

弱電レクテナに適用した DC 電源回路の開発

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あらまし 本報告では、mW 級低電力の RF-DC 整流回路に適用する DC 電源回路を提案する。レクテナの RF-DC 変換効率は負荷または入力電力の変動によって変化する。負荷変動するユーザに対して安定した効率で電力を提供できない問題がある。この問題を解決するために、RF-DC レクテナと DC-DC コンバータを組み合わせた RF-DC-DC 電源回路を検討した。Agilent の ADS シミュレータを用いて、レクテナのマイクロ波周波数が 2.45 GHz、DC コンバータのスイッチング周波数が 1.8 MHz、入力電力が 100 mW でシミュレーションを行った。提案した RF-DC-DC 電源回路は RF-DC レクテナに比べて、375 Ω から 1300 Ω までの広い負荷範囲で 70%以上の効率が得られたことを確認した。

キーワード 弱電レクテナ DC-DC コンバータ DC 電源回路 RF-DC-DC 回路

Development of a DC Power-supply Circuit for a Low Power Rectenna

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Abstract This study proposes a DC power-supply circuit for an mW low power RF-DC rectifier circuit. We know that the efficiency of a RF-DC rectifier circuit is affected by the load and the input power. So it can't supply a steady power for an available load user. In order to improve the efficiency characteristics, a RF-DC-DC power-supply circuit was proposed which consists of a RF-DC rectifier circuit and a DC-DC converter in this study. We simulated the proposed circuit with microwave frequency of 2.45 GHz in rectenna and switching frequency of 1.8 MHz in DC converter using Advanced Design System (ADS) simulator. The conversion efficiency was over 70% in a wide range of load 375 Ohm to 1300 Ohm at 100 mW input power in comparison with a RF-DC rectifier circuit at the same conversion efficiency.

Key Words low power rectenna DC-DC converter DC power-supply circuit RF-DC-DC circuit

1. INTRODUCTION

As wireless sensor network becomes pervasive and sensor nodes operate at lower average power levels, there is an increased need for energy harvesting techniques to provide power to the sensors. But the power of environmental energy is varying and the efficiency of transducers often is strictly affected by the various environmental conditions. Therefore, in order to get a needed DC voltage and higher conversion efficiency, a

DC-DC converter is always used in lower power energy harvesting system [1].

We also know that the RF-DC conversion efficiency of a rectenna system mainly depends on the characteristic of a diode. As the optimal load on the output port is changed, the RF-DC conversion efficiency will drop down. The reflection will be increased with the RF-DC conversion decreasing. There are mainly three reasons for a low efficiency of a RF-DC rectenna [2]. Firstly, the efficiency

is small in the low power region because the voltage swing at the diode is below or comparable with the forward voltage drop of the diode. Secondly, the efficiency increases as the power increases and levels off with the generation of strong higher order harmonics. Thirdly, the efficiency sharply decreases as the voltage swing at the diode exceeds the breakdown voltage (V_b) of the diode. It means that three parameters of diode such as V_b , zero-bias junction capacitor (C_{jo}), and series resistance (R_s) determine the power conversion efficiency of a rectenna.

On the development of a rectenna as a source power of vehicles and sensor networks, we need to develop a high RF-DC conversion efficiency of rectenna and supply stable DC power whether the load is changed or not.

In this study, to solve the third reason of low efficiency, we indicated a RF-DC-DC circuit to give a steady RF-DC conversion efficiency on a wide range of various loads. We simulated the proposed circuit using the Harmonic Balance (HB) Method of Advanced Design System (ADS) simulator. We could get almost constant conversion efficiency (over 70%) of the proposed circuit as the load varying from 375 Ohm to 1300 Ohm with 100 mW input power. The various range of load was much wider than the RF-DC rectenna at the same condition. This paper first gives an overview of a RF rectifier with a quarter-wave microstrip line in Section 2. Section 3 introduces the DC-DC converter and the section 4 gives a description of the RF-DC-DC power-supply circuit. Conclusions and future works will be related in section 5.

2. RECTIFIER DESIGN

The rectenna is very important for converting wireless RF power into DC power. A rectenna contains a receiving antenna which collects microwave incident power and a rectifying circuit to convert RF power into DC power. A rectifier is a combination of Schottky diodes, an input HF filter, an output DC filter and a load resistance. The efficiency of the rectifier depends mainly on Schottky diodes and power level as related in section 1.

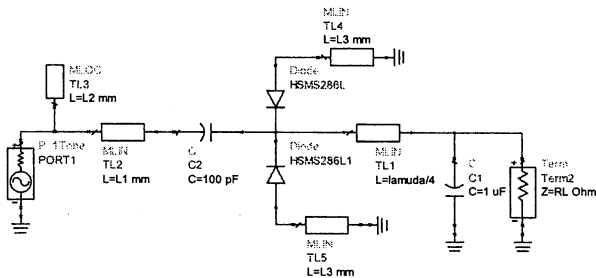


Fig.1 Quarter-wave microstrip rectifier circuit model

Fig.1 shows the rectifying circuit using a $\lambda/4$ microstrip line and diodes. Two HSMS286L High Frequency Schottky Diodes were used as rectifying devices. HSMS286L diode is a package of three parallel arranged HSMS2860 diodes which also belongs to the Agilent's HSMS-286x series. HSMS2860 has the equivalent circuit parameters as follows: series resistance $R_s = 6$ Ohm, zero-bias junction capacitor $C_{jo} = 0.18$ pF, junction potential voltage $V_j = 0.65$ V, and breakdown voltage $V_b = 7$ V.

In Fig.1, the TL1 is a $\lambda/4$ line, TL2, TL3, TL4 are matching circuit. A 100 pF chip capacitor (C2) was used as a DC block and 1 uF capacitor (C1) smoothed the DC voltage and reutilized harmonics energy. A 1.6 mm thickness Arlon AD260A substrate with a dielectric-constant 2.6 and $\tan\delta = 0.0017$, was used for the circuit design. The characteristic impedance of all lines was 50 Ohm and the fundamental frequency of the input microwave was 2.45 GHz with 100 mW input power.

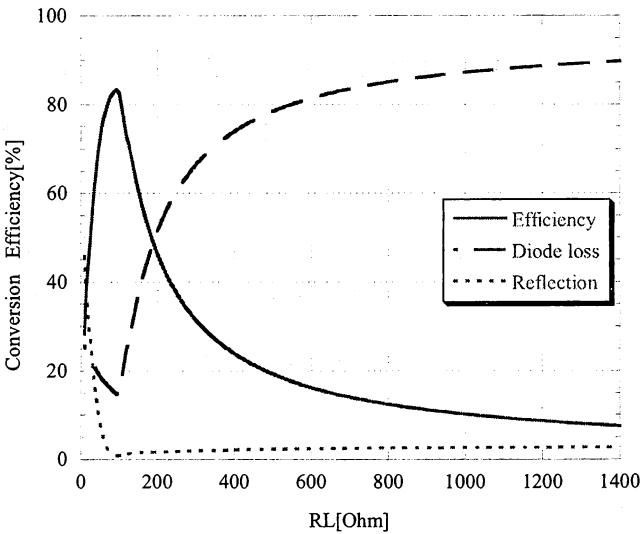


Fig.2 RF-DC conversion efficiency, reflection and diode loss versus load resistance

We simulated the rectifier circuit using HB Method of the ADS. Fig.2 shows the simulation results of the rectifier circuit. We obtained the maximum RF-DC conversion efficiency of 83.4% at an optimal load of 95 Ohm, and the conversion efficiency was over 70% at the range of load resistance from 50 Ohm to 125 Ohm. The conversion efficiency was strictly decreasing as the load resistance over the optimal load because the reverse voltage of the diode was over breakdown voltage. The reflection and diode loss were 0.8%, 14.7% respectively at the optimal load.

3. DC-DC CONVERTER DESIGN

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are employed in many applications such as computers, office equipments, spacecraft power systems and telecommunications equipments. The basic components of the DC-DC converter can be rearranged to form a step-down (buck) converter, a step-up (boost) converter, or an inverter (fly back). A boost converter is widely applied in the energy harvesting system because of a very low power [3]. The ideal DC-DC converter exhibits 100% efficiency. In practice, an efficiency of 80% to 95% is typically obtained [4]. This is achieved using switched mode, or chopper, circuits whose elements dissipate negligible power. Pulse-width modulation (PWM) allows control and regulation of the total output voltage.

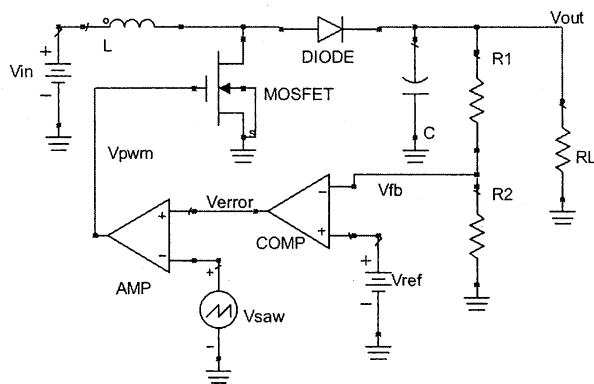


Fig.3 DC-DC PWM boost converter

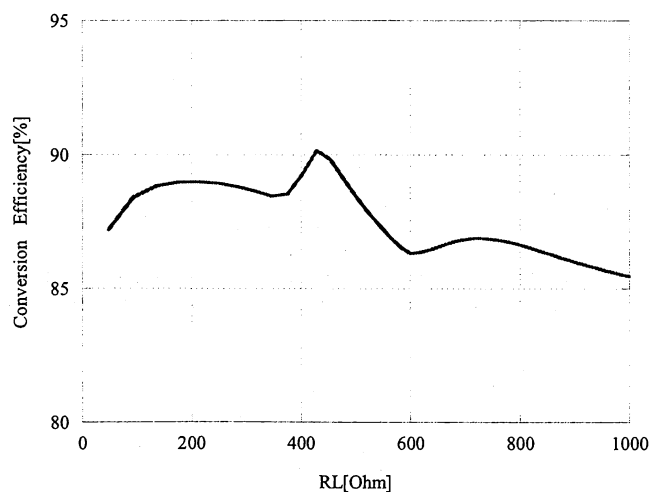


Fig.4 Efficiency of DC converter

In this study, we used a feedback control of DC-DC PWM boost converter which is shown in Fig.3. The voltage difference between the feedback node (Vfb) and

the reference (Vref) is called the error voltage (Verror). The PWM wave is generated by comparing the error voltage to the sawtooth wave (Vsaw). Then the PWM wave controls the gate of the MOSFET. Most DC converters employ MOSFET device as switching devices because of their very low on-resistance and zero gate-current. When the gate of MOSFET is off there is practically no current, and when it is on, there is almost no voltage drop across the drain and source.

In the simulation, we set the inductance $L = 10 \mu\text{H}$, the load capacitor $C = 10 \mu\text{F}$ and a MBR0520L diode model was used. The MBR0520L diode has a low junction potential voltage $V_j = 0.38 \text{ V}$ and a high breakdown voltage $V_b = 20 \text{ V}$. We optioned BSIM4_NMOS and Bsim4_Model as a MOSFET model. We simulated the circuit at the input voltage $V_{in} = 2.8 \text{ V}$ and the switching frequency 1.8 MHz by the HB Method of ADS.

Fig.4 shows the conversion efficiency versus the load resistance. The efficiency was over 85% as the load varying from 50 Ohm to 1000 Ohm and the maximum efficiency was 90.2%.

4. RF-DC-DC CIRCUIT

In this section, we contacted the proposed DC converter in section 3 with the RF-DC rectenna which is called as RF-DC-DC circuit here.

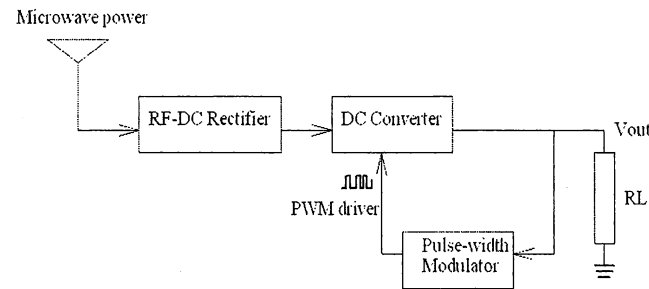


Fig.5 Block diagram of the RF-DC-DC circuit

Fig.5 shows the main components of the RF-DC-DC circuit. The microwave power is firstly regulated by the RF-DC rectifier and the DC output voltage of the RF-DC rectifier is regulated by the PWM boost converter again. The DC output of the RF-DC rectifier is as an input of the DC converter. That is to say the input impedance of the DC converter seeing from left is the output impedance of the RF-DC rectenna. So if we can control the input impedance of the DC converter at a suitable range with a variable load resistance, we will get a steady conversion efficiency of the RF-DC-DC circuit.

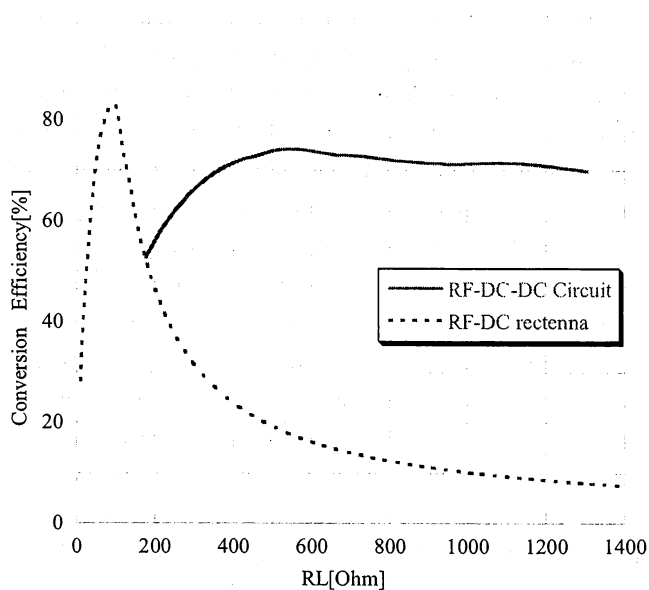


Fig.6 Comparison of the efficiency

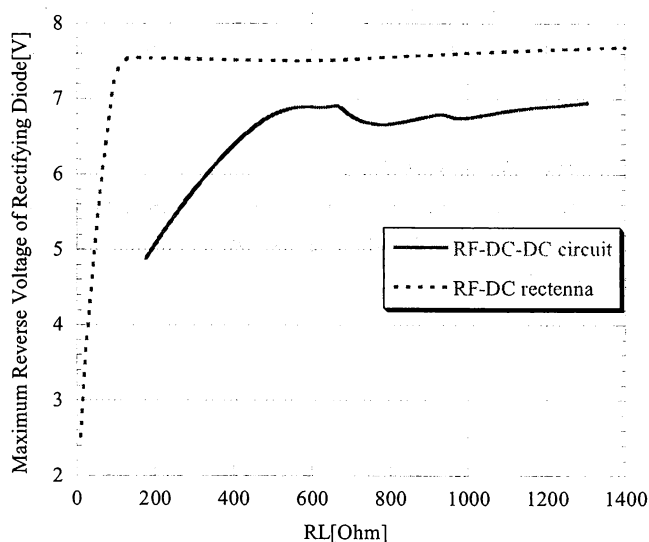


Fig.7 Comparison of the maximum reverse voltage of the rectifying diode

We simulated the RF-DC-DC circuit with HB Method in ADS at two fundamental frequencies of $\text{Freq}[1] = 2.45 \text{ GHz}$ and $\text{Freq}[2] = 1.8 \text{ MHz}$ and the input microwave power was also 100 mW the same as the RF-DC rectenna. The RF-DC conversion efficiency of the RF-DC-DC circuit comparing with the RF-DC rectenna is shown in Fig.6. The efficiency of the RF-DC-DC circuit was over 70% and almost constant at the load changing from 375 Ohm to 1300 Ohm comparing to a range from 50 Ohm to 125 Ohm of the RF-DC rectenna. We also gave a comparison of the maximum reverse voltage of the rectifying diode of the two circuits which is shown in the

Fig.7. We can see that the maximum reverse voltage of the diode of the RF-DC rectenna is over 7 V (breakdown voltage) when the load resistance is bigger than the optimal load (95 Ohm in section 2). But it is still under 7 V for the rectifying diode of the RF-DC-DC circuit even though the load resistance is increasing to 1300 Ohm. So we can say that the DC-DC converter limited the maximum reverse voltage of the rectifying diode to prevent the conversion efficiency of RF-DC rectenna from sharply decreasing.

5. CONCLUSION AND FUTURE WORK

This paper gives a RF-DC-DC power-supply circuit to improve the conversion efficiency of a RF-DC at a varying load resistance. The proposed circuit obtained an almost steady high RF-DC conversion efficiency (over 70%) at a wide load range from 375 Ohm to 1300 Ohm, which is a remarkably advanced comparing to the RF-DC rectenna. We also found that the DC-DC converter connected to the RF-DC rectenna can limit the maximum reverse voltage of the rectifying diode under its breakdown voltage at a wide range of load resistance.

Unfortunately, the conversion efficiency is very low at the light load (under 200 Ohm) addition to Fig.6. We will consider a bulk-boost converter or a bulk converter to solve it in future work. And we also want to make the converter into one IC chip including coil, MOS and PWM control circuit. The driving power of this IC chip will be supplied by the same or another RF-DC rectenna.

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