Design Optimization of an Energy Harvesting RF-DC Conversion Circuit Operating at 2.45GHz

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Abstract - **In this paper, the optimization process of an RF-DC conversion circuit for energy harvesting from 2.45 GHz indoor Wi-Fi signals is discussed. The estimated power from a Wi-Fi router is about 0dBm, and it is expected to turn on an off-the-shelf-low-temperature sensor which has input impedance of 10kOhm. In this research, a series type RF-DC conversion circuit with a Schottky diode, SMS7630 from Skyworks is adopted. To specify the potential maximum RF-DC conversion efficiency, the input power, the load and matching circuit are optimized. As a proof-of-concept, the circuit is investigated and optimized with the relationship between the input power of 9dBm and load resistance of 10kOhm. As a result, the highest conversion efficiency of 72.7% and the maximum output voltage of 1.53V are achieved.**

I. INTRODUCTION

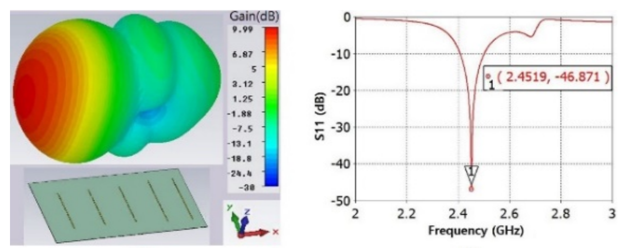
One of the most active research areas now-a-days is the investigation and identification of alternative ways to exploit ambient energy and convert it into electrical energy for powering low power electronics directly or store it for later use [I]. One of potential energy forms to be harvested is the ambient electromagnetic energy emitted by TV, cellular phones, and Wi-Fi routers. The fundamental concept of RF energy harvesting involves utilizing RF signals to generate DC power. The basic energy harvesting circuit is composed of an antenna, a matching circuit, a diode, output filters and an output load. Due to the low received power from electromagnetic ambient source, RF-DC conversion efficiency needs to be high enough to transfer sufficient amount of power to the desired output. Therefore, minimizing the power loss in the circuit through appropriate diode selection and impedance matching are crucial parts of RF energy harvesting circuits.

II. TECHNICAL SPECIFICATIONS

Since the design of RF-DC conversion circuit rely heavily on the operation frequency, available power, load resistance, a realistic scenario has to be considered as follows.

A. Input Power

At the output of its transmitter, the Linksys Wi-Fi Router (WRTl900AC) transmits RF energy at the 2.45GHz frequency range with an output power of l9dBm. The antenna of the router has 4 dipoles with a realized gain of 2.5dBi. In the harvesting topology, we used and optimized through CST simulations a 5-element microstrip Yagi antenna array with a realized gain of 10dBi as shown in Fig.1 (a). The conformal antenna design can be easily integrated with the RF-DC conversion circuit. The S11 plot in Fig.1 (b) indicates that the operation frequency of the designed antenna is in the range of 2.4 to 2.5GHz with the center frequency of about 2.45GHz. For the proposed scenario, the distance between transmitting (router) and the receiving (harvester) antennas is expected to be about 2m.



(a) (b)

Fig. 1 (a) Far-field (b) S-parameters plots of a 5-element

The amount of power received at the input can be calculated with Friis-equation that relates the received and transmitted powers with the distance and antenna gains [2]. For this preliminary estimation, the effect of multi-path is not taken into account. With the equation, the theoretical received power is about 0dBm.

B. Output Load

In this system, Monnit's temperature sensor, MNS-9-TS-WI-ST is expected to be used. It features a resistance of 10kOhm with a minimum turn-on voltage of 2.0V.

III. RF-DC CONVERSION CIRCUIT DESIGN

The RF-DC conversion circuit is consists of three major components: schottky diode, matching circuit and output filters. From the preliminary simulation on ADS, a series-type RF-DC conversion circuit with a shunt short-circuited stub is adopted. The schematic of the circuit is shown in Fig.2. It is fabricated with Roger Corporation's R4003C which has a dielectric constant of 3.38, and a loss tangent of 0.0021 at 2.45GHz. The thickness of the substrate is 0.5mm. The width of microstrip line is adjusted for a characteristic impedance of 50Ohm at 2.45GHz.

A. Circuit Components

1) Schottky diode: For this design, SMS7630 from Skyworks is adopted [3]. By measuring the actual parameters with a multimeter and a DC power supply, it has a low threshold voltage of 0.36V, a breakddown voltage of 2.05V and a breakdown current of 0.142mA. For the simulation with ADS, the series inductance of 0.6nH and the shunt capacitance of 0.25pF are also added to model the parasitic.

2) Matching Circuit: The matching circuit includes a single shunt short-circuited stub [7]. The distance between the stub and the diode (D) and the length of stub (L) are altered to optimize the circuit.

3) Output Filter: In order to achieve a high conversion efficiency, the voltage difference between diode's anode and cathode needs to be high as much as possible. Therefore, the output filters are introduced to suppress the fundamental and second harmonics [4]. Each filter has length of 19mm and 9.6mm, which is the quarter-wavelength at each frequency.

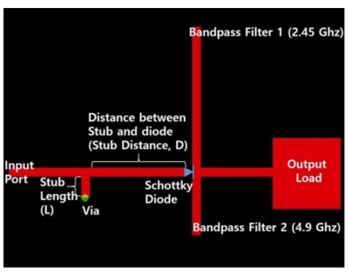


Fig. 2 RF-DC conversion circuit schematic.

IV. SIMULATION AND MEASUREMENT

Two different cases are tested with the RF-DC conversion topology presented in the previous section. The goal of the first case is to find the highest possible RF-DC conversion efficiency of the circuit by changing the input power, the load, D and L. The Input power and the load are changed in the range of -10 to 10dBm and resistance vary in the range 100 to 10kOhm, respectively. The second case seeks to find the maximum voltage at the output for fixed values of the input and the load by modifying D and L. Before the fabrication, the initial values for input power, load resistance, D and L are determined by utilizing ADS. In the optimization process, the D and L parameters are adjusted by 1/16 and 1/32 of wavelength to experimentally specify the optimal circuit design.

A. Highest Conversion Efficiency Test

ADS optimizer is used to determine the initial optimal parameters as shown in Table 1. 14 different circuits are built with varying L and D values by the optimization method mentioned above. After multiple iterations with varying input power and the load, the highest efficiency of each circuit is experimentally found with the circuit design parameters shown in Fig.3. It shows L and D as XY coordinates in millimeters and depicts the conversion efficiency in color spectrum.

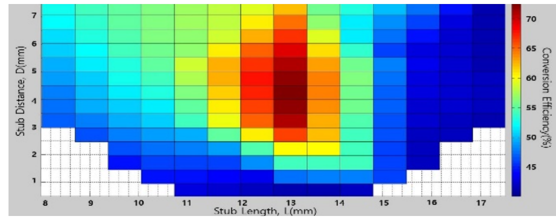


Fig. 3. RF-DC conversion efficiency with respect to stub distance and length with the optimal input power and the load.

The area with darkest red yields the highest conversion efficiency of 72.6%, achieved under the condition of D=4mm, L=12.7mm, the load=531Ohm and the input=9dBm.

B. Maximum Output Voltage Test

Unlike the efficiency test, the input power and the load are fixed and matched to the actual design as 0dBm, 10kOhm. The initial optimal stub parameters are again obtained by the ADS optimizer. With the highest efficiency test presented in the previous subsection, 11 circuits with varying L and D values are built and tested. The circuit with L=l.46mm and D=14.0mm yields the maximum voltage of l.53V with 23% conversion efficiency. It can be easily calculated from this result the available power is about 0.23mW. Therefore, the interval of temperature measurement with the sensor must be greater than 3.75sec to satisfy the required energy of 0.86J per measurement. Also to meet the required minimum turn-on voltage of 2.0V for the sensor, the input power has to be above 2.72dBm.

V. CONCLUSION

In this paper, the highest possible conversion efficiency of series type RF-DC conversion circuit with the Schottky diode, SMS7630 from Skyworks is specified with a novel systematic optimization process by utilizing ADS simulations and experimental circuit modification. In addition, the highest output voltage for a specific practical Wi-Fi and wireless sensor scenario is analyzed with the same optimization process. As a result, the highest RF-DC conversion efficiency of 72.6% is achieved for an ambient Wi-Fi input power of 9dBm and a load of 531Ohm. The maximum output voltage of l.53V is achieved for 0dBm input power and 10kOhm load.

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