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The mW-class High Efficient RF-DC Conversion Circuit using the Resonance Structure

Tsunayuki YAMAMOTO [1], Kazuhiro FUJIMORI [2], Minoru SANAGI [3], Shigeji NOGI [4]

[1−4] The Graduate School of Natural Science and Technology, Okayama University

3-1-1 Tsushima-Naka, Okayama, 700-8530, Japan

[1]yamamoto@micro.elec.okayama-u.ac.jp

[2]fujimori@elec.okayama-u.ac.jp

[3]sanagi@elec.okayama-u.ac.jp

[4]nogi@elec.okayama-u.ac.jp

1. Introduction

The microwave transmission technology has been developed for Space Solar Power System (SSPS) which realizes to transmit the power generated in space to the ground with microwave [1] [2]. Recently, this technology is applied to RFID and electric vehicles etc. [3]. A rectifying antenna (Rectenna) consisting of the radio frequency to the direct current (RF-DC) conversion circuit and the receiving antenna is one of the most important components to realize this system. For an efficiency system, the rectenna must be designed with high RF-DC conversion efficiency.

Various kinds of rectennas had been investigated [4]- [7]. In past reports, characteristics of passive components such as the antenna or the filter for composing the rectenna are investigated experimentally or analytically. A RF-DC conversion circuit which has the resonance structure in the anode terminal of the diode [8] had been reported, and this circuit rectifies the RF signal using the half-wave rectification. We paid an attention to this rectifying structure and investigate an RF-DC conversion circuit operated the full-wave rectification for achieving the high efficient RF-DC conversion circuit.

In this paper, we propose the RF-DC conversion circuit using the full-wave rectification, and we demonstrate experimental results of RF-DC conversion characteristics.

2. The Composition of the RF-DC Conversion Circuit

The Figure 1 shows the RF-DC conversion circuit using the half-wave rectification (Type 1), and the Figure 2 shows the RF-DC conversion circuit we propose (Type 2).

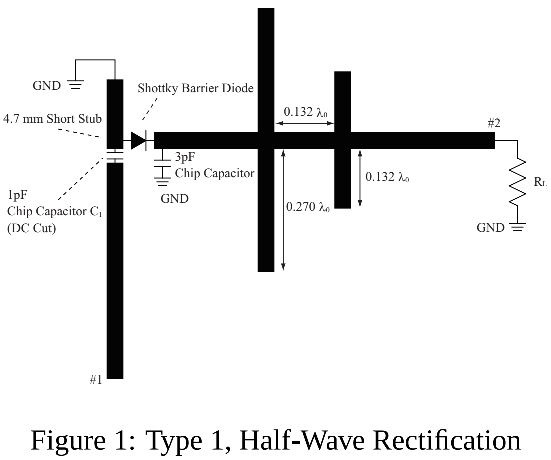

Figure 1: Type 1, Half-Wave Rectification

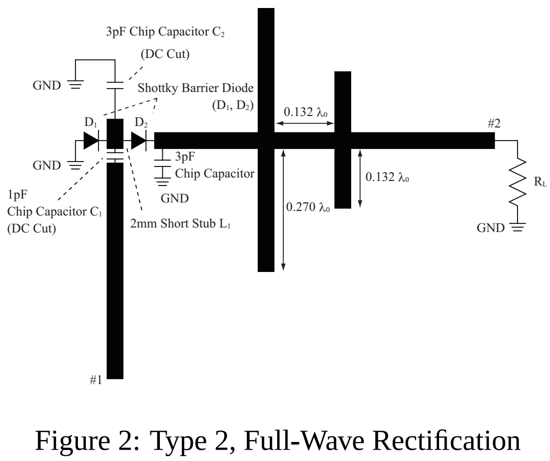

Figure 2: Type 2, Full-Wave Rectification

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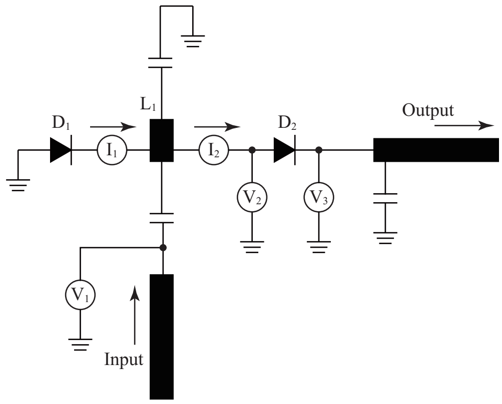


Figure 3: The Mounting Part of Two Diodes

A Resin substrate is used for the circuit design. (thickness: 0.5mm, dielectric constant 3.4 and tanδ 0.003) The characteristic impedance of all lines is 50Ω at input frequency 5.8GHz. The device for rectifying is the Shottky Barrier Diode (SBD). To achieve the rectenna with high conversion efficiency, it is important to use the SBD which can follow the high frequency, and has the low built-in voltage to operate at a low input power. So, an M/A-COM MA4E2054-1141T Schottky Barrier Diode is chosen for the rectifying device. The input port (#1) has a 1.0pF chip capacitor (C_1) for DC cut. This capacitor rejects the direct current. In Figure 2, the terminals of two diodes are connected for the root of C_1, and short stub (L_1) is connected in series with the C_1. Applying a microwave input of 5.8GHz, the arisen voltage between the anode and the cathode terminal causes the switching of the SBD. The RF-DC conversion circuit has an output filter for obtaining only the direct current at the output port (#2). This filter is designed to block effectively the higher order harmonics produced by the nonlinearity of two diodes as well as the input microwave. In addition, RF-DC conversion efficiency η is represented as follows.

$$\eta = \frac{(V_{DC}^2/R_L)}{P_{RF}} \times 100 \tag{1}$$

where V_{DC}, R_L, P_{RF} are the DC output voltage, the load resistance, and the microwave input power, respectively.

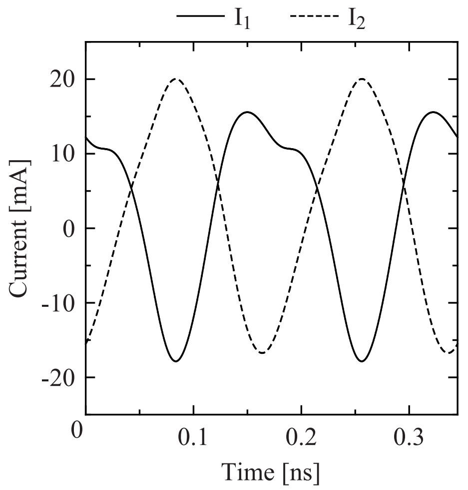
3. The Operation Principle of RF-DC Conversion Circuit

We investigated the operation principle of RF-DC conversion circuit (Type 2) using the simulator for the design of the high frequency circuit.

In the Figure 3, I_1 is the RF current which flows from D_1 to L_1, and I_2 is also the RF current which flows from L_1 to D_2. V_1, V_2 and V_3 are voltages appeared at of the input port, the anode terminal of D_2 and the cathode terminal of D_2, respectively. The Figure 4 shows current waveforms of I_1 and I_2, and the Figure 5 shows the voltage waveforms of V_1, V_2 and V_3.

In the Figure 4, the phase of I_1 and I_2 is different for about 180 degrees, and I_2 is larger than I_2, about 5mA. When the voltage between D_1 and D_2 is negative voltage, the input power is rectified at D_1, and I_1 is positive, I_2 is negative. When the voltage between D_1 and D_2 is positive, the input power is rectified at D_2, and I_1 is negative, I_2 is positive. In the Figure 5, V_1 is the input signal waveform, and DC is not contained. V_2 contains DC rectified at D_1 (about 1V), and V_3 contains DC rectified at D_1 and D_2 (about 2.5V).

From these results, it is confirmed that the RF-DC conversion circuit of Type 2 rectifies the RF signal using the full-wave rectification.



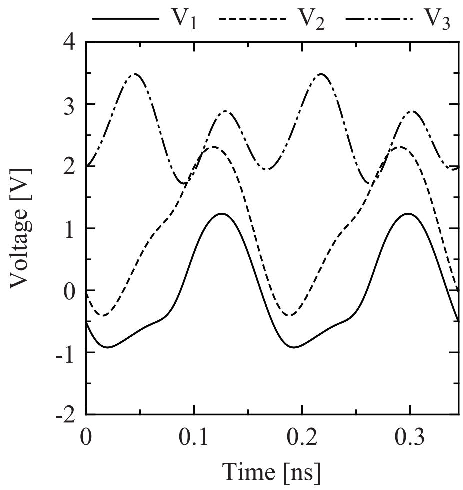
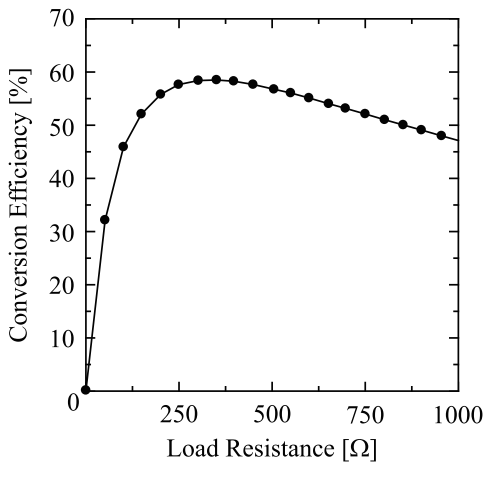


Figure 4: The Current Wave-Form (I_1, I_2) Figure 5: The Current Wave-Form (V_1, V_2, V_3)

4. The Measurement Results

We measured the conversion efficiency, and we compared the results of Type 1 with the results of Type 2. Figure 6 shows the conversion efficiency of Type 1 corresponding to the load resistance, and Figure 7 shows the conversion efficiency of Type 2 corresponding to the load resistance. (The input power is 10mW.)

In the Figure 6, the conversion efficiency rapidly increases, until the load resistance is 250Ω. The maximum conversion efficiency 58.5% is obtained, when the load resistance is 351Ω. In the Figure 7, the conversion efficiency gently increases, until the load resistance is 750Ω. The maximum conversion efficiency 63.4% is obtained, when the load resistance is 925Ω.



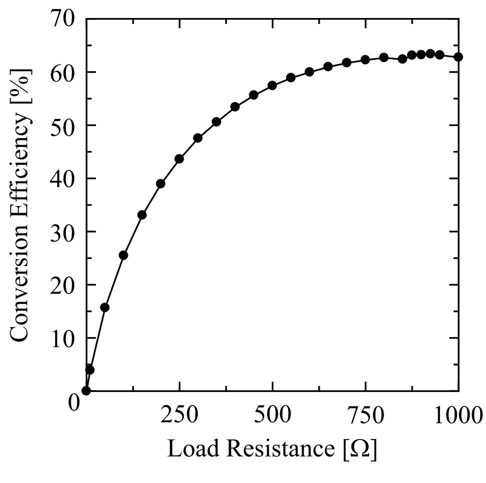


Figure 6: The Conversion Efficiency of Type 1 Figure 7: The Conversion Efficiency of Type 2

Figure 8 shows the conversion efficiency of Type 2 corresponding to the input power. (The load resistance is optimum.)

In Figure 8, The conversion efficiency rapidly increases, until the input power is 30mW. The maximum conversion efficiency 70.7% is obtained, when the input power is 45mW. From these results, we

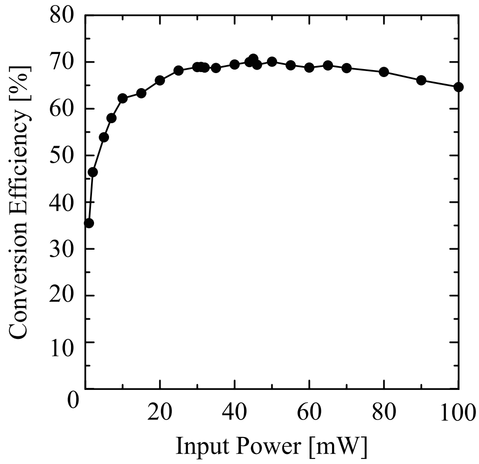


Figure 8: The Conversion Efficiency corresponding to the Input Power

confirmed the effectiveness of the RF-DC conversion circuit using the full-wave rectification.

5. Conclusion

In this paper, we proposed the RF-DC conversion circuit using the full-wave rectification. This RF-DC conversion circuit has the conversion efficiency which is higher than the circuit using the half-wave rectification, and the maximum conversion efficiency is 70.69% (The input power is 45mW, the load resistance is 925Ω.).

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