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DUAL BAND RECTIFYING CIRCUIT FOR RF ENERGY SCAVENGING

M. A. Meor Said, Z. Zakaria, M.N. Husain, M. Abu, N. Mohd Salleh and M. H. Misran
Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: maizatul@utem.edu.my

ABSTRACT

This paper reports the design and experimental characterization of a dual-band rectifier for RF energy scavenging. The proposed circuit achieves comparable performances at 1.8 GHz and 2.45 GHz (GSM and ISM bands) for the wireless sensor network (WSN) system. The efficiency of RF-DC conversion can be improve by influence of the rectifying circuit. The analysis is conducted using ADS simulation version 2011, to determine the dc output voltage as well as the efficiency of the rectifier. The results show the rectifier efficiencies around 74.6% at 2.45 GHz and 78.06% at 1.8 GHz. DC output voltages is 6.7 V for simulation, while for measurement the output result is 5.2 V at input signal 20 dBm. The resulting rectifier has shown good effect of input power, load changes and matching circuit with single stub impedance matching, multi stage Wilkinson power combiner and voltage doubler to implement the dual band operation. This study is useful to provide understanding on the optimum technique to design dual-band rectifying circuit for RF energy scavenging. RF signal is used to powered the rectifier including the two frequencies of interest.

Keywords: RF energy scavenging, dual frequency rectifier, power combiner.

INTRODUCTION

With the growing technologies of integrated circuits towards low power consumption and low voltage, energy scavenging has been a fast growing topic. Energy scavenger is the process by which energy is derived from ambient sources and converted into suitable direct current (DC) power for wireless application such as sensor network, portable medical devices and radio frequency identification (RFID) tags. The developing in this technology can potentially be used to reduce or eliminate the dependence most wireless applications and low power integrated technology have on wire or non-autonomous power sources.

RF powered devices are often used in structural monitoring applications where the devices are embedded into a structure making battery replacement impossible without destroying the structure.

Deployments of wireless sensor network (WSN) are rapidly increasing where mostly of these sensor nodes are battery-powered [6]. Battery-based device are easy to deploy, but the maintenance cost is expensive. The industry needs low-cost, reliable, and long-term power source to scale WSNs and extend the deployment into hard-to-service areas where wiring or replacing batteries is impractical or very expensive. The uses of RF energy scavenging allow the overcoming of these problems. Quite a number of works have been carried out on energy scavenging for WSNs [1].

The RF signal received by the antenna is simply an AC signal and cannot be used to power applications that used DC power to switch them on. The function of rectifier circuit is to convert the AC signal received by the antenna to DC signal. There are various rectifiers or also known as voltage multiplier circuit topologies that have been proposed by researchers such as Dickson voltage multiplier and Villard voltage multiplier. The Villard voltage multiplier circuit was chosen in this project because it can produce two times of the input signal voltage and its design simplicity. The Villard voltage multiplier has many stages of design where one stage of this circuit consists of 2 diodes and 2 capacitors. The increased of number of stages for this voltage multiplier can increase the input AC voltage to a higher level.

Several studies on rectifying circuits have been investigated [2-5]. For example in a 0.25 m CMOS technology using floating gate transistors, they can produced passive rectifier circuits as rectifying diodes. Input voltages as low as 50 mV can be rectify by the 36-stage rectifier and operates with received power as low as 5.5 μW (22.6 dBm) and a maximum measured efficiency of 60% with a voltage gain of 6.4. It is suitable to be implemented in passively powered sensor networks because of the low load current achieved at high voltage [2].

A three multistage rectifiers and three diode doublers were fabricated with custom no-mask added Schottky diodes in a 130 nm CMOS process. Its improving the RF to DC power conversion efficiency in UHF RFID if compared with others rectifiers, DC output voltage 8%, 1253 mV [3] and in the requirement of current rejection.

Another method of rectifying circuit design used a quartz resonator at 24 MHz in front of a Schottky-Diode with high quality factor (Q) for an impedance transformation. The design has been improved in order to get the maximize sensitivity. The measurement results show a sensitivity of -30 dBm (1μW) and an efficiency of more than 22% for DC output voltage of 1 V [4].

A design of a rectifying circuit with single Schottky diode HSMS-2860 at 2.45 GHz was developed by using 10 kΩ load and -20 dBm input power, the simulated DC output voltage is obtained as 36.2 mV and a

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maximum measured efficiency of 1.3%. It is discovered that Vout depends on the design parameters like value of inductors and capacitors. The value of DC output voltage can be effected by the choice of load, characteristic of schottky diode and matching circuit [5].

Therefore, it is observed that from the existing studies the efficiency is around 1% - 60%. In addition, the output voltage that has been detected is ranging around 36.2 mV – 2V which is still considered very low.

Rectifier being a significant portion in RF energy scavenging system in order to improve the efficiency of the RF-to-DC power conversion. Various forms of rectifier designs are analyzed with the statement of modification made in the design.

In this paper, a dual band rectifier circuit was proposed to operates at frequency 1.8 GHz and 2.45 GHz. This rectifier circuit consist of single stub matching network, Wilkinson power combiner and voltage doubler.

DUAL BAND RECTIFIER CIRCUIT DESIGN

The block diagram of the proposed dual band rectifier circuit for RF energy scavenging is shown in Figure-1. The circuit consists of matching network to maximize the power transfer for both frequencies. Wilkinson power combiner is used to combine both frequencies 1.8 GHz and 2.45 GHz to be single input source for voltage doubler. A voltage doubler is choose as a RF to DC conversion circuit because voltage doubler will produce twice the output signal as at it input. In the following, the description of the parameters that influnce the circuit will be discuss.

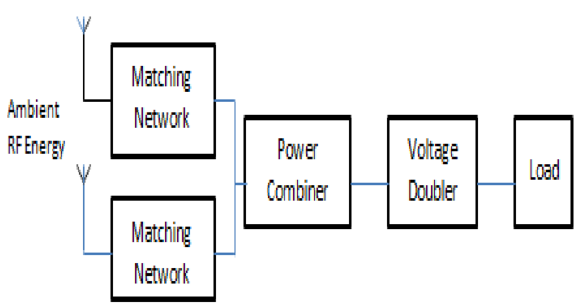

Figure-1. Block diagram of dual band rectifying circuit.

a) Diode specification

Since the energy scavenging circuit is working with high frequency, diode with very fast switch time need to be used. As Schottky diode uses a metal-semiconductor junction instead of semiconductor-semiconductor junction [6]. A fast switching diode is important in order the circuit to archive the high efficiency of RF to DC conversion. Four different types of Avago Technologies diode that are HSMS 2820, HSMS 2850, HSMS 2860 and HSMS 286B are compared. The simulation result in Figure-2 shows that HSMS 286B gives higher performance eventhough HSMS 2820 gives the highest value of output voltage but it has the slowest time switching.

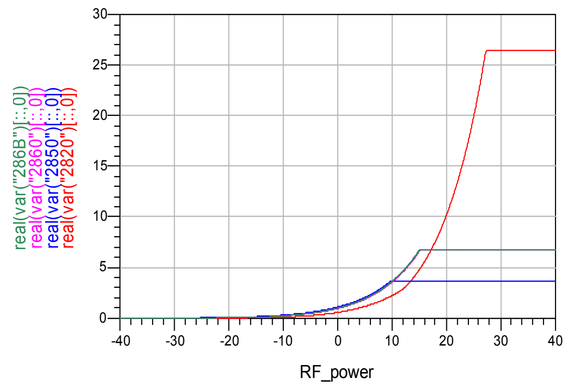

Figure-2. Output voltage with differences diode.

b) Choices of load

Choice of resistor load gives the impact on the performance of energy scavenging circuit. Differences value of load is simulated on the circuit by using parameter sweep of input power -20 to 20 dBm from 377 Ω to 500 kΩ. The output voltage is directly proportional to the increasing resistor value but it reached the limit voltage that is at 500 kΩ.

Figure-3 and 4 shows the output voltage for frequency 2.45 GHz and 1.8 GHz respectively. From both figures, 500kΩ load gives the highest output voltage for both frequencies.

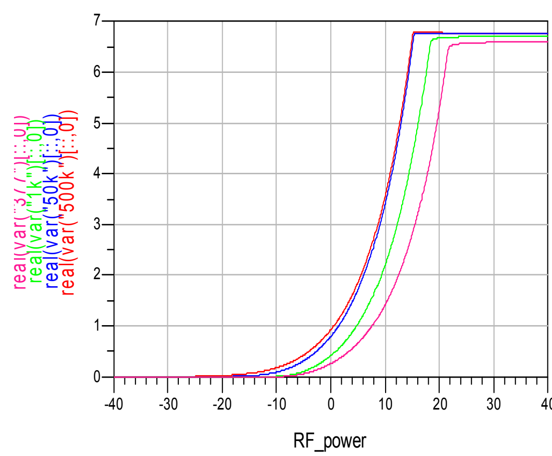

Figure-3. Output voltage of difference load for voltage doubler at frequency 2.45 GHz.

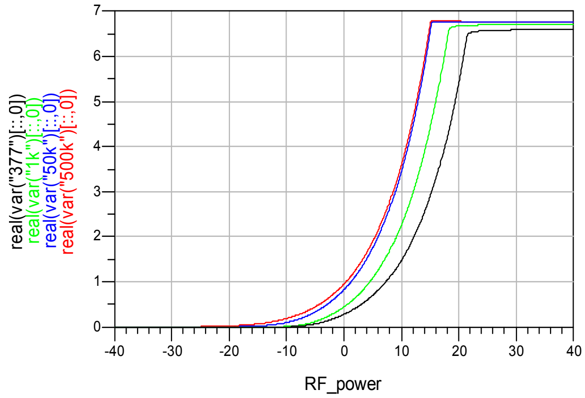

Figure-4. Output voltage of difference load for voltage doubler at 1.8 GHz.

Although 500 kΩ gives the highest output voltage, it has the lowest efficiency. From Figure-5 and 6, load resistor 377Ω produce high efficiency. It can achieved 74.6% at 2.45 GHz and 78.06% at 1.8 GHz. This is due to the 377Ω is air resistance value.

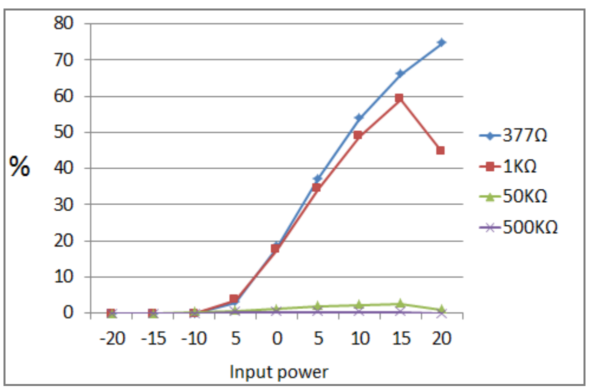

Figure-5. Efficiency of voltage doubler circuit with difference loads at 2.45 GHz.

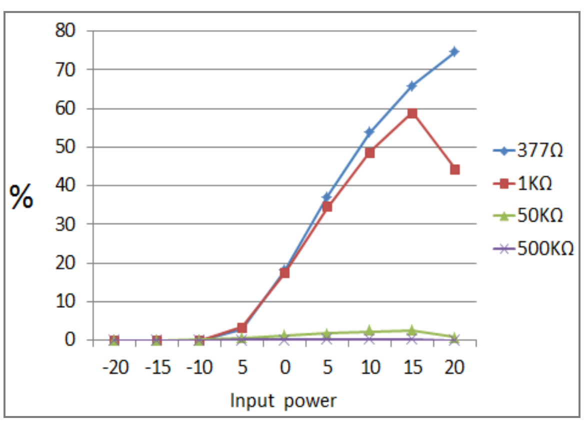

Figure-6. Efficiency of voltage doubler circuit with difference loads at 1.8 GHz.

c) Matching network

A single stub matching network is chosen to match the two impedances between antenna and the rectifier circuit. A comparison between single, double stub matching network and a circuit without a matching network has been done as shown in Figure-7. It is observed that the lowest input power can be achieved by using single stub matching circuit.

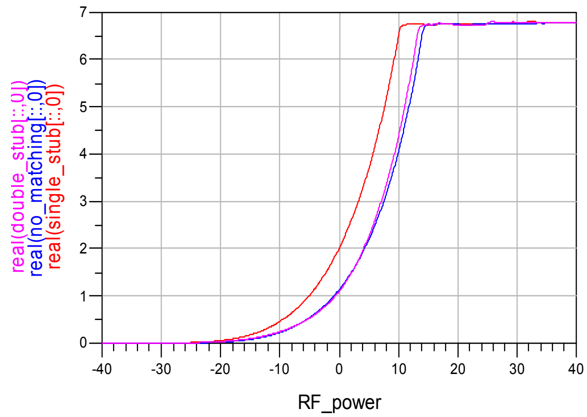

Figure-7. Output voltage versus the input power.

d) Power combiner

Figure-8 shows the comparison of single stage and multistage of the Wilkinson power combiner. The return loss for single stage is S44 and for multistage the return loss is S11. From the result shows multi stage Wilkinson power combiner gives wideband from 1.8 GHz to 2.45 GHz. The ideal lossless for Wilkinson power combiner would show the insertion losses S21 and S31 equal to -3dB.

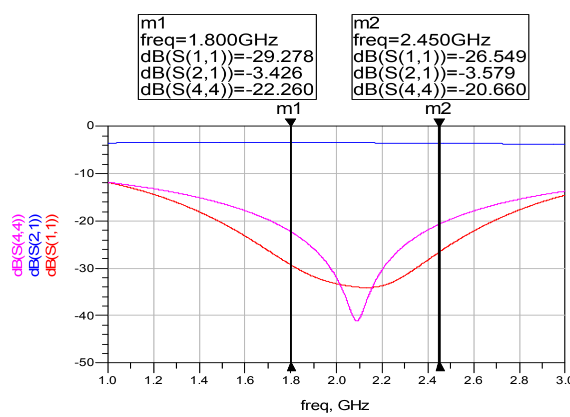

Figure-8. Return loss and insertion loss versus frequency.

e) Design layout

For this project, FR4 substrate is used. The FR4 specification is shows in Table-1.

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Table-1. FR4 specifications.

Parameter	Value
Er	4.6 mm
H	1.6 mm
Hu	3.9e +34
T	0.035
TanD	0.019

Figure-9 shows ADS simulated schematic diagram of dual band rectifying circuit that constists of input termination, single stub matching network, multistage Wilkinson power combiner and voltage doubler. The fabricated dualband rectifying circuit as shown in Figure-10.

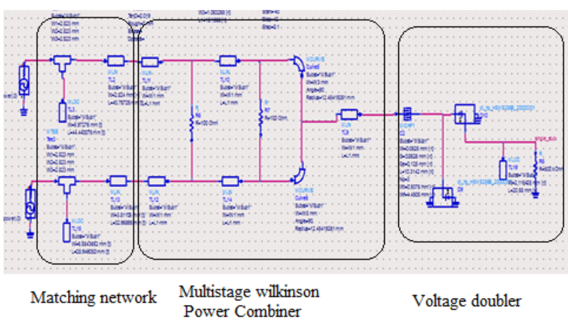

Figure-9. Schematic design of dual band rectifying circuit.

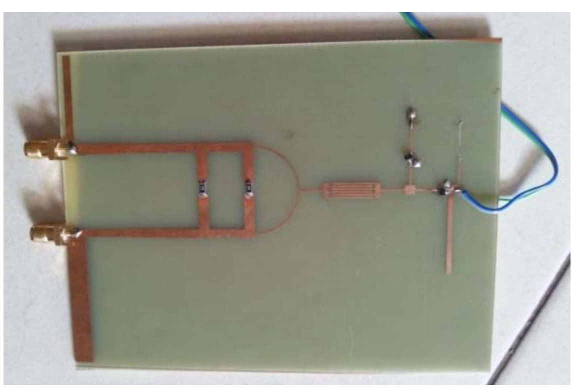

Figure-10. Prototype of the dual band rectifying circuit.

SIMULATION RESULTS

The dual band frequency rectifier circuit is simulated by using ADS software. The harmonic balance analysis is used as a simulation method for the circuit since it compute the steady state of a nonlinear circuit. The input signal is measured from -40 dBm to 40 dBm. Figure-11 shows the circuit of dual band rectifying circuit at 1.8 GHz and 2.4 GHz. Every frequency is matched with a single stub matching network. Multistage Wilkinson power combiner is used to combine the input signal, multistage Wilkinson power combiner. Voltage doubler will convert the RF signal to DC signal. The highest output voltage the circuit can be reach is 6.752 V at the input signal 20 dBm. The output voltage for the circuit can reached up to 2.01 V when the input power is 0 dBm.

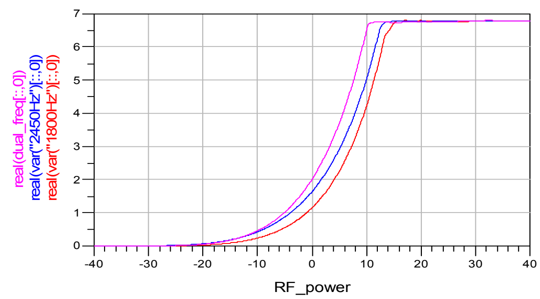

Figure-11. Comparison between single band frequency circuit with dual band circuit.

EXPERIMENTAL RESULTS

The rectifying circuit for dual band frequency was fabricated by using FR4. The rectifying circuit was measured by using the Hittite HMC-7200 signal generator. In order to measure the output voltage, digital multimeter has been used. Because of the limitation of the equipment, the input signal can be calculated only from -20 dBm to 20 dBm. Table-2 shows the comparison of output voltage for measurement and simulation. Both results clearly show that the output voltage is directly proportional to input power. The output voltage is 5.2 V and 6.7 V for measured and simulation result respectively. The difference result in measurement compared to the simulation is maybe due to the distance of the matching network, stub is too close to input port and also due to human errors such while during the fabrication.

Table-2. Comparison output voltage of measurement and simulation result.

Input power (dBm)	Output voltage, V	
	Measurement	Simulation
-20	0.260	0.058
-15	0.269	0.178
-10	0.272	0.461
-5	0.310	1.020
0	0.456	2.019
5	0.745	3.706
10	1.592	6.510
15	2.823	6.733
20	5.271	6.752

CONCLUSIONS

A dual band frequency rectifying circuit that consists of single stub impedance matching, multi stage Wilkinson power combiner and voltage doubler has been proposed at 1.8 GHz and 2.45 GHz. The input frequency operates simultaneously. More than 5V output dc voltage were measured over an optimal resistive load of 500 kΩ and an input power of 20 dBm for each frequency. The dual-frequency rectifier would have applications in wireless power transmission systems such as RFID tag, embedded sensor and defense millitary system.

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