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An Efficient RF Energy Harvesting from 4G Frequency Band

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ABSTRACT

The future mainly depends on sensor nodes. Emerging sensor nodes require efficient power management to reduce battery replacement cost and eliminate the chemical discharge from the battery, which may damage the sensor node. However, while considering the remote areas it is difficult to provide power supply. Thus, RF energy can be used in such places. Radio Frequency Energy Harvesting (RFEH) is the type of energy which harvests energy from the environment itself. A compact wideband rectenna is used for radio frequency (RF) energy harvesting in 4G application. The rectifier is the main component in energy harvesting (EH) circuit as it converts RF energy from available sources to DC power. A Modified Villard voltage doublers circuits that performs radio frequency energy harvesting (RFEH) was proposed. To provide the proper impedance matching between antenna and rectifier , frequency dependent complex load based impedance matching network was designed. A Schottky diode HSMS281C is selected for designing the rectifier circuit. Simulation of the circuit was done by ADS. Experimental result shows that an output power is about 0.33W and maximum power conversion efficiency is 47.142%.
Index Terms—rectifying circuit, energy conversion, Schottky diode

I. INTRODUCTION

The RF energy harvesting system is known as remotely powered device that converts RF to DC power without requiring any internal source while extracting its power from propagating radio waves [1]. However, the electrical power generated by energy harvesting techniques is small and less than few milli-watts depending on the techniques.

However the power derived is enough for small electrical or low power consumption devices. Thus, energy harvesting technology promotes a promising future in low power con- sumer electronics and wireless sensor networks. RF energy harvesting is a green technology that suitable for a wide range of wireless sensing applications such as wireless sensor networks, wireless power as well as used in RFID tags and implantable electronics devices.

The RF signals received by the antenna will be trans- formed into DC signals by a diode based rectifying circuit. In order to obtain an optimum power transfer, a matching circuit and rectifier will be used. The matching circuit is used in this stage to achieve impedance matching between the antenna and rectifier. However, for this wideband antenna for RF energy harvesting system, there are several range frequencies need to be covered particularly at 2.3GHz (WiMax), 2.4 GHz (WLAN), 2.6 GHz (LTE/4G) and also 5.2 GHz (WLAN). The applications particularly use as low-power sensor networks in remote areas.

The concept of energy harvesting is to receive energy from surroundings sources and convert it into a useful form to power any applications or store the energy for future usage. In wireless (RF) energy harvesting, electromagnetic energy from multiple sources received by an antenna, converts it into an electric energy and use as a power source for other devices. Impedance matching is one of the important aspects of high frequency circuit analysis. To avoid reflections and for maximum power transfer the circuits have to be impedance matched. Transmission line sections can be used for the purpose of impedance matching.

The harvested energy from alternating current to direct current a rectifying network was implemented. A full wave rectifier was chosen since there are no space restrictions and all energy is needed. The simplest way to do this is by a voltage doublers which will both rectify and boost the voltage at the same time with minimal losses. Since the frequency of the alternating current radio wave is very high a Schottky diode was chosen .It has fast switching speed.

Schottky diode has the advantage of having a low forward voltage as well. This makes it well suited for energy harvesting. A voltage multiplier or doubler circuit is a special type of rectifier circuit consisting of a network of capacitors and diodes grouped into n stages. It provides RF-DC conversion and secondly it amplifies /boosts the DC voltage according to the number of stages in the doublers circuit .The storage unit is a storage unit is a storage unit is a storage capacitor that acts as an energy reserve.

In DC, power transfer is optimum when the resistances of the source and load are indistinguishable. However, the impedance imbalance between the source and the load leads to the creation of a reflected power flow, which is the source of the decrease in the efficiency of the system. For maximum power collected by the antenna to be transferred to the RF/DC conversion circuit, the input impedance of the rectifier must be the combined complex of the source impedance.

The remainder of the paper is organized as follows. Section II presents the related work. The proposed method is described in Section III. The obtained results are reported in Section IV. Conclusions are drawn in Section VI.

II. RELATED WORKS

Esraa Mousa Ali et al., The design aimed at developing a novel rectifying circuit to be used in harvesting applications at a frequency of 900 MHz. A rectifier is the main component in energy harvesting circuits as it converts RF energy from available sources to DC power. Cockcroft Walton rectifier circuit and Dickson rectifier were designed. The design is built by integrating the Cockcroft Walton rectifier, arranged in series, with the Dickson rectifier, arranged in parallel. The Schottky diode HSMS 285C is selected for designing the rectifiers circuit. Each stage of the Dickson charge pump is formed using voltage doublers. Simulation and experimental results show that the conversion efficiency of 35.44% at 900MHz.

Faza Mohd Noor S. et al.,proposes a dual-band aperture- coupled rectenna for radio frequency (RF) energy harvesting at 2.45 and 5 GHz application is proposed. Dual- band rectifier using voltage doublers topology of that HSMS286B Schottky diode for RF energy harvesting application. The rectifier of voltage doublers topology consists of two inter digital capaci- tors, four HSMS286B Schottky diodes, and load resistors. The minimum DC voltage of 0.167 and 0.236 V with 0 dBm.

Hakan Partal P. et al.,The complete harvester system de- signed and developed here consists of a zero-bias RF energy rectifying antenna (rectenna), DC boost converters and energy storage super-capacitors. To achieve a successful harvester performance, rectifier circuits with high sensitivity Schottky diodes and proper impedance matching circuits are designed. Impedance matching network is implemented to reduce the reflected input RF power, DC to DC converters are evaluated for their compatibility to the rectifiers, and super- capacitor for charging and storage capabilities.

The single stage and double stage rectifier circuit designs by using the Dickson voltagedoubler. Schottky diode SMS7630 was used in the design.The maximum output voltage is 30%.The rectenna achieves a good performance design and increased battery life or battery free operation for ultra-low power electronics applications, such as RFID, LoRa, ZigBee, and wireless sensor networks.

Hichem Mahfoudi et al., proposes a novel wideband rectenna for RF energy harvesting applications. The operating frequency bands of the antenna are GSM, UMTS, Wi-Fi, and LTE2600/4G bands. The RF energy harvesting system is made up of a microwave antenna, a matching circuit, rectifying circuit and a resistive load. Schottky diode model HSMS-286B is used. For this rectifying circuit, the single stage rectifier design consists of one diode and one capacitor. This circuit is chosen as it is less complex and minimizes the diode losses. The rectenna performances are simulated and measured. The experiments show an output DC voltage of 1 V over the frequency band with a peak efficiency of 50%. This voltage can be used to low power sensors in sensor networks in place of batteries.

Jianwei Jing et al.,proposes a compact and high- efficiency loop rectenna with matching network elimination for wireless sensor applications at 2.45 GHz is presented. The proposed hollowed-out square loop antenna is designed and directly provides a conjugate matching to a compact voltage- doubler rectifier. Two Schottky diodes (HSMS 2862) are applied to achieving a higher output voltage .The experiment results show that the peak microwave-to-dc conversion efficiency of 33% is obtained at2.45 GHz when the input power is 2 dBm. Hence, the proposed rectenna can provide a convenient and practical charging solution for wireless sensors in various applications.

Sandhya Chandravansh et al.,(2018) A triple band differential rectenna for RF energy harvesting applications is proposed. The rectenna is designed to operate in frequency bands of universal mobile telecommunication service (2.1 GHz), lower WLAN/Wi-Fi (2.4– 2.48 GHz), and WiMAX (3.3–3.8 GHz). A triple band differential rectifier is designed using the Villard voltage doubler where interdigital capacitors (IDCs) in lieu of lumped components are used. The single- stage voltage doubler topology is used for the rectifier circuit consisting of the Schottky diode HSMS-285C packaged with SOT-323.The conversion efficiency at 3.5 GHz band is lower as compared with the other two bands due to impedance mismatch as the band. the lowest frequency of 2 GHz, a very good rectenna efficiency at lower input RF power level is obtained. Measurement of the proposed rectenna shows an approximate maximum efficiency of 53% at 2 GHz, 31% at GHz, and 15.56% at 3.5 GHz.

Mengyao Yuan et al., (2020) proposes a Dickson charge pump, Cockcroft-Walton charge pump circuit and an impedance matching network is designed. It mainly focus on maximizing the overall rectifier efficiency, including the rectifier circuit and the impedance matching network. In order to convert the AC signal into a DC signal available to the load, a rectifier circuit is necessary for the RF energy harvesting system. HSMS-285X series of Schottky diode is used.Both of charge pump circuit provide enough voltage. the circuit structure is simple, which is convenient for increasing the number of stages. the output voltage can be boosted by increasing the number of stages of the circuit. But the same time, due to the series structure of capacitors between the stages, resulting in a reduction in circuit efficiency . The maximum RF-DC conversion efficiency of 78.7%at 915MHz

III. PROPOSED METHOD

ADS harmonic balance and transient analysis have been used for simulations. The input impedance of the rectifier is simulated at an input power level and an operating frequency of 2.45GHz. and values are 200pF and 1pF.

A normal diode will have a voltage drop between 0.6 to 1.7 volts, while a Schottky diode voltage drop is usually between 0.15 and 0.45 volts. This lower voltage drop provides better system efficiency and higher switching speed. In a Schottky diode, a semiconductor–metal junction is formed between a semiconductor and a metal, thus creating a Schottky barrier. The N-type semiconductor acts as the cathode and the metal side acts as the anode of the diode. This Schottky barrier results in both a low forward voltage

drop and very fast switching. Figure 3.6 shows that schottky diode symbol.The main objective for choosing a diode is too fast, accurate and at the same time reliable to calculate the impedance which are the features of schottky diode. In order achieve the high efficiency for RF-to-DC conversion the switching-time diode must be considered as it is a promising device to detect the ambient RF energy. Schottky diode HSMS281C is proposed. Table 3.1 shows that the Spice Parameters for HSMS281C.

Table 3.1 Spice Parameters for HSMS281C

Parameters	Unit	Values of HSMS281C
	pF	1.1
	Ω	10
	A	

For maximum power transfer between the antenna and the rectifier, a matching network is designed, simulated and measured is the input impedance of the voltage doubler. At an operating frequency of 2.45GHz, the impedance of the voltage doubler is found to be 5.3-j0.00Ω.

A matching network is designed to transform this impedance to 50 ohms. The designed matching network will match the impedance of the voltage doubler to that of the antenna at 2.45GHz.

To design a microstrip patch antenna operating at 2.45 GHz.To design a microstrip patch antenna the dimension of the antenna are to be calculated.Design equations for the antenna,Length value can be calculated by using the equation where, L is the length of the patch ,W is the width of the patch, Capacitance value can be calculated by using the equation Capacitive reactance can be calculated by using this equation where, is the capacitive reactance, is the angular frequency,C is the capacitor Inductive reactance can be calculated by using this equation in where, is the inductive reactance, is the angular frequency,L is the inductor Output power is calculated by using equation

Power Conversion Efficiency is calculated by using equation

PCE(%)= *100

where, is the input power, is the output power from the rectenna circuit.

IV. RESULTS AND DISCUSSION

Modified Villard Voltage Doubler Rectifiers is used to achieve high conversion efficiency at fixed frequency bands.

For simulation purpose, Advanced Design System (ADS) software is used which has built-in HF diode libraries for HSMS series diodes. The circuit schematic of Modified Villard Voltage Doubler topology is shown in Figure 2.

During the negative half cycle, diode D1 conducts and charges the capacitor to its peak voltage of input signal but practically, the voltage drop of diode is also to be considered. Similarly, during the positive half cycle, the voltage stored in capacitor C1 gets added to the input voltage supply in series. Thus at the output, cumulative voltage drop due to each of the diodes is added and output voltage is get doubled.

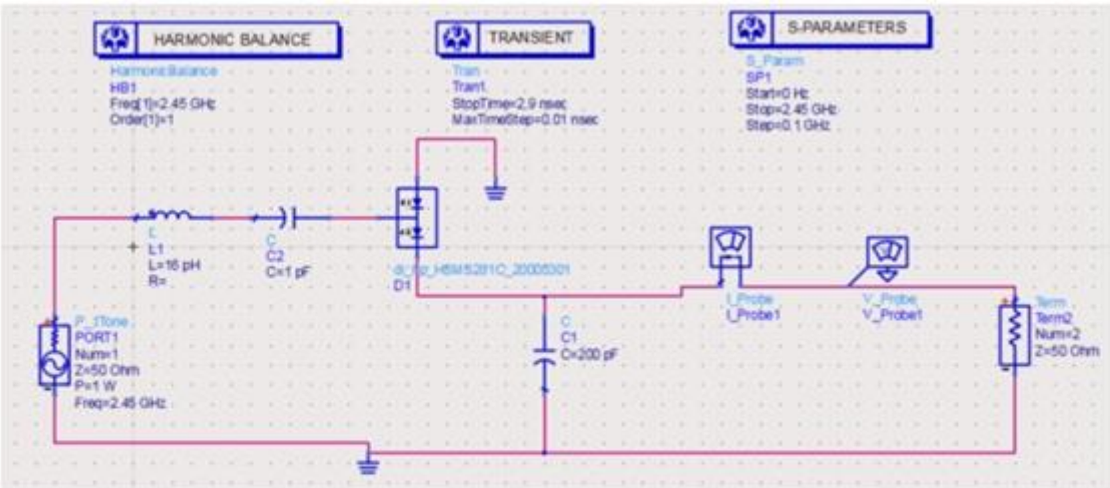

Figure.2 Modified Villard Voltage Doubler Circuit

Proposed work, a Modified Villard voltage doubler using Schottky diode HSMS- 281C. The Modified Villard voltage doubler, the arrangement of the one capacitors in Modified Villard voltage doubler rectifier is in series with diodes and another capacitor is placed in parallel with resistance. This arrangement was chosen to reduce the parasitic capacitor effect and and to increase the output voltage.

Simulation results shows that impedance matching and rectifier can provide maximum efficiency through the Modified Villard voltage doubler rectifier.To match the input impedance of rectifier which is complex, with the antenna impedance (50Ω) for a input power ranges.

Hence, a matching network is required to match the input impedance of the rectifier to the antenna impedance. It is usually designed to provide maximum RF power transferred from antenna to rectifier circuit at dynamic operating conditions, which are frequency band, input power level and load impedance. Therefore, impedance matching circuit located between the input port and rectifying branches is designed. At First, the input impedance of rectifying circuit is determined as a function of the frequency and input power. After that, each complex impedance is matched with 50 Ohm.

Transmission line with high frequency, if there forms series inductive effect then that effect is called as (+j). Transmission line with high frequency, if there forms capacitive effect in between the transmission line then that effect is called as (-j). If the load is inductive load(+j) then the antenna impedance is complex conjugate of capacitive(-j). Similarly, load is capacitive load(-j) then the antenna impedance is complex conjugate of inductive (+j). Finally, the overall matching network is optimized using ADS.

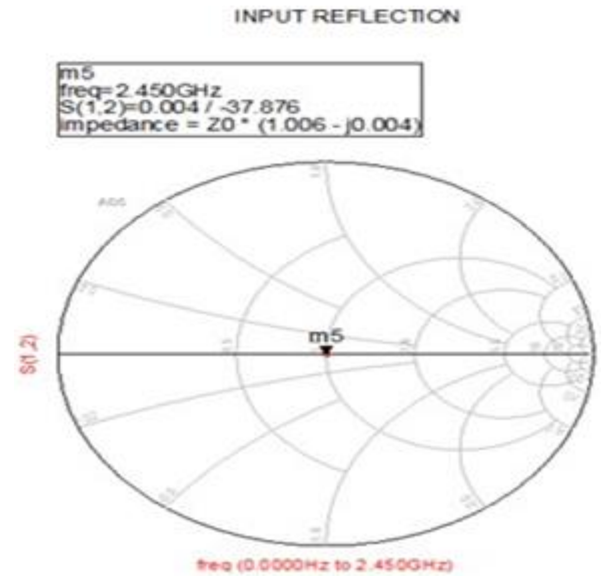

Figure.3 Input Reflection

Figure 3, shows that the input reflection is 50.3-j0.00 at 2.45GHz

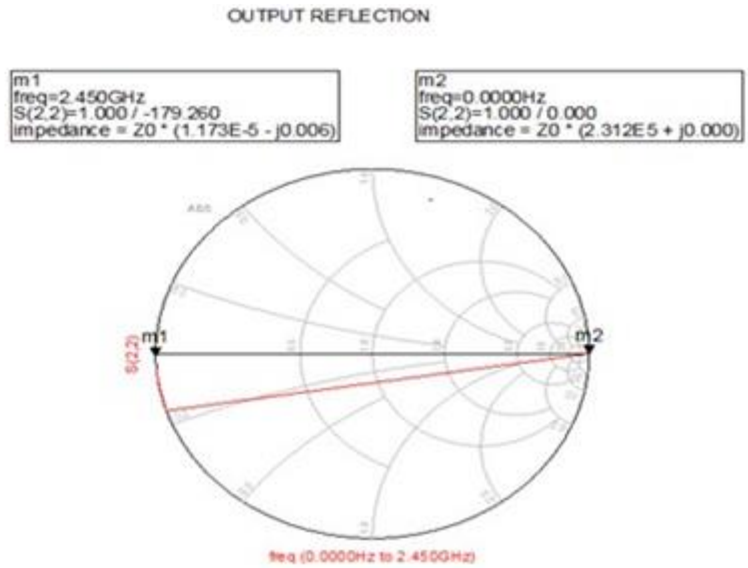

Figure 4 Output Reflection

Figure 4, shows that the output reflection is 5.86 at 2.45GHz and output refelction is about 11.56 at 0.00Hz

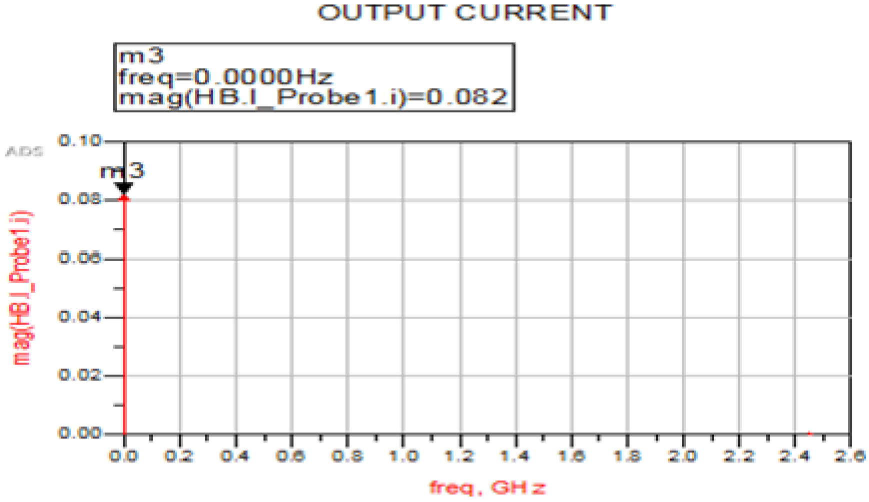

Figure.5 Output Current of the Rectenna

Figure 5, shows that After rectification the output current for the rectenna is 0.082 .

The output voltage is obtained for the simulated rectenna is 4.109 as shown in figure 6.

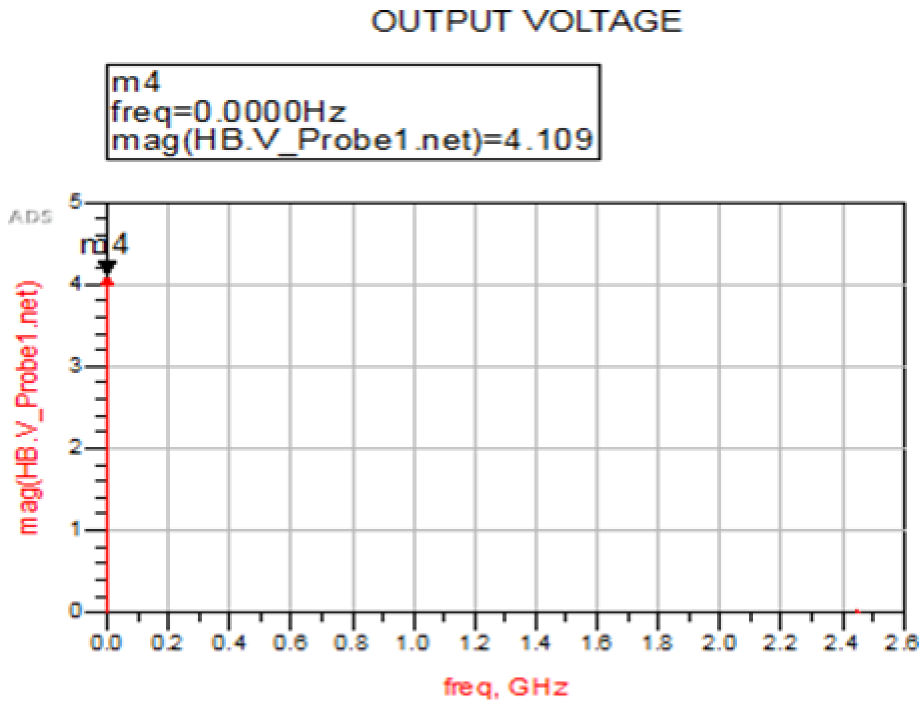

Figure.6 Output Voltage

Table .1 Comparison of the Rectenna for RF Energy Harvesting

References	**Frequency**	**Topology**	**Schottky Diode**	**Input power to rectanna**	**Peak conversi on efficiency (%)**
1. Hichem Mahfou di, et.al [9]	2.45GH z	Singlestag e Voltage doubler	HSMS 2852	-10dB	20
2. Jianwei Jing, et .al [10]	2.45GH z	Greinache r Voltage doubler	HSMS 2862	2dBm	33
3. Sandhy a Chandr avansh, et. al [21]	900MH z	Seven stage of Dickson voltagem ultiplier	HSMS 285C	10dB	37.82
Propos ed work	2.45GH z	Modified Villard voltagedo ubler	HSMS 281C	1dBw	47

Table 1 shows that the summarize relationship between the rectifier , input power and operating frequency. Proposed work, a Modified Villard voltage doubler using Schottky diode HSMS- 281C. The maximum power conversion efficiency of 47% was obtained.

From the reference [10] and proposed work indicates that the circuits used are the same but differs in capacitor value and diodes. There is difference in power and efficiency

V. CONCLUSION

A Wideband rectenna is designed and analysed. A Wideband RF harvester has been proposed for ambient WEH applications to overcome the challenge of battery recharging and replacement in wireless sensor area network. The proposed harvester with wideband characteristics to capture RF energy from 2.45GHz in all possible directions. A wideband and voltage doubler rectifiers have been proposed with high conversion efficiency at low power ambient conditions. The broadband rectifier achieved a peak conversion efficiency of 47% at an input power of 1w. The obtained DC power can be used to charge a low profile battery or to operate low power electronics. In future work,to find maximum power transfer between the antenna and rectifier the input impedance of antenna should be matched with the rectifier circuit.

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