RF Energy Harvesting Circuits and Designs

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Abstract. The RF energy harvesting, a new booming research area during last decade for generating a small amount of electrical power, and its application in low-power electronics. A novel approach of Schottky diode-based Villard voltage multiplier circuit for energy harvesting application is proposed. A two-port Wilkinson power combiner circuit followed by Villard voltage multiplier circuit to combine output power from different energy sources is also studied. A Monte Carlo simulation has also been carried out for 10% tolerance value of the circuit components and results show proximity to the nominal or actual outcome. 30 mW power is achieved for Wilkinson power combiner circuit for 1 V input voltage.

Keywords: RF energy · Energy harvesting · Voltage multiplier · Power combiner · Monte Carlo simulation

1 Introduction

RF energy harvesting is a promising area of research during this decade. One of the applications of energy harvesting in electronics is the production of enough electrical power which is the essential requirement to drive the low power electronic devices [1]. Recharge of the battery is a major problem for the low power electronic devices in situation where the power source is not available. Energy harvesting [2, 3] is the solution of this problem. The energy harvesting technology also takes crucial role in biomedical field where the output power delivered by the biomedical devices needs to be constant to decrease the patient's risk of death. There are wide range of frequencies (3 kHz to 300 GHz) of RF energy sources [4, 5] available in nature. RF signal is available in our daily lives in form of signals transmission from TV, radio, wireless LAN, mobile phone, etc. [6, 7]. Though most commonly used popular frequencies are 900 MHz and 2.4 GHz ISM bands but also comparatively low frequency like radio, TV signals can take important role as energy sources, since the attenuation of the RF waves is inversely proportional to the frequency.

In this work 909 kHz frequency (AM radio) is taken as input RF source. This work first addresses the design, implementation, and characterization of a Villard voltage multiplier circuit including rectifier and latter transmission line-based Wilkinson power combiner [8] connected voltage multiplier circuit to harvest RF energy. The voltage

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output of an n-stage voltage multiplier circuit, with stage capacitance (C) can be given by Eq. 1.

$$Vo = n.(2Vin) - \frac{n-1}{fC} I_{Load} \tag{1}$$

V_O, V_{in}, I_{Load} are the output voltage, input voltage, load current, respectively, and C, f, n are the value of capacitance, operating frequency, and number of stage of voltage multiplier, respectively.

2 Results and Discussions

A two-stage voltage doubler circuit to convert RF to DC signal is shown in Fig. 1. A Schottky diode-based voltage multiplier circuit for RF energy harvesting system [9] has been proposed by authors. Schottky diode shows low forward voltage, high switching speed, low noise and can be considered as an ideal component for RF energy harvesting. After studying different Schottky diode from literature it is found that HSMS series of Schottky diode (Ex: HSMS 2850) is most suitable for almost zero bias voltage.

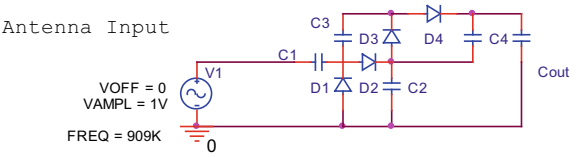

Fig. 1 Two Stage Voltage doubler Circuit

Figure 2 shows the output voltages for two stage voltage doubler circuit obtained as 1.75 and 3.493 V for first stage and second stage, respectively, after 20 ms.

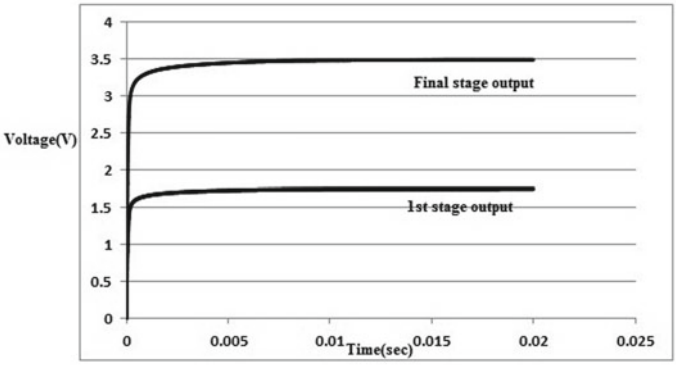

Fig. 2 Output voltage of voltage doubler circuit

Monte Carlo Simulation is also carried out for final output voltage for 100 samples as shown in Fig. 3. It is observed that output voltage varies between 3.490 and 3.498 V for 10% tolerance of circuit components and results show maximum 0.143% variation only from nominal or actual value of output voltage.

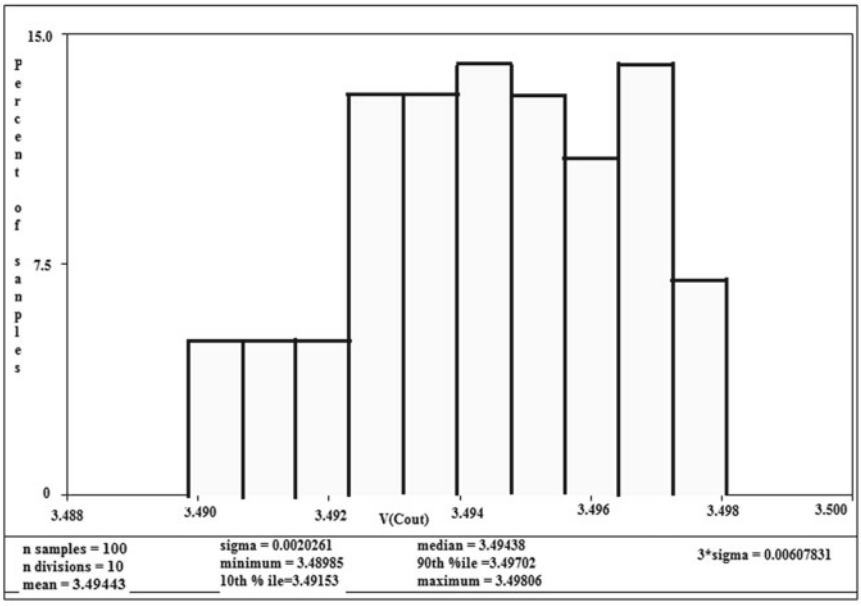

Fig. 3 Monte Carlo simulation output for final stage voltage

As captured RF power by antenna [7] is limited, authors have proposed to insert a Wilkinson power combiner circuit between antenna and voltage doubler circuit as shown in Fig. 4. Wilkinson power combiner is a good choice due to its low loss and good isolation characteristics.

The output voltages for first stage and second stage of Wilkinson power combiner connected voltage multiplier circuit are 3.51 and 7.01 V, respectively, after 20 ms as shown in Fig. 5. Monte Carlo simulation of the circuit for final stage as shown in Fig. 4 has also been carried out for 20 samples, and the results are shown in Fig. 6.

Monte Carlo results of Fig. 6 show the variation of output voltage between 6.6 and 7.5 V range for 10% tolerance of circuit components. It is observed from Monte Carlo simulation that there is maximum 7% variation at output voltage comparing with nominal or actual output voltage.

The output power obtained from the output capacitor for conventional voltage multiplier circuit and Wilkinson power combiner connected circuit are shown in Figs. 7 and 8, respectively. The improvement is observed in Wilkinson power combiner connected circuit increasing output power by 85.41% comparing with conventional voltage multiplier circuit.

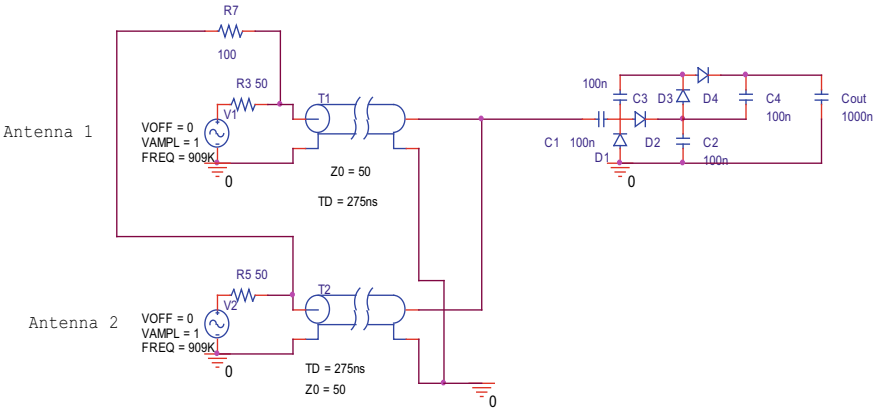

Fig. 4 Wilkinson power combiner connected voltage multiplier circuit

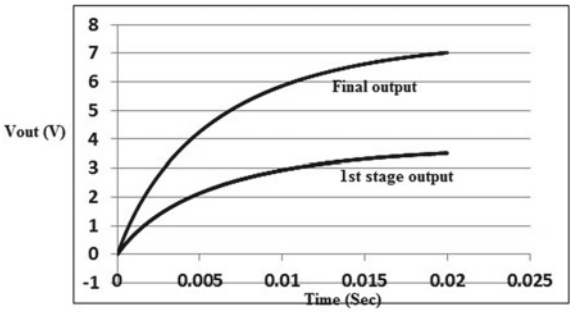

Fig. 5 Output voltage of Wilkinson power combiner

In this proposed design, the Wilkinson power combiner is basically composition of transmission lines, each having one quarter-wavelength long. The fabrication of this component can be easily achieved by using microstrip line through photolithography or milling techniques.

Authors have measured the RF input voltage captured by single dipole antenna at different frequency like 93.3, 104 MHz. The RF voltage is obtained at dBuV range at this frequency. The captured RF power can be improved if proper rectenna is designed for this energy harvesting system.

3 Conclusions

Results obtained from the simulation show higher output voltage and output power generation from Wilkinson power combiner connected voltage doubler circuit as compared with conventional voltage doubler circuit. Also, the output voltage obtained from power combiner followed by two-stage voltage doubler has been found double in comparison with conventional voltage multiplier. The maximum output voltages of final stages were

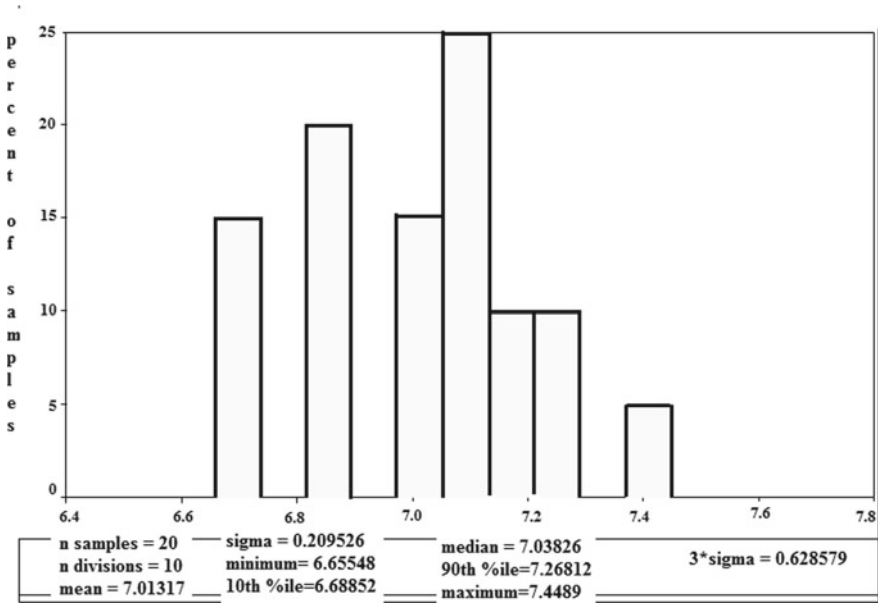

Fig. 6 Monte Carlo simulation output of Wilkinson combiner connected circuit

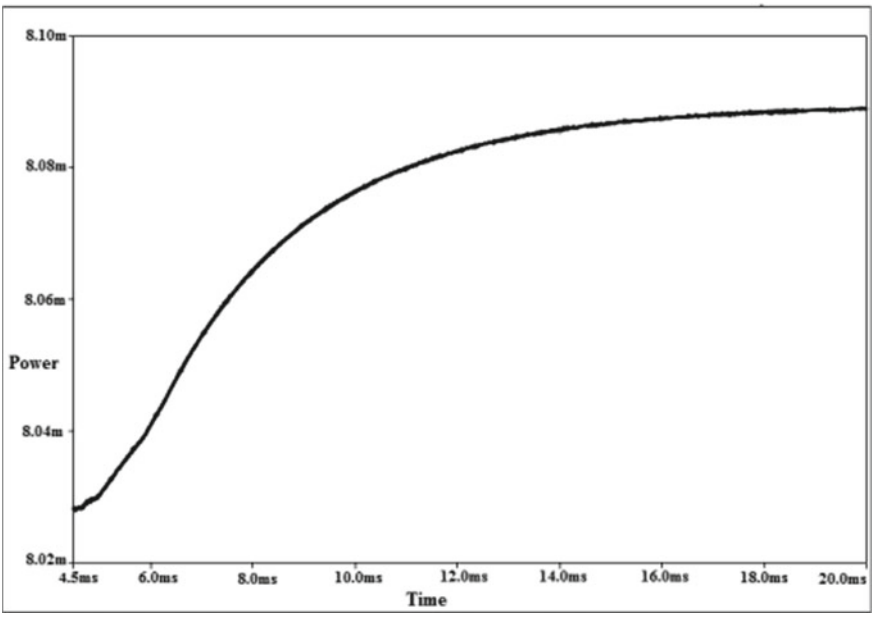

Fig. 7 Output power from output capacitor of two stage voltage doubler circuit

obtained as 3.493 and 7 V for the conventional two-stage voltage doubler and Wilkinson

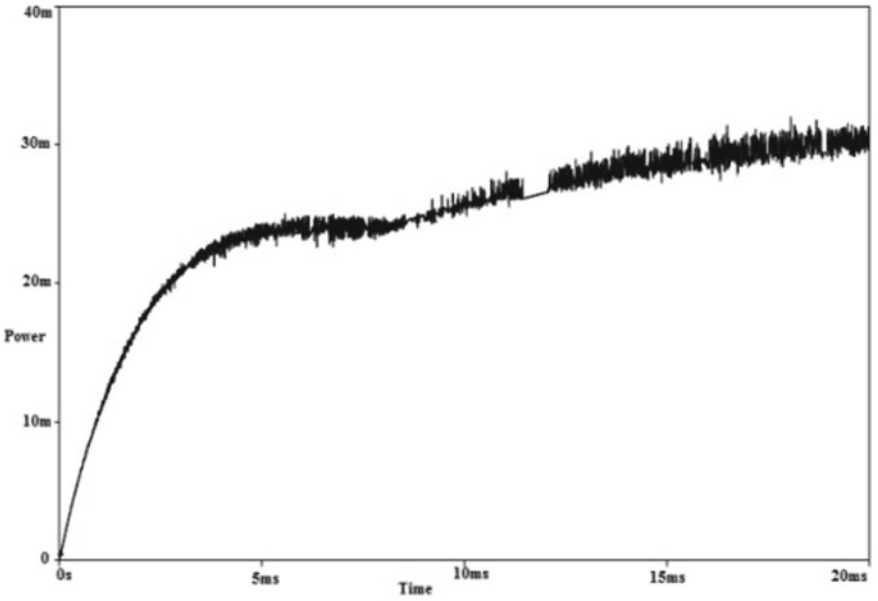

Fig. 8 Output power from output capacitor of Wilkinson combiner connected circuit

power combiner connected voltage doubler circuit, respectively. Monte Carlo simulation for the final stage output voltage shows close proximity to the actual output voltage in both circuits. The 85.41% improvement is observed at the output power generation of Wilkinson power combiner connected circuit as compared to conventional diode-based circuit. These circuits promise as powerful techniques for the application of energy harvesting technology.

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