harmonics are generated by the rectification. The output DC power is obtained from the load resistance connected to the output port of circuit. Moreover, in general, the matching circuit that higher conversion efficiency is obtained is needed for the input circuit. In the operation of the RF-DC conversion circuit, the voltage between the anode and the cathode terminals of the diode is very important. Fig. 1 shows a design of RF-DC conversion circuit at 5.8GHz that these requirements are satisfied.

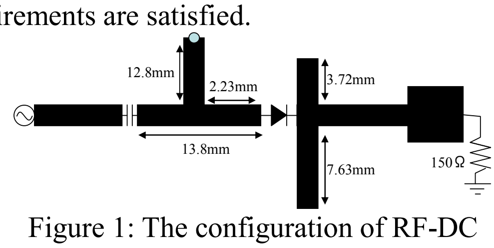

Figure 1: The configuration of RF-DC conversion circuit at 5.8GHz

This circuit is printed on the dielectric substrate. Its thickness and relative permittivity are 0.5mm and 3.4, respectively. The characteristic impedance of the microstrip line is 50Ω at 5.8GHz. The Si schottky barrier diode(Avago HSMS-282B) is chosen for rectifying device because it operates well at 5.8GHz and has low built-in voltage. Structural parameters in this figure indicate optimum for highest conversion efficiency when the input power and the load resistance are varied. In this design, the cathode terminal is grounded because the output filter consists a quarter wavelength open stubs at the input wave and its second harmonic. That is, it is necessary to enlarge the voltage at the anode terminal for obtaining higher conversion efficiency. Fig. 2 shows analytical results obtained by using the LE-FDTD method when the input power and the load resistance are varied.

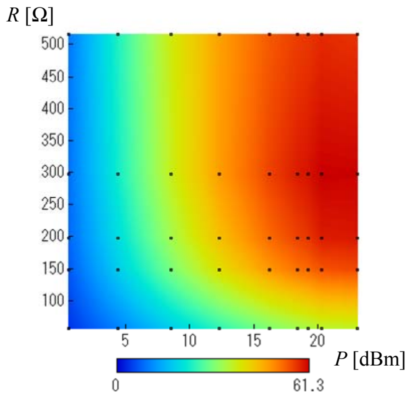

Figure 2: The efficiency of RF-DC circuit

In this case, the structural parameters in each point have been changed, and the conversion efficiency at the best structural parameters are shown. V_{DC} is the DC component of the voltage at the load resistance *R*. In Fig.2, maximum conversion efficiency is 61.3% in input RF power 200mW.

3. GENETIC ALGORITHM AND DESIGN

Genetic Algorithm is metaheuristics optimization algorithm, and it can solve problem which has huge search space. So if we design RF-DC conversion circuit using genetic algorithm, we can design the structure automatically and we can get more conversion efficiency at new RF-DC conversion circuit structure. The number of parameter of RF-DC conversion circuit structure is large. In this paper, we design the structure between the power source and the diode in RF-DC conversion circuit. This circuit is devided in two areas, and each area has three patches. Also, area2 has one via. Each size and location of these patches and the location of the via is chosen as the GA parameters. Fig.3 shows automatic design area and RF-DC conversion circuit structure.

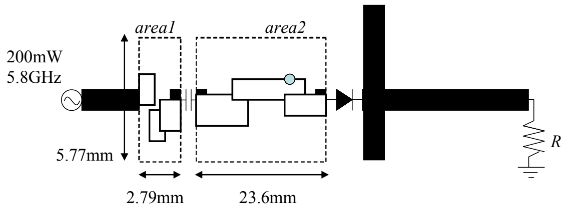

Figure 3: The configuration of RF-DC conversion circuit

In area1, at least one of three patches is restricted to connecting with the input port and the capacitor, respectively. In ares2, also, patches are restricted same condition, and the via is restricted to be on the edge of a patch. The characteristic impedance of the microstrip line used for the input port and the output circuit connected with the cathode terminal is 50Ω at 5.8GHz. Fig. 4 shows one design of RF-DC conversion circuit, automatically.

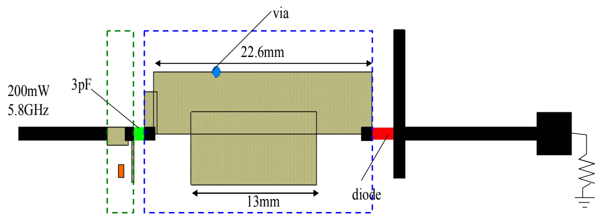

Figure 4: The structure of RF-DC circuit using automaticity design of genetic algorithm.

This time, the structure is designed so that the highest conversion efficiency is obtained when the input RF power is 460mW and the frequency is 5.8GHz. Fig. 5 shows a comparison of conversion efficiencies obtained by analysis and experiment.

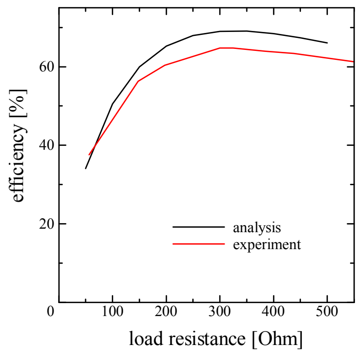

Figure 5: The conversion efficiency of RF-DC circuit using genetic algorithm.

In Fig. 5, maximum conversion efficiency is

64.8% when load resistance is 300Ω in experiment. The experiment result is slightly small compared to the analysis one because of errors in manufacture, but trends are in good agreement. And, this conversion efficiency is higher than the one which is based on the circuit theory. Therefore, the automatic design using genetic algorithm is effective technique for designing RF-DC conversion circuit.

4. CHARACTERISTIC OF MATCHING CIRCUIT

In our RF-DC conversion circuit, the cathode terminal of diode is grounded at 5.8 and 11.6GHz, and the matching circuit connected to the anode terminal is designed by genetic algorithm. So, we examined characteristics of this matching circuit for investigating optimal RF-DC conversion circuit. First, we design another optimal RF-DC conversion circuit by the genetic algorithm and demonstrate in Fig. 6.

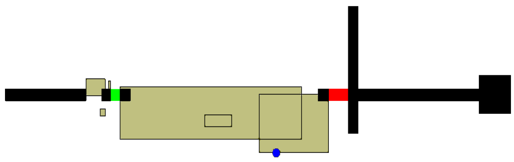

Figure 6: The structure of another RF-DC conversion circuit.

This design of the RF-DC conversion circuit using the genetic algorithm is different from Fig. 4. Hence, characteristics of two matching circuits are compared. Fig. 7 shows only a matching circuit and its ports definition. Port #1 is connected to the power source and Port #2 is connected to the anode terminal of diode.

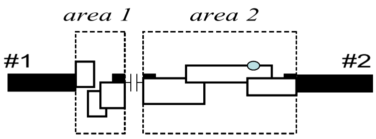

Figure 7: The matching circuit

Figs. 8 and 9 show S parameters of two matching circuits of RF-DC conversion circuits.

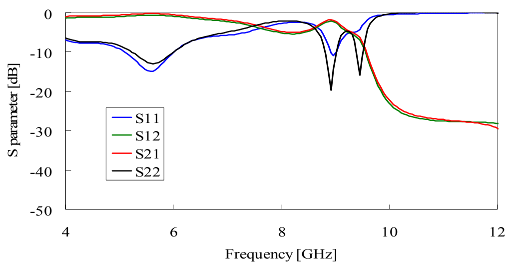

Figure 8: The S parameters of matching circuit of RF-DC conversion circuit

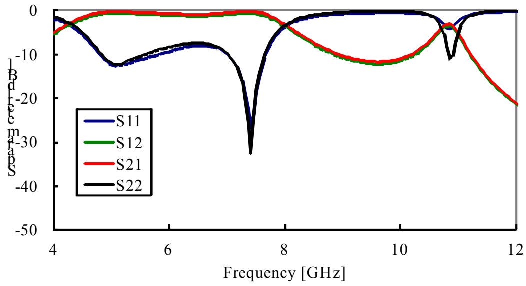

Figure 9: The S parameters of matching circuit of another RF-DC conversion circuit

In Figs. 8 and 9, S_{21} and S_{12} at 5.8GHz are almost zero in both circuits. On the other hand, Z22 of these matching circuits at 11.6GHz which is second harmonic frequency are 37.8+j97.7 and 24.3+j66.2Ω, respectively. In this result, both matching circuits are tuned at 5.8GHz, but not done at harmonic frequencies because its degree of freedom is not enough. Next, we increase number of patches in the area1 and area2 of the matching circuit from 3 to 4. Fig.10 shows the schematic of this arrangement as an example.

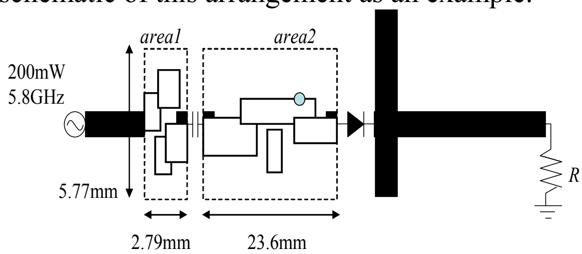

Figure10: The structure of 4 patches circuit

Under the same condition as a situation of 3 patches, two different RF-DC conversion circuits are designed by using the genetic algorithm. Figs. 11 and 12 show designed structures.

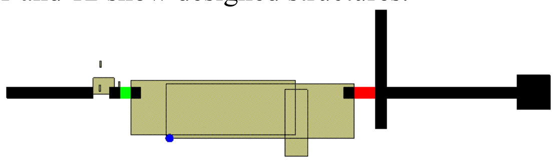

Figure 11: The structure of circuit #1

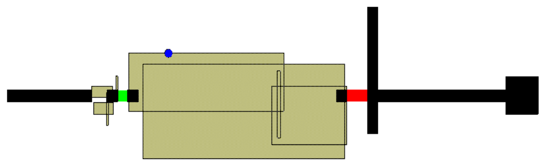

Figure 12: The structure of circuit #2

Fig. 13 shows a comparison of conversion efficiencies obtained by 4 patches and 3 patches circuit.

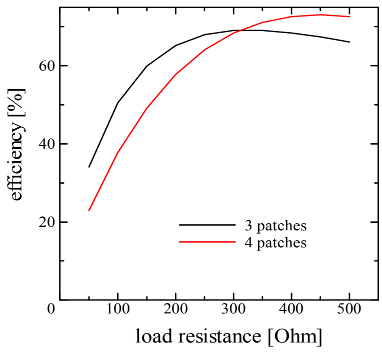

Figure 13: The conversion efficiency of RF-DC conversion circuit.

In this figure, maximum conversion efficiency is 73.1% at 450Ω in analysis and this conversion efficiency is higher than 3 patches circuit. So, characteristics of the circuit for which 4 patches are used are investigated in comparing with the circuit for which 3 patches are used. Figs. 14 and 15 show S parameters of two matching circuits shown in Figs. 11 and 12, respectively.

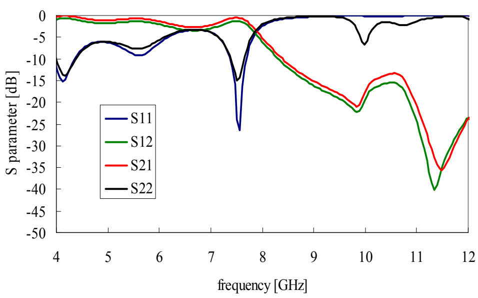

Figure 14: The S parameters of circuit #1

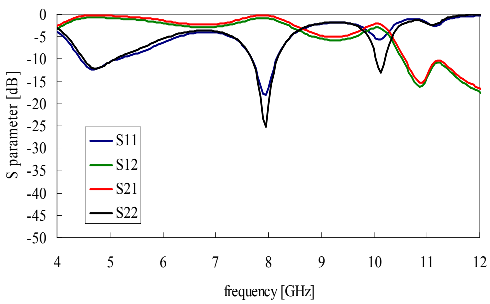

Figure 15: The S parameters of circuit #2

. In these figures, S parameters at 5.8GHz and 11.6GHz almost agree with another, and Z_{22} of these matching circuits at 11.6GHz are 4.76+j2.67 and 3.41+j25.3Ω, respectively. These results indicate that the matching circuit prevents the second harmonic generated at the diode from leaking because the cathode terminal is grounded at 11.6GHz by the output filter. Consequently, the RF-DC conversion circuit for which 8 patches are used has higher conversion efficiency than one for which 6 patches are used.

5. Summary

We suggest automatic design of RF-DC conversion circuit using the genetic algorithm. In this technique, best RF-DC conversion circuit structure can be designed by automatic design, which is difficult now. The conversion efficiency using genetic algorithm is 64.8% in experiment. It is higher than the conversion efficiency of one based on the conventional circuit design. Therefore, the automatic design using genetic algorithm is an effective technique for designing RF-DC conversion circuit. In addition, we investigated characteristics of the matching circuit of the RF-DC conversion circuit. As results, optimal circuit designs and their conditions are able to found. In this paper, the RF-DC conversion circuit which the cathode terminal of diode is grounded at 5.8 and 11.6GHz is chosen. Hence, in the future, we will investigate conditions of the cathode terminal of diode for obtaining highly efficiency by using genetic algorithm.

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