Design and performance analysis of Rectenna Circuit

K. El Batal,1,5*, N. Chakhchaoui2,3, A. Eddiai1, M. Meddad4, M. Rguiti5, M. Mazroui1, O. Cherkaoui2

1 Laboratory of Physics of Condensed Matter (LPMC), Faculty of Sciences Ben M’Syik, Hassan II University, Casablanca, Morocco
2 REMTEX Laboratory, Higher School of Textile and Clothing Industries (ESITH), Casablanca, Morocco
3 BGIM Laboratory, Higher Normal School (ENS), Hassan II University, Casablanca, Morocco
4 LAS Laboratory of Setif, Mohamed el Bachir el Ibrahimi BBA University, Algeria
5 Univ. Valenciennes, EA 2443 - LMCPA - Laboratoire des Matériaux Céramiques et Procédés Associés, F-59313 Valenciennes, France.
* khadija.elbatal-etu@etu.univh2c.ma

Abstract: Radio Frequency Energy harvesting is an extremely important research subject, linked to sustainability, and could be a potential solution to conventional energy supplies. The main idea is to develop battery-free wireless sensors able to capture the available energy into the mentioned bandwidth. In this paper, a 1.8–2.4 GHz wideband rectenna is designed for radio frequency (RF) energy harvesting in the context of wireless sensor nodes (WSN). For this purpose, the agilent Advanced Design System (ADS) was used. This article presents the design and simulation of a high output voltage rectifier. First, we designed a rectifier based on Metelics MSS20-141 Schottky diode using a series topology to convert electromagnetic energy into DC. Then, a low-pass filter was implemented to filter out undesirable harmonics generated by the non-linear Schottky diode. Simulation results show that load resistance, input frequency and input power are important parameters to evaluate the performances of RF energy harvester. Also, the three RF bands, GSM1800, UMTS and Wi-Fi, are considered. Therefore, the designed system has an average RF-to-DC conversion of 18 % for an incident power of -10 dBm for a variation of 20 to 1200 Ω.

Keywords: RF energy harvesting, Schottky diode, Rectenna, RF–DC conversion efficiency.

1. Introduction

Wireless sensor networks (WSN) are mainly powered by batteries. However, Batteries have a short lifespan despite substantial progress. Which motivates people to develop alternative methods of powering these objects. One exciting approach is to harvest energy from the ambient environment of microsystems. Besides using thermal gradients [1], mechanical vibrations [2-6], or solar energy[7-8] as sources of energy. Recently, electromagnetic waves have attracted attention as an important source of energy. Unlike the majority of energy sources, electromagnetic or RF energy sources are permanently available. The downside of RF sources, while pervasive in our everyday lives, is that the power density they can offer is small relative to other source [9-12].

A rectifying antenna (rectenna) is a key component of the microwave power transfer system. The principal drawback of a rectenna circuit is that it is designed for a very specific operating point. Generally, the key problem when designing rectennas is optimizing the electrical power supplied to the load or the conversion efficiency RF-to-dc [13].
This paper proposes a novel reconfigurable electromagnetic harvesting device that is ensuring the best possible energy conversion efficiency over a very wide range of input power levels. The purpose of this work is to design, simulate, and characterize an innovative high voltage rectifier circuit. A series topology is used and a low-pass filter is placed at the output of the circuit to provide a stable DC output voltage. Furthermore, the rectenna was designed and simulated using Agilent's Advanced Design System (ADS). And Harmonic balance method has been employed to take into account the rectifier's non-linear characteristics.

2. Rectenna Design

The objective of the RF energy harvester, also known as Rectenna consists of converting the electromagnetic energy contained in ambient RF sources into continuous dc electrical voltage. The rectenna is generally composed of a receiving antenna and an impedance matching network followed by a rectifier, a dc filter and a load containing the corresponding impedance of the sensor to be supplied. The developed circuit is in series topology, the series design of the rectifier was established for simple adaptation purposes. Firstly, the proposed rectenna is adapted to three RF bands, GSM1800, UMTS and Wi-Fi. Matching circuit is important to ensure maximum power transfer from the antenna to the rectifier circuit. It is then followed by a Schottky diode positioned in series and a low-pass filter. The diode chosen for our circuit is Metelics MSS20-141 diode. Moreover, The output dc filter consists of a 3.3 nH inductance and a 68 pF capacitor [9]. With an incident power of -10dBm, these values were calculated by simulation to achieve a higher output voltage. Moreover, the impedance of the antenna is set at 50 and the load is a resistance of 430Ω. We have simulated the behaviour of the rectenna circuit under Harmonic balance. The design is displayed in figure 1.

![Figure 1. Schematics of the proposed Rectenna circuit simulated under ADS.](image)

3. Simulated Results of Rectenna

The schematic of the rectenna simulated under ADS with the Harmonic Balance mode. Subsequently, we handle the variation of the output voltage depending on the incident power and sweep the input power from -10dBm to 30dBm using "Power Sweep Simulation" for f = 1.5GHz. The curve shows the increase of the output voltage as a function of power up to the maximum value of 2.9V. Thus, important value is obtained with only one rectification diode, It is clear from the plots that the rectifier’s performance has improved significantly.
The conversion efficiency as a function of the load value $R_L$ for an input power of 20 dBm is shown in Figure 3. The adaptation network was designed in such a way as to transfer the maximum power to the load. And the load of the energy harvester represents the equivalent impedance of the sensor to be supplied. For the three frequencies, GSM, UMTS and Wi-Fi bands, we notice an increase in the maximum voltage approximately equal to 3V at $R=1200 \ \Omega$ for $F=2.4 \ \text{GHz}$.

To achieve an optimal energy harvesting system, the rectenna should have a high RF-DC conversion efficiency, which is defined as:

$$
\text{Efficiency} = \frac{P_{\text{DC}}}{P_{\text{RF}}} \times 100\% = \frac{1}{R_L} \times 100\% 
$$

Where the $P_{\text{DC}}$ is the output DC power harvested, $P_{\text{RF}}$ the input RF power and $R_L$ is the load to supply. The efficiency of the rectenna varies with change in the input frequencies as depicts in Figure 4. The effects of the $R_L$ on the RF-to-DC conversion efficiency are evaluated for three frequencies, 1.8, 2.1 and 2.1 GHz, at 20dBm input power level. It can be seen that when the load resistance varies within the 20 to 170 $\Omega$ ranges, the rectifier has the highest efficiency at the three frequency bands.
4. Conclusion

A high-voltage rectifier was presented to address the needs of applications involving wireless power transmission. The rectenna is one of the key components of RF energy harvesting system. In this paper, rectenna designed for GSM, UMTS and Wi-Fi bands has been presented and discussed. We have used Metelics MSS20-141 diode as a series-connected rectifier device. At the circuit output, low-pass filters were used to increase rectifier efficiency by effectively removing undesired RF components. Simulations were performed using Advanced Design System and the results obtained indicate that the proposed harvesting device is capable of recovering the available RF energy by using opportunities sources and providing wireless sensor nodes.

References

[1] Gusarov, B., Gusarova, E., Viala, B., Gimeno, L., Boisseau, S., Cugat, O., Louison, B. (2016). Thermal energy harvesting by piezoelectric PVDF polymer coupled with shape memory alloy. Sensor. Actuat: A-Phys. 243, 175-181
[2] Meddad M, Eddiai A, Farhan R, Benahadouga S, Mazroui M, Rguiti M, Superl and Microst 2019 127 86-92
[3] Chakhchaoui N, Ennamiri H, Hajjaji A, Eddiai A, Meddad M, and Boughaleb Y 2017 Theoretical modeling of piezoelectric energy harvesting in the system using technical textile as a support Polymers for Advanced Technologies 28(9) 1170-1178
[4] Farhan R, Eddiai A., Meddad M, Mazroui M, and Guyomar D 2019 Electromechanical losses evaluation by energy-efficient method using the electrostrictive composites: experiments and modeling Smart Materials and Structures 28(3) 035024
[5] Eddiai A, Meddad M, Farhan R, Mazroui M, Rguiti M, Guyomar D Superl and Microst 2019 127 20-26
[6] Chakhchaoui N, Jaouani H, Ennamiri H, Eddiai A, Hajjaji A, Meddad M, and Boughaleb Y 2019 Modeling and analysis of the effect of substrate on the flexible piezoelectric films for kinetic energy harvesting from textiles Journal of Composite Materials 53(24) 3349-3361.
[7] Lekbir, A., Meddad, M., Benhadouga, S., Khenfer, R. (2019). Higher-efficiency for combined photovoltaic-thermoelectric solar power generation. Int. J. Green. Energy. 16(5), 371-377
[8] López-Lapeña, O., Penella, M. T., Gasulla, M.: A new MPPT method for low-power solar energy harvesting. IEEE. T. Ind. Electron. 57(9), 3129-3138 (2009)
[9] Kuhn, V. (2015). Capture opportuniste d’énergie micro-onde pour l’autonomie des objets communicants (Doctoral dissertation).
[10] Pavone, D., Buonanno, A., D’Urso, M., & Della Corte, F. (2012). Design considerations for radio frequency energy harvesting devices. Progress In Electromagnetics Research, 45, 19-35.
[11] Kuhn, V., Seguin, F., Lahuec, C., & Person, C. (2015, September). Matching network improvement for RF energy harvesters in Body Sensor Area Network context. In 2015 European Microwave Conference (EuMC) (pp. 303-306). IEEE.
[12] Kuhn, V., Seguin, F., Lahuec, C., & Person, C. (2016). Enhancing RF-to-DC conversion efficiency of wideband RF energy harvesters using multi-tone optimization technique. International Journal of Microwave and Wireless Technologies, 8(2), 143.
[13] Okba, A. (2017). Conception et réalisation de rectennas utilisées pour la récupération d’énergie électromagnétique pour l’alimentation de réseaux de capteurs sans fils (Doctoral dissertation, Université Paul Sabatier-Toulouse III).