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Session Chairs:

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RF Energy Harvesting Circuit for Low Power Applications

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***Abstract*—This paper presents a RF energy harvesting circuit for low power applications that can provide high conversion efficiency and output voltage. The proposed RF harvesting circuit consists of a single/dual band matching network, villard voltage doubler, low pass filter, and load resistor. To improve performances at low power, low series resistance schottky diodes with a low threshold voltage and several stage villard voltage doubler are utilized. Moreover, to increase output voltage, a dual band RF energy harvesting circuit is also realized. For the experimental validation, the dual band RF energy harvesting circuit is designed and fabricated at 0.88 and 2.44 GHz. The measurement results show that output voltage and conversion efficiency of dual band RF energy harvesting circuit are 270 mV and 12% at -20 dBm/tone, respectively.**

Keywords*— Dual band matching, low power applictions, RF energy harvesting, villard rectifier.

I. INTRODUCTION

The energy harvesting systems (EHS) from solar, wind, vibration, heat, electromagnetic wave and etc., is a key technology to replace limited energy sources. With increase demand of wearable device and sensor networks in the internet of things (IoT), one of main research issues is to solve battery capacity problem or replace power source of small power mobile devices by utilizing EHS. A RF EHS is a technology that utilizes the unused radio wave radiated in the atmosphere to reproduce the DC energy. Therefore, the RF EHS is relatively less affected by the environmental conditions, such as rain, sunlight, airflow and etc.

From the previous researches of RF EHS, it was found that the RF to DC conversion efficiency can be increased by several technique such as employing the harmonic suppression circuits on the output or in/output both side and designing dual band RF EHS [1]-[4]. Generally, dual band signals have higher peak voltage than single band or single tone signal for the same power level. Using the characteristic, the dual band RF EHSs were presented in [3] and [4] to improve output voltage and conversion efficiency. However, the conversion efficiency and output voltage in these works are optimized at higher than 0 dBm input power range. In [5], the RF EHS in the semi-urbans environments with power density of RF signals of -10 dBm was demonstrated.

In this paper, a RF energy harvesting circuit for low power applications is presented. Based on analysis, the optimized experimental results of dual band RF EHS are shown at low power.

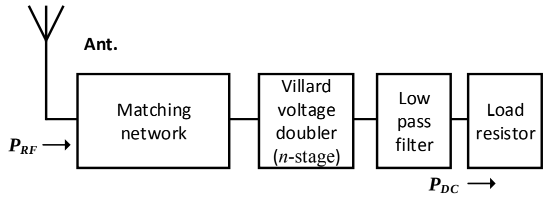

Fig. 1. Block diagram of proposed RF energy harvesting circuit.

II. ANALYSIS OF RF HARVESTING CIRCUIT

Fig. 1 shows a block diagram of the proposed RF energy harvesting circuit (EHC) which consists of input matching network, n-stage villard voltage doubler (VVD), low pass filter (LPF), and load resistor. The matching network is used to maximize received input power at the VVD. The RF signals are rectified into the DC by n-stage VVD circuit. The LPF is used to improve the electrical performances by suppressing harmonics caused by schottky barrier diodes (SBD) in the VVD. In general the output voltage and conversion efficiency of RF harvesting circuit can be expressed as (1) and (2).

$$V_{out} = n(V_{in.peak} - V_{th}) \tag{1}$$

$$\eta = P_{DC} / P_{RF} \tag{2}$$

where n, $V_{in.peak}$, V_{th}, P_{DC}, and P_{RF} are number of diodes, peak voltage of input RF signal, threshold voltage of diode, output DC power, and input RF power, respectively. From (1), the output voltage can be increased by n. However, the RF EHC cannot convert RF signal to DC when $V_{in.peak}$ is less than V_{th}. Even though $V_{in.peak}$ is slightly larger than V_{th}, it can be predicted that the conversion efficiency and output voltage are still low. Therefore, the performance of RF EHC depends on SBD characteristics and number of stages of VVD at low power region (less than -10 dBm).

To obtain the performance improvement at low power region, the SBD should be carefully selected such that threshold voltage and equivalent series resistance should be as low as possible. Therefore, in this work, HSMS-2852 SBD was employed due to its ultra-low threshold voltage (150 mV), low series resistance (25 Ω), and low junction capacitance (0.18 pF). Similar, to improve output voltage, the dual band RF EHC was realized because dual band signals has higher peak voltage than single band or single tone signal on the same power level. As a result, the RF EHC can operate in the low power region.

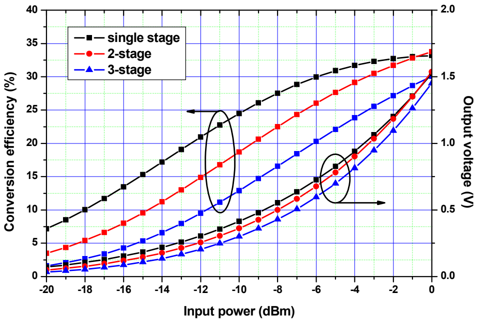

Fig. 2. Simulation results of conversion efficiency and output voltage according to number of stages in condition of R_L = 5 KΩ.

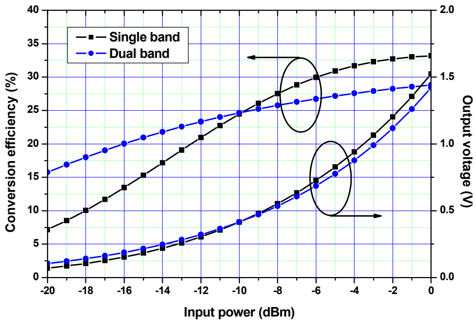

Fig. 3. Simulation results of conversion efficiency and output voltage according to single band (2.44 GHz) and dual band (0.88/2.44 GHz) with in condition of R_L = 5 KΩ.

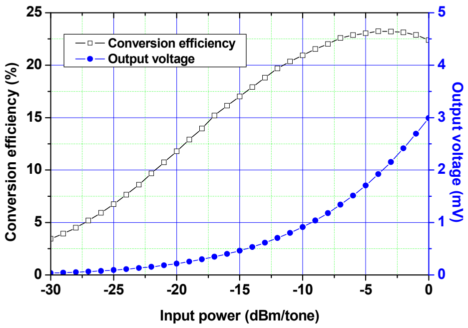

Fig. 4. Measurement results of conversion efficiency and output voltage of proposed dual band RF energy harvesting circuit in condition of R_L = 20 KΩ.

After optimizing the load resistor (R_L) for high conversion efficiency and output voltage at low input power, the overall EHC was fabricated.

III. Simulation and Measurement Results

Fig. 2 shows the simulation results of conversion efficiency and output voltage according to number of stages of the villard doubler with R_L of 5 kΩ at 2.44 GHz. From this graph, it is observed that single stage RF EHC provides high conversion efficiency and output voltage at low power level. Fig. 3 shows the simulated results of single band and dual band EHCs for the comparison. In the -20 to -10 dBm input power range, the output voltage and conversion efficiency of dual band RF EHC are always higher than single band RF EHC. This is due to the high peak voltage of the dual band signals.

The proposed dual band RF EHC was fabricated on a RT/Duriod 5880 substrate from Rogers, Inc., with a dielectric constant (ε_r) of 2.2 and a thickness (h) of 31 mils. The optimum load resistance is 20 KΩ. Fig. 4 shows the measurement results of the fabricated dual band RF EHC. From the measurement, maximum conversion efficiency is determined as 23% at -6 dBm/tone. Table 1 shows the performance comparison results at -20 dBm input power level. From this table, it is observed that the conversion efficiency is slightly lower than other works. However, the output voltage is much higher than other works.

TABLE I. Performance Comparison Of the Proposed Dual Band RF EHC With Previous Works.

	Rectifier Structure	RF-DC Conversion Efficiency	Output Voltage @ -20 dBm	Operating Frequency [GHz]
[6]	Series diode	19% @ -20 dBm	63 mV	0.915, 1.8
[7]	Villard voltage multiplier	18% @ -17 dBm	75 mV	0.49, 0.86
This work	Villard voltage multiplier	12% @ -20 dBm	278 mV	0.88, 2.44

IV. Conclusion

In this paper, the RF energy harvesting circuit for low power applications is described. To obtain the improved electrical performances at the low power, dual band single stage RF energy harvesting circuit is realized along with low pass filter. Compare with other previous works, the fabricated dual band RF energy harvesting circuit has good RF to DC conversion efficiency and output voltage. The proposed RF energy harvesting circuit is applicable for low input power applications such as wearable device and sensor networks in internet of things.

Acknowledgment

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Presented to

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Title: RF Energy Harvesting Circuit for Low Power Applications

General Chair, ISITC 2016

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Date