Advanced Rectifier Circuit Design for RF/Microwave Energy Scavenging Applications

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ABSTRACT

A design of Rectifier circuit for energy scavenging from an ambient field is proposed in this paper. The ability to harvest RF energy, from ambient or dedicated sources, enables wireless charging of low-power devices and has resulting benefits on product design, usability, and reliability.The average of the density of RF waves is in the range of -30dBm to 20dBm.These RF signals can be received by means of multiband antenna which can then be rectified into DC voltage and stored in suitable storage devices.This proposed work focuses on the design of rectifier circuit using the surface mount RF schottky diode (HSMS-2822) by Agilent.The simulation is carried out for various stages of rectifier circuit and the performance is studied by using Agilent Advanced Design System (ADS) software tool.The proposed rectifier can be optimized for various frequencies with high RF-to-DC conversion efficienciesupto 98% for the input RF power in the range of -20dBm to 10 dBm.

Keywords : **RF energy, Ambient field, Schottky diode, Rectifier circuit, RF-DC conversion**

I. INTRODUCTION

The last decade has witnessed a huge development in the field of electronics. Particularly portable electronic devices, consumer devices like smart phones, and industrial applications, like wireless sensor networks. These devices offer many functions but their autonomy is limited because of the tradeoffs on batteries regarding size and power density. Batteries need to be periodically recharged. Most often the charge relies on a wall plug charger, which somehow limits the portability of a wireless device [1]. Practically it is not possible to carry charger wherever we go and also to expect availability of power supply everywhere. To avoid such disadvantages some sort of solution should be given and that can be wireless charging of mobile phones. If the mobile can receive RF power signals from the mobile towers, why can't we extract the power from the received signals? This can be done by the method or technology called RF energy harvesting [2], [4].Other names for this type of technology are Power harvesting, Energy scavenging and free energy, derived from Renewable energy.

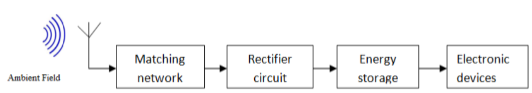

Fig 1: Schematicof Ambient RF energy harvesting

Fig. 1 shows the components of the proposed energy harvesting circuit. The incident RF power is converted intodc power by the voltage multiplier. The matching network, composed of inductive and capacitive elements, ensures themaximum power delivery from antenna to voltage multiplier. The energy storage ensures smooth power delivery to the load and as a reserve for durations when external energy is unavailable. Increasing the number of multiplier stages gives higher voltage at the load and yet reduces the current through the final load branch. This may result in unacceptable charging delays for the energy storage capacitor. Conversely, fewer stages of the multiplier will ensure quick charging of the capacitor, but the voltage generated across it may be insufficient to drive the. Along similar lines, a slight change in the matching circuit parameters alters significantly the frequency range in which the efficiency of the energy conversion is maximum, often by several megahertz. Hence, RF harvesting circuits involve a complex interplay of design choices, which must be considered together.

II. AMBIENT EM SOURCES AND POWER DENSITY

Available RF energy in the ambient or areas close to transmission towers provides an opportunity to harvest that energy. Some of the most prominent sources are FM radio systems ((88-108 MHz, transmitted power few tens of KW), TV Transmission (180-220 MHz, transmitted power few tens of KW), Cell Tower Transmission (10 to 20 W per carrier), Wi-Fi (2.45GHz, 5.8GHz), AM Transmission (540-1600 KHz, transmitted power few hundred KW) and mobile phones (transmitted power 1W to 2W), etc.The output power of RF devices is limited by regulations, such as Federal Communications Commission (FCC), USA due to safety and health concern offered by EM radiations [12]. The maximum theoretical power available for RF energy harvesting is 7.0 μW and 1.0 mW for 900 MHz and 2.4 GHz frequencies respectively for a free space distance of 40 meters[6].

A 1V/m electric field can yield power density of about0.26μW/cm2. Only when close to a powerful transmitter, fieldstrengths of a few volts per meter can be measured [6].

An attempted to charge mobilephonebatteries by capturing RF energy at 915 MHz,4mV/second charging time was observed by reference [14].RF energy generation and delivery systems to provide energyto down-hole electrical equipment without wires usingconductive pipes for radiating RF signals was done by [15].An integrated circuit for RF energy harvesting studies for868.3MHz implemented in a Silicon-on-Glass substratetransfer technology are also presented by [16] [17]. Circuitand system for both Solar and 900MHz RF power scavengingand management is developed for medical purposes [18].

III. RF-DC RECTIFIER TOPOLOGIES

The Rectenna has been a growing area of research in recent years, as the microwave integrated circuit and monolithic microwave integrated circuit technologies became more mature allowing for high level integration. The Rectenna termed as rectifying antenna, is combination of an antenna and a nonlinear rectifying element (Schottky diode, IMPATT diode…etc.) where the two elements are integrated into a single circuit [8].

The RF-to-dc conversion efficiency of a rectenna is influenced by the amount of power loss in the diodes, by the impedance match between the antenna and the rectifier and between the rectifier and the load, and also by the antenna efficiency[1]. For a rectenna, the RF-to-dc conversion efficiency is usually defined as the ratio of the total amount of power delivered to the load to the amount of power that the receiving antenna could inject in a perfectly matched circuit

$$\eta = \frac{P_{DC}}{P_{RF}} = \frac{V_{out}^2}{R_{load}} . \frac{4\pi Zair}{|E|^2 .G.\lambda^2} (1)$$

whereR_{load} is the load resistance, Z_{air} is the air characteristic impedance, E is the electric field efficient value at receiver position, G is the receiver antenna gain, and λ is the wavelength.

Microwave rectifiers have different topologies, depending on the position and number of HF diodes. The simplest and most common configurations are series- or shunt-mounted single diode. They are a good choice for very low incident power levels . For higher power levels, bridge-type rectifiers and rectenna associations offer better performances, primarily due to their higher power-handling capabilities[1].A basic schematic of a Villard voltage doubler, sometimes also called Cockcroft-Walton voltage multiplier, is shown in Fig. 4.

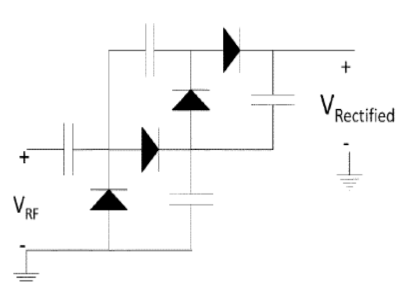

Fig 3: Two stage Villard voltage multiplier

By coupling the AC signal to the diodes through capacitors in parallel instead of in series, a Dickson [7] voltage multiplier, as shown in Fig. 3, provides stronger current drive ability with the penalty that the capacitors have to withstand the full DC voltage developed along the chain. A comparison of the two rectifier topologies is made.

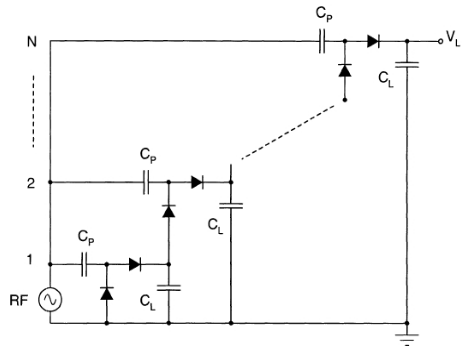

Fig 4: DicksonVoltage multiplier circuit

Fig.3 shows a simple diode based capacitive voltage multiplier circuit. Such circuits have been used for many years in various rectifier and charge pumps applications. The RF input is fed in parallel to the all the stages through pump capacitors C_p.The DC outputs are developed across the load capacitors C_L and add up in series to produce the final load voltage V_L. V_L is approximately given by as

$$V_L=2N(V_{in}-V_{th}) \quad (2)$$

Where $V_{in}$is the amplitude of theRF input, and V_{th} is the forward voltage drop of the diodes at the specified load current I_L. Ideally, each doubler stage produces a DC voltage $2(V_{in}-V_{th})$.To obtain operation at low values of $V_{in,}$ Schottky (metal semiconductor) diodes with low values of V_{th} are used. For this circuit (and in general for all diode based rectifiers),its necessary to have V_{th} to be as low as possible to improve performance.

The series type schottky diode with part number HSMS-2822 by Agilent technologies which has a low

Turn-On voltage of 340mV at 1mA is used in this proposed work.

IV. SIMULATION RESULTS

The energy harvesting circuit is simulated using Agilent Advanced Design System (ADS) software. The number of voltage doubler stages can boost the input AC voltages to a higher level and convert it to the DC. After studying different combinations of the Villard and Dickson voltage multiplier, by following the techniques and simulation presented in [14] and [16], different stages of voltage multiplier was constructed with each stage using a series type HSMS2822 Schottky diodes and 1pF capacitors. The design of the voltage multiplier is preceded by the matching network which helps us to match the impedence of the antenna with the rectifier.Fig-5 shows the proposed single stage voltage multiplier circuit proposed in this work.

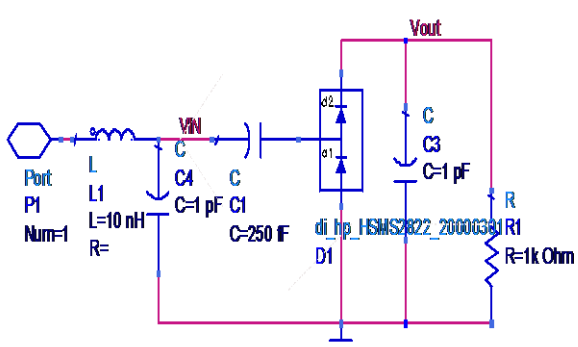

Fig 5: Simulation circuit for Single stage voltage multiplier circuit to harvest energy

The ADS simulation of several stages of Dickson topology and Villard voltage multiplier topology revealed no significant difference. The maximum RF-DC conversion has been achieved at the resonant frequency. The design of five stage voltage multiplier circuit is also carried out.

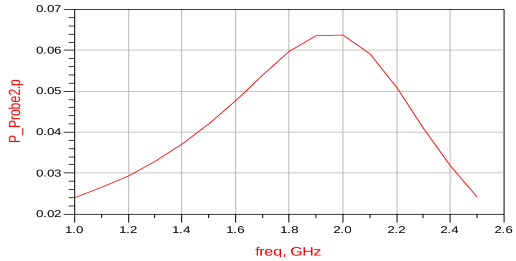

Fig 6: Frequency Vs output power of five stage voltage multiplier circuit

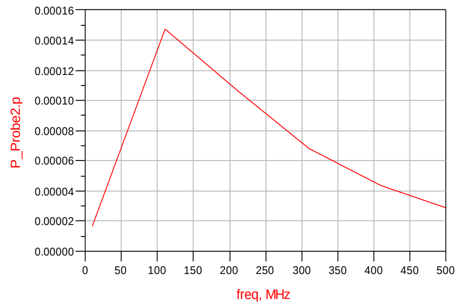

Fig 7: Output power as a function of Frequency for the Simulation circuit optimized at 110MHz central frequency

The figure 6 shows the simulation result for the rectified circuit optimized for 1.9GHz frequency. The power density in the environment depends on the frequency of the RF power source. From figure 7 it is evident that with the decrease in frequency, the rectified power is decreased for the rectifier circuit with the central frequency of 110MHz. Figure 8 shows the plot of current flow at the output circuit with respect to the frequency for the five stage voltage multiplier circuit.

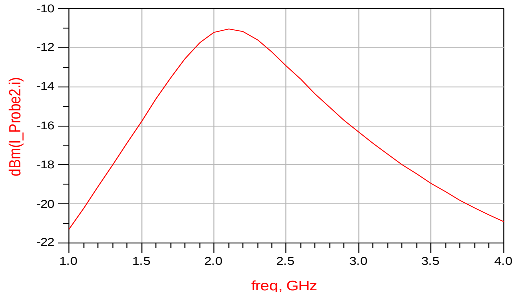

Fig 8:Output current in dBmVs Frequency of five stage voltage multiplier circuit

As shown in Fig. 9, with a fixed inductance, smaller capacitance brings higher output voltage at a higher resonant frequency. The number of rectifier stages has a major influence on the output DC power of the energy harvesting circuit. Each stage is a modified voltage multiplier, arranged in series. The output power is directly proportional to the number of stages used in the energy harvesting circuit. Figure 10 shows the variation of the output power as the function of frequency for the different stages of the voltage multiplier circuit.

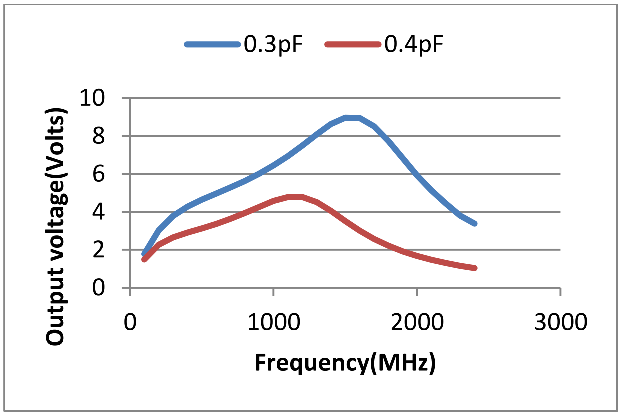

Fig 9: The output DC voltage as a function of input signal frequency, for different input signal power and open circuit load.

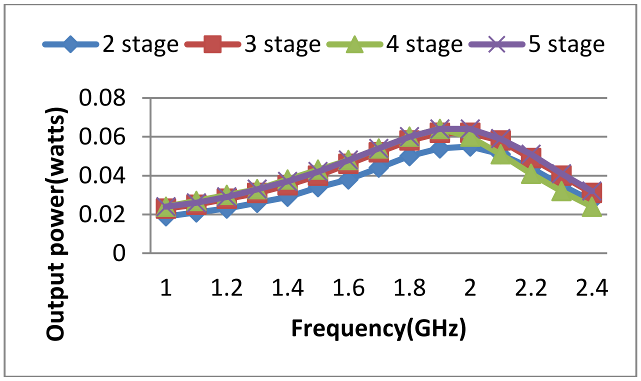

Fig 10: Output power as the function of frequency for various stages of voltage multiplier circuit.

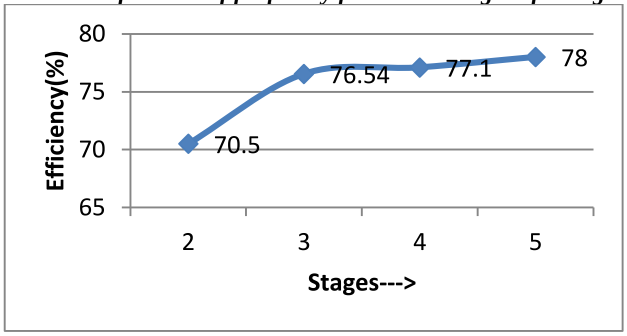

Fig 11: Plot of Efficiency Vs Stages of Capacitive Voltage Multiplier circuit

It can be inferred from the figure 11 that with the increase in number of stages of the capacitive voltage multiplier circuit the efficiency is also increased. Thus a maximum efficiency of 78% is obtained for a load resistance of 10K Ω. With the decrease in Load resistance the output power and efficiency increases.

V. CONCLUSION

RF energy harvesting holds a promisable future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronics. A rectifier circuit for energy harvesting from the ambient field is presented in this paper. The design is carried out using the HSMS-2822 schottky based diodes. The designed circuit can be used to capture the RF energy from the RF sources with the help of multiband antenna (wireless routers, cell phone towers etc.,).The efficiency upto 78% is obtained for the power density ranging between -30dBm and 20 dBm. The circuit can be implemented in mobile handsets, wireless sensor nodes etc

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