Design of A Low Power 2.45 GHz RF Energy Harvesting Circuit for Rectenna

Saad Bin Alam, Mohammad Sakib Ullah and Sanjida Moury
Department of Electrical Engineering and Computer Science
North South University
Dhaka, Bangladesh
sazid1909@yahoo.com

***Abstract*—In this paper, design procedure and characteristics of an RF energy harvesting circuit based on single-stage voltage multiplier rectifier have been discussed and analyzed. This circuit is capable to recycle RF energy at 2.45 GHz, and by connecting to a 2.45 GHz antenna, it is possible to form a complete rectenna device. The values of output dc voltage and power according to the received RF power have been measured and the best value of load resistance to harvest maximum output dc power has been selected by simulation.**

Keywords—RF energy; matching network; rectifier; load

I. INTRODUCTION

The technology of wireless microwave energy harvesting is become popular very rapidly. Over hundred years ago, Nikola Tesla proposed and demonstrated the concept of wireless power transmission [1]. In 1964, a microwave-powered helicopter prototype was successfully demonstrated by W. C. Brown and his team [2]. Four years later, P. E. Glaser proposed the concept of solar power satellite system (SPSS) [3], and the first experimental microwave power transmission in space was carried out by Hiroshi Matsumoto's team in 1983 [4][5]. In recent years, the research based on the technology of empowering very small devices like biomedical implant devices, wireless sensor nodes, storing the energy in rechargeable micro-batteries and super-capacitors by ambient RF energy recycling attracts the interests of engineers. Wireless energy harvesting is necessary for biomedical implants or wireless senor nodes because recharging or replacing the batteries of these very tiny devices is non-feasible [6]. In most cases, to energize these devices, the best choice is energy recycling or harvesting from RF waves because the environment is full of radio energy.

The sources of microwave signals are mainly the UHF band (885 to 915 MHz) mobile communication systems (GSM), wireless based high speed internet network (WiMax) operating at 2.40 to 2.48 GHz (ISM band) etc. In urban areas, many public places are now declared as Wi-Fi zones. On the other hand, the wireless sensor networks also adopt these frequency bands because of the advantage of high data speed.

The wireless sensor motes like MICA2, MICAz are the examples of those kinds of sensors. So it is very convenient to harvest RF energy from UHF or ISM band microwave signal to recharge the batteries included with these sensors.

The device used to harvest RF energy is called 'Rectenna'. The first rectenna was also designed by W. C. Brown [7]. After his contribution, a lot of research work has been done. Rectenna is basically a rectifying antenna; which is used to harvest RF signal, and then it converts the RF signal to DC output. The most of the works are based on designing the suitable antenna for receiving RF signal and increasing the efficiency of rectifier. The main objective of this paper is to demonstrate a simulation based RF energy harvesting circuit and its characteristics at low RF power density. The circuit can be used as a rectifier unit of any rectenna operating at 2.45 GHz frequency band. At first, the basic principle of a rectenna has been discussed. In later section, the design methodology of the RF energy circuit has been presented. Finally the simulation results have been shown to describe the characteristics of the circuit.

II. BASIC PRINCIPLE OF RECTENNA

From the fig. 1, the operational concept of a typical 2.45 GHz rectenna can be understood. The incident 2.45 GHz RF signal is received by an antenna, which operating frequency must be same as the signal frequency. The power of the incident RF signal is converted to dc signal by the rectifier circuit. Between the antenna and rectifier, an impedance matching network composed of inductive and capacitive elements is introduced, which ensures the maximum power delivery from antenna to rectifier [8]. These impedance matching network and rectifier circuit are jointly called RF energy harvesting circuit.

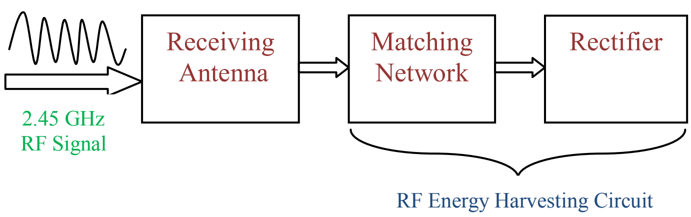

Figure1: Block diagram of a 2.45 GHz 'Rectenna'

III. DESIGNING RF ENERGY HARVESTING CIRCUIT

As said earlier, our target is to harvest RF energy from low RF power density area. The received RF power level in that area generally differs from -15 dBm to 0 dBm according to the distance from transmitting to receiving antenna, and the voltage level of the RF signal usually varies from 0.15V to 1V respectively, which is not sufficient to drive any device. Hence, voltage multiplier circuit is the better choice to design the rectifier. The topology used for our rectifier is Grainacher voltage doubler circuit. It is also known as single stage Cockroft-Walton voltage multiplier circuit [9]. The main feature of this circuit is it just doubles the input voltage to its output terminal. The diodes used for the rectifier are zero biased HSMS2850 Schottkey diode. The threshold voltage of this diode is 0.15V, so it is appropriate for extreme low input power. In fig. 2, the values of both capacitors (C2 and C3) of the rectifier are equal to 150 pF.

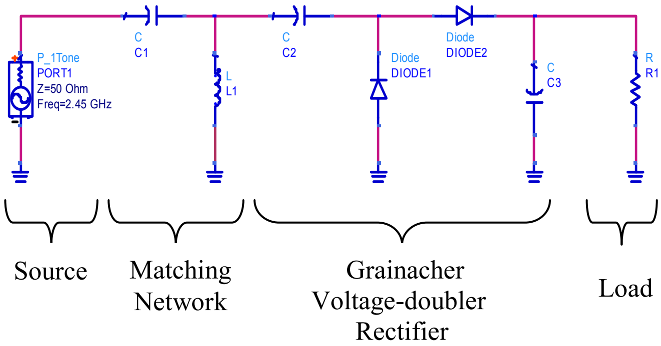

Figure2: Schematic diagram of designed RF energy harvesting circuit

Since this work is simulation based, a monotonic frequency depended power source is connected at the input of the circuit instead of an antenna. The value of the power source is swept from -15 dBm to 0 dBm at 2.45 GHz frequency. The impedance of the source is set to 50 Ω, since in general the impedance of typical commercial antenna is equal to 50 Ω. In previous section, it is mentioned that an RF energy harvesting circuit is the combination of an impedance matching network and a rectifier. To match the rectifier's impedance to the source impedance, we built a matching network consists of a capacitor C1 (= 0.27 pF) and an inductor L1 (= 5.35 nH) between the source and the rectifier. Finally a resistive load R1 is added to the output terminal of the complete circuit to measure the output dc power. This circuit designing and simulation work has done by Agilent Advanced Design System (Agilent ADS) 2009.

IV. SIMULATION RESULTS

In this section, output characteristics of the voltage-doubler rectifier based RF energy harvesting circuit have been

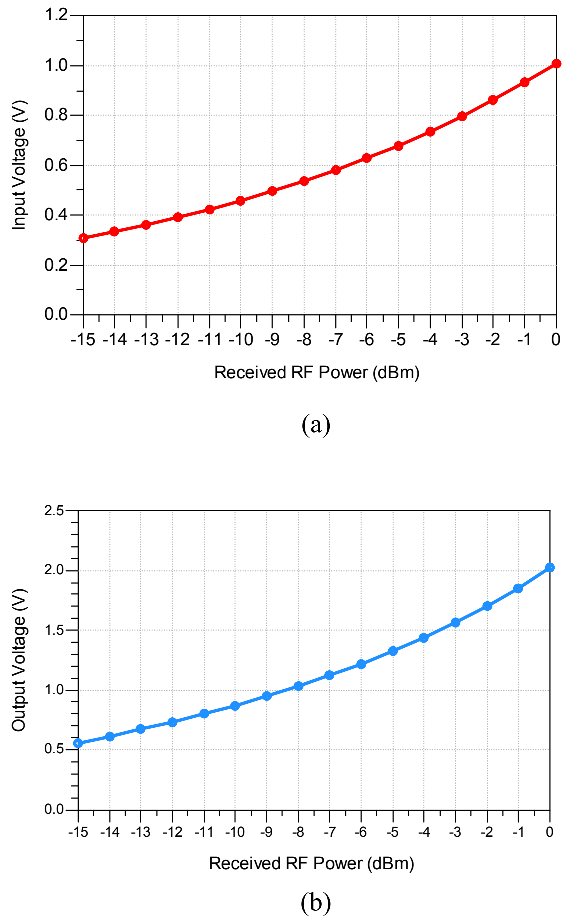

Figure3: (a) Input voltage across capacitor C2 vs. received RF power (b) Output voltage across capacitor C3 vs. received RF power

shown and described by simulated graphs. These characteristics are categorized in three parts. At first, the effect of Grainacher voltage-doubler circuit on the input and out voltage is shown. Second, effect of different load resistance values on output dc power is described. Finally, depending on best selected load, the output dc power against received RF power characteristics is observed.

a. Effect of Voltage-Doubler Rectifier:

In fig. 3(a), the input voltage characteristics curve across the capacitor C2 has been shown. The input voltage level increases gradually with respect to as increasing of received incident RF power. But in fig. 3(b), for the same input power level, the output voltage across the capacitor C3 (without load at output terminal) is twice times of input voltage across capacitor C2. Depending on the received input power, the input voltage is varied from lowest 0.3 V to highest 1.0 V, whereas the output voltage is varied from lowest 0.5 V to highest 2.0 V. By comparing the both graphs, the voltage multiplying characteristics of the rectifier circuit has been proved.

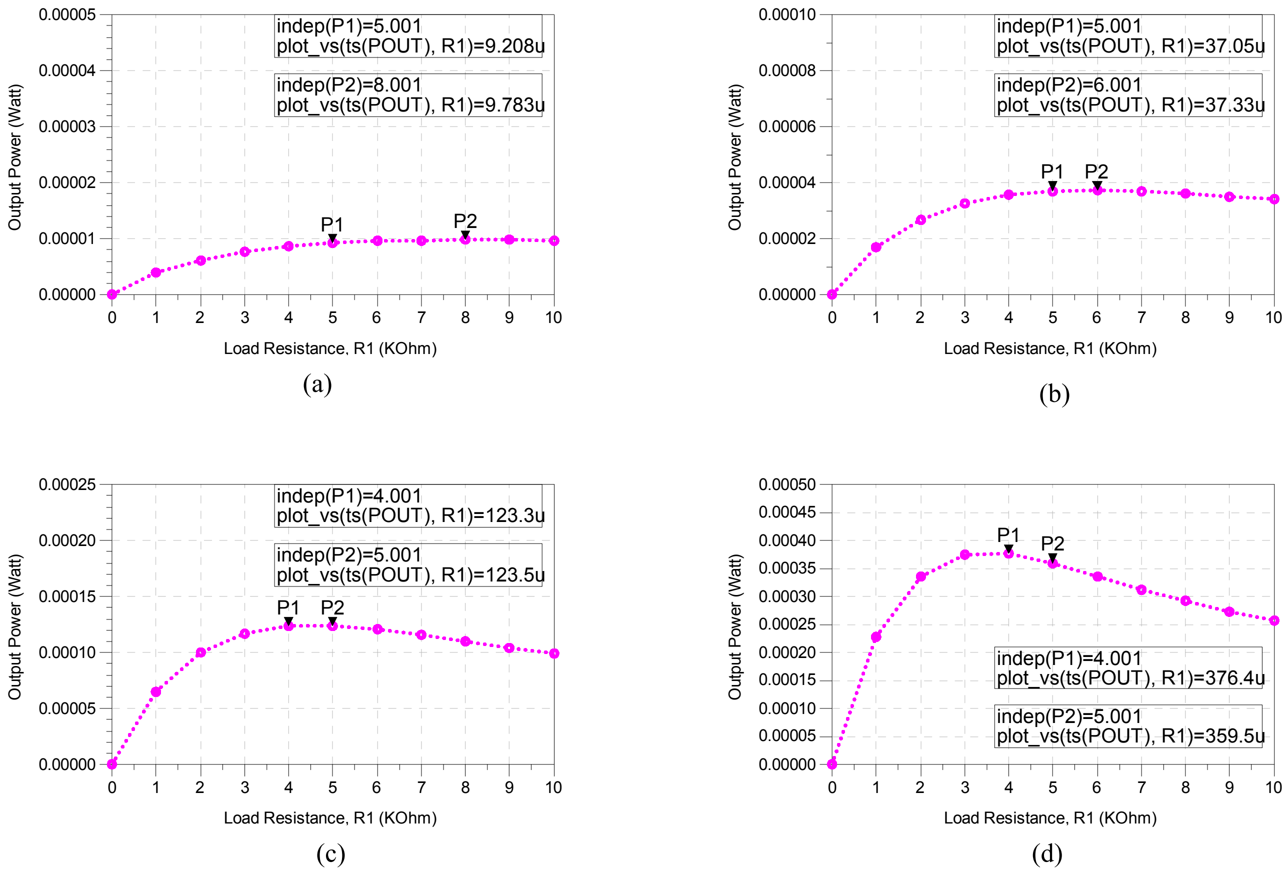

Figure4: The output dc power characteristics against the load resistance values from 1 Ω to 10 KΩ for the received input RF power of (a) -15 dBm, (b) -10 dBm, (c) -5 dBm and (d) 0 dBm

b. Effect of load resistance:

To measure the output dc power, a resistive load should be attached at parallel to capacitor C3; since without any resistive load, current cannot be drawn at the output terminal. For the same input RF power, the output dc power differs for individual value of resistance of the load. To measure the output dc power characteristics against the changing of load resistance R1, we select four fixed values from sweeping parameter of input RF power; they are: -15 dBm, -10 dBm, -5 dBm and 0 dBm. The parameter of the load resistance is swept from 1 Ω to 10 KΩ. In fig. 4(a), for -15 dBm, the harvested dc power has been reached to maximum when the load resistance is 8 KΩ. And at 5 KΩ, the power level is almost equal to as the maximum. In fig. 4(b), 4(c) and 4(d), the values of harvested dc power have become highest for the load resistance at 6 KΩ, 5 KΩ and 4 KΩ respectively. For all cases, the unit of the maximum value of the output dc power is in microwatt range. From these graphs, we can see the average harvested dc power will be optimum if we attach 5 KΩ load to the output terminal of the rectifier circuit.

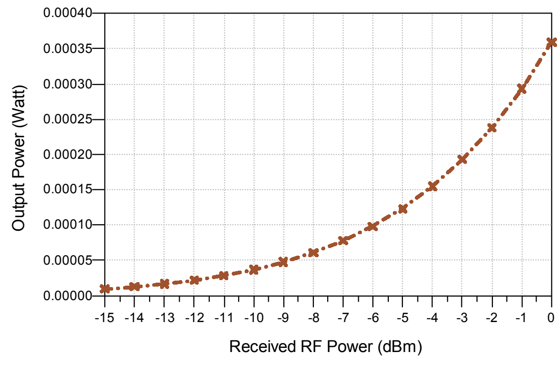

Figure5: The harvested dc power vs. received RF power curve when load resistance is 5 KΩ

c. Output dc Power Characteristics at Selected Load:

After selecting the resistive load of 5 KΩ, now we observe the output dc power characteristics with respect to the input RF power. From fig, 5, we see the harvested power has been increased gradually as the received RF power increases. For received RF power varying from -15 dBm to 0 dBm, the output dc power varies from 9.2 uW to 359.5 uW respectively.

V. FUTURE WORKS AND CONCLUSION

In this paper, RF to dc voltage and power conversion characteristics of the RF energy harvesting circuit have been discussed. The necessity and effect of voltage multiplier rectifier have been described by simulation. To ensure the recycling of optimum dc power, we have selected 5 KΩ resistive load. This RF energy circuit is capable to convert RF energy from any antenna operating at 2.45 GHz to dc power, which can be stored in a super-capacitor for future purpose. In future, our research work will be focused on designing a printed miniaturized antenna or antenna array operating at 2.45 GHz, which can be used to receive incident RF signal and deliver the signal power to the input of the RF energy harvesting circuit. Finally, we will conduct a practical experiment of the complete 'rectenna' to prove the RF to dc power conversion capability of the designed circuit.

REFERENCES

[1] N. Tesla, "The transmission of electric energy without wires," in *13th Anniversary Number of the Electrical World and Engineer*, 1904.

[2] W. C. Brown, J. R. Mims, and N. I. Heenan, "An experimental microwave powered helicopter," in *Proc. IRE Int. Conv. Rec.*, Mar. 1965, vol. 13, Part 5, pp. 225–235.

[3] P. E. Glaser, "Power from the Sun, Science", No.162, 1968, pp.857-886.

[4] H. Matsumoto, "Microwave Power Transmission from Space and Related Nonlinear Plasma Effects", in *The Radio Science Bulletin,* No.273, 1995, pp.11-35.

[5] H. Matsumoto, "Research on Solar Power Station and Microwave Power Transmission in Japan: Review and Perspectives", in *IEEE Microwave Magazine,* Dec. 2002, pp.36-45.

[6] E. O. Torres and G. A. Rincon-Mora, "Electrostatic energy-harvesting and battery-charging CMOS system prototype," in *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 56, no. 9, pp. 1938–1948, Sep. 2009.

[7] W. C. Brown and J. F. Triner, "Experimental thin-film, etched-circuit rectenna," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1982, pp. 185–187.

[8] P. Nintanavongsa, U. Muncuk, D. R. Lewis and K. R. Chowdhury, "Design Optimization and Implementation for RF Energy Harvesting Circuits," in *IEEE Journal On Emerging And Selected Topics In Circuits And Systems,* vol. 2, no. 1, Mar. 2012.

[9] C. L. Wadhwa, "High Voltage Engineering," *published by New Age Internatinal (P) Limited, Publishers,* 1994, pp. 49-51.