

Energy Harvesting with 2.45 GHz Rectenna for urban application

Achraf Waguaf, Romain Alvernhe, Ludivine Fadel, Marjorie Grzeskowiak

▶ **To cite this version:**

Achraf Waguaf, Romain Alvernhe, Ludivine Fadel, Marjorie Grzeskowiak. Energy Harvesting with 2.45 GHz Rectenna for urban application. 2018 25th IEEE International Conference on Electronics, Circuits and Systems (ICECS), Dec 2018, Bordeaux, France. pp.345-348, 10.1109/ICECS.2018.8618025 . hal-02163185

HAL Id: hal-02163185
https://hal.science/hal-02163185

Submitted on 24 Jun 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive Toulouse Archive Ouverte (OATAO)

OATAO is an open access repository that collects the work of some Toulouse researchers and makes it freely available over the web where possible.

This is an author's version published in: https://oatao.univ-toulouse.fr/23836

Official URL: https://doi.org/10.1109/ICECS.2018.8618025

To cite this version :

Waguaf, Achraf and Alvernhe, Romain and Fadel, Ludivine and Grzeskowiak, Marjorie Energy Harvesting with 2.45 GHz Rectenna for urban application. (2019) In: 2018 25th IEEE International Conference on Electronics, Circuits and Systems (ICECS), 9 December 2018 - 12 December 2018 (Bordeaux, France)

Any correspondence concerning this service should be sent to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Energy Harvesting with 2.45 GHz Rectenna for urban application

Achraf $Waguaf$[1], Romain Alvernhe[1],
Ludivine Fadel[2]
[1] *ENSEIRB-MATMECA*
[2] *Universit de Bordeaux, Laboratoire IMS,*
UMR-5218, 33405 Talence, France

[3]Marjorie Grzeskowiak[3]
Universite de Paris-Est Marne-la-Valle ESYCOM (EA 2552)
UPEMLV, ESIEE-Paris, CNAM F-77454
Marne-la-Vallee, France

***Abstract*—This paper describes the conception of a 2.45 GHz rectenna for energy harvesting application. Electromagnetic simulations have been carried out using Computer Simulation Technology software. The enhancement of the simulated output DC voltage is obtained with resonant circuit and Cockroft Walton boost (containing four zero bias diodes) for a sinusoidal input voltage. The simulated proposed rectenna with single zero-bias diode and RF-DC boosting circuit have been realized and measured inside an anechoic chamber. The behavior of measured plots is in accordance with the simulated ones. The simulated RF-DC boosting rectenna enhanced the output DC voltage up to 140 mV for 1 μW/cm^2 power density.**

***Index Terms*—WI-FI; RF energy harvesting; Rectenna; Wireless Sensor Networks.**

I. Introduction

In recent years, Wireless Sensor Networks (WSNs) push harvester development to provide almost infinite lifetime to sensor from environmental energy. Further- more, the use of wireless electronic devices has become relevant in many fields (military, medical) and especially in unsafe places where common power supply remains restrictive. Among different renewable ambient power sources such as solar, vibration, or electromagnetic waves, radio frequency (RF) energy presents ubiquitous availability with low power density (around 1 μW/cm^2 at 2.45 GHz indoors) in comparison with the energy sources (up to 15 mW/cm^2 outdoors and 10100 μW/cm^2 indoors for solar energy) [1], [2].

This work addresses the issue of energy harvesting with the development of COTS based RF harvesters for urban areas with the ultimate goal of using the large transparent surfaces of the urban environment as a support for implementation. The RF energy harvester, commonly named rectenna, is dedicated to transform electromagnetic waves into an electrical signal by combining an antenna and an RF-DC conversion circuit, [3]. The rectifier is usually realized with Schottky diodes because of their low threshold voltage in RF harvesting applications.

While a RF-DC rectifier provides 0.3 V with 20 dBm [4], the voltage requirement for transistor switching operation is at least 0.5 V. To overcome low rectified voltage, DC-DC converter or RF-DC boost have been studied [5-11]. Finally, to improve the input voltage of the rectifier, and so increase the efficiency of the RF-DC conversion, a resonator is added between the antenna and the rectifier [7].

This paper focuses on the design and implementation of a rectenna in the unlicensed ISM Bands at 2.45 GHz on FR4 printed circuit boards (PCB) with off-the-shelf components. Each part of the schematic bloc is studied; in section 2, with electromagnetic software for the antenna de- sign and with electrical software for boost structure in harmonic balance to take into account the non- linearity of the diodes. In section 3, co-simulation of the antenna, matching network, resonant circuit and Cockroft Walton circuit have been carried out under CST (Computer Simulation Technology) and compared with measurement in anechoic room.

II. Rectenna building blocks

The basic architecture of an RF energy harvester is presented in Fig. 1. It is composed of antenna to receive the electric field, L-matching circuit to optimize impedance matching between the antenna and the boosting circuit, a resonant circuit to improve the RF signal and a RF-DC boost to convert the RF signal in DC output voltage. The power density of the electromagnetic source varies from 1 to 30 W/cm^2 corresponding to ambient (E $\approx$1.94 V/m) and transferred energy (E $\approx$10.63 V/m).

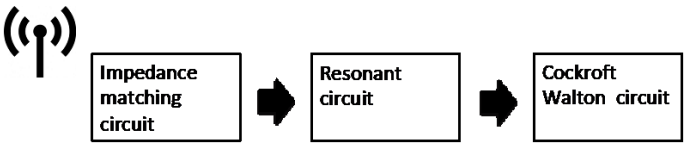


Fig. 1: Block diagram of rectenna

The different blocks have been designed and realised on 1.6 mm thickness FR4 substrate to obtain a cheap prototype by microetching.

A. Antenna

The first bloc of the rectenna is a strip-loop antenna designed on a 1.6mm thickness FR4 substrate [3] whose electrical characteristics are (ϵ_r = 4.4 and tan δ = 0.025). The design of the antenna is illustrated in Fig.2. A capacitor of 100 pF is placed in the gap on the side W_1.

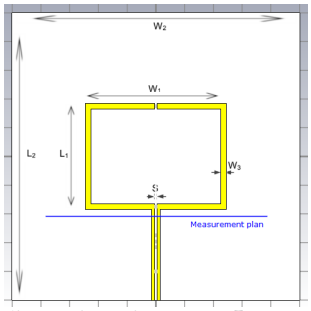


Fig. 2: Antenna dimensions in mm : L_1 = 37, L_2 = 100, W_1 = 49, W_2 = 100, W_3 = 2, S = 1

The antenna impedance has been simulated in the measurement plan mentioned in Fig.2 and reported in Fig.3 with the value of Zin = 343 Ω at 2.72 GHz.

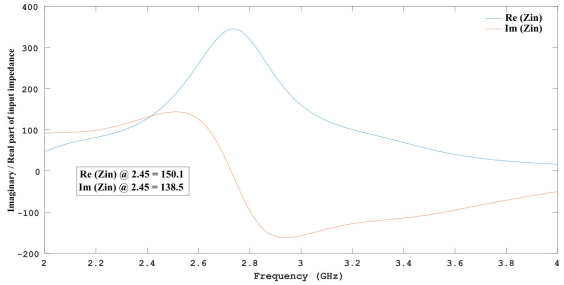


Fig. 3: Simulated antenna impedance

B. Matching circuit

An L-matching circuit was designed to achieve impedance matching with the Cockroft Walton impedance at the working frequency. These values have been fixed at L = 14.56 nH and C = 0.6 pF, (Fig.4).

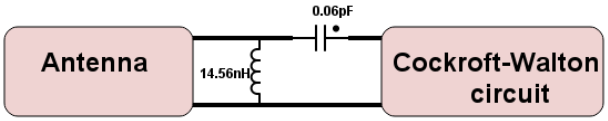


Fig. 4: L-matching circuit

C. Cockroft-Walton Voltage multiplier circuit

In order to increase DC output voltage a resonant circuit followed by a Cockroft Walton circuit, have been added at the end of the antenna to enhance the RF voltage amplitude by the resonant circuit L = 1.5 nH, Cc = 5.6 pF and C1 = 15 pF. The Cockroft Walton circuit is composed of four Schottky diodes from Avago (SMS 7630) and four capacitors (C2 = 100 pF). A 10 MΩ load resistance is connected in the output to measure DC output voltage.

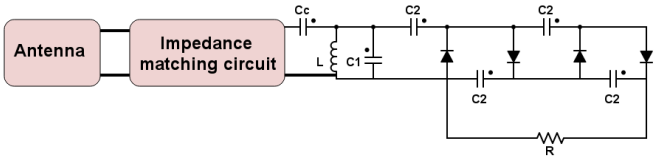


Fig. 5: Cockroft Walton voltage multiplier circuit

Fig.6 and Fig.7 report respectively the simulated reflexion and transmission parameters of the resonant circuit versus frequency with the Cockroft-Walton circuit. A well matching and transmission up to - 0.3 dB at the working frequency are obtained. The -16 dBm input power corresponds to 60mV input voltage (V_{in}).

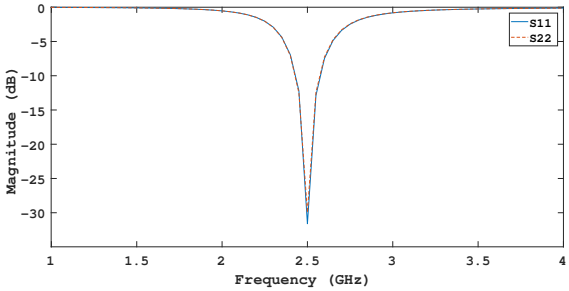


Fig. 6: Simulated S11 parameter of resonant circuit

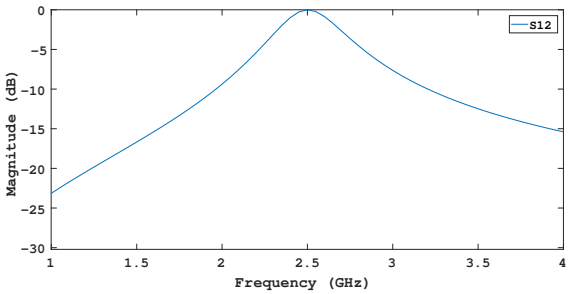


Fig. 7: Simulated S12 parameter of resonant circuit

Fig.8 presents the output voltage (V_1) after the first stage of the Cockroft Walton circuit and the output (V_{DC}) after the second stage. DC output voltage is two times greater than the input voltage.

The first stage acts as a DC offset voltage for the second stage: the voltage (V_{DC}) is approximately twice the voltage (V_1).

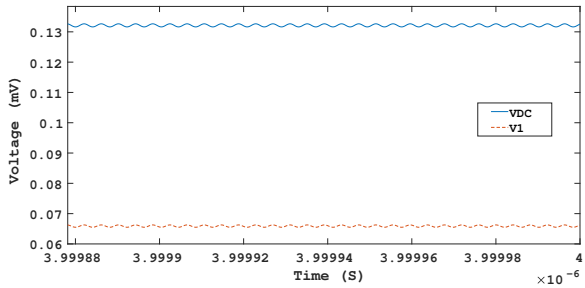


Fig. 8: Transient simulation ADS

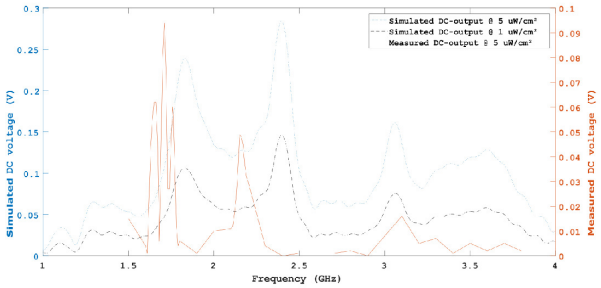


Fig. 10: Simulated and measured DC-output voltage

III. RF-DC BOOSTING RECTENNA

The proposed rectenna have been realized by mi- croetching and measured inside an anechoic chamber. The measurement setup contains a 9 dB transmitting antenna, RF generator (Agilent 864D) and a gain power amplifier (Amplifier research 15S1G3), Fig.9. The final dimensions of the rectenna are $7{\times}7.6\ cm^2$.

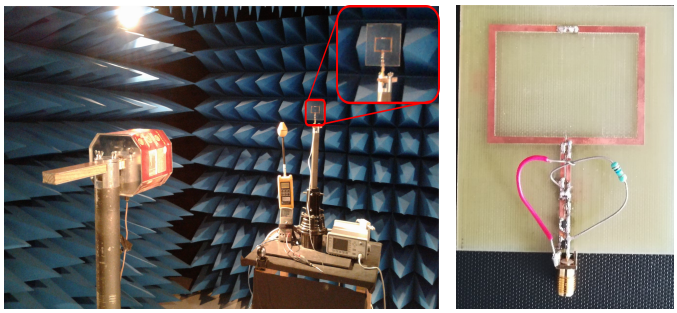


Fig. 9: Rectenna measurement setup

The distance between the emitting and receiving antennas is 2 m to be in far field conditions. A voltage meter (Voltcraft VC150) is connected in parallel with the output load to measure DC output voltage. A RF probe (RF Survey Meter, EMR-300 Broadband) is placed next to the receiving antenna to measure the power density. In simulation a wave plane linearly polarized is applied on the rectenna (antenna + circuit). DC output voltage is obtained on the resistive load. On Fig.10, DC output voltage is reported versus frequency from 1 to 4 GHz.

The behavior of the measured and simulated plots presents three voltage peaks. The discrepancies between simulation and measurement are twofold. First, the measured working frequency is lower than the simulated ones. Secondly, the level of DC voltage is weaker experimentally.

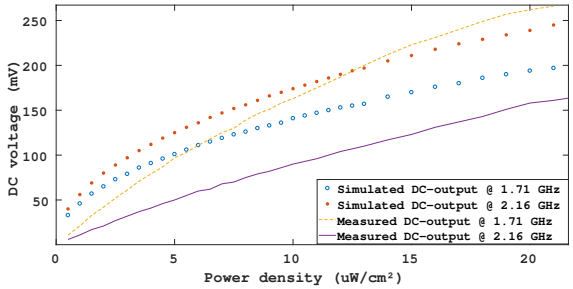


Fig. 11: Simulated and measured DC-output voltage

DC output voltage is shown when the power density varies from 0.5 μW/cm^2 to 21 μW/cm^2. While the measured DC output voltage is lower for some power density values in comparison with the simulation, the evolution versus power density is such as expected. Each bloc of the rectenna is measured experimentally and confirms the matching between the antenna with LC matching circuit and the Cockroft Walton associated to the resonant circuit. A frequency shift is observed for the antenna resonance while the reflection parameter is less than 15 dB from 1 to 4 GHz for the RF-DC boosting circuit: the antenna with LC matching circuit is matched at 1.81 GHz (S11 = -15 dB). The discrepancy between measured and simulated results is attributed to the weak measured power efficiency of the RF-DC boosting circuit. The RF-DC boosting circuit has to be realized again and the system shifted to the Wifi working frequency, 2.45 GHz.

IV. CONCLUSION

A compact RF-DC boosting rectenna has been developed with components (capacitors, inductors and diodes) inside the receiving part of the structure. Co-simulation and measurement have been compared: DC output level is observed versus frequency and power density, while RF-DC boost has been highlighted in transient simulation. The rectenna prototype has

to be improved experimentally, especially the power efficiency of the RF-DC boosting circuit: to discuss the RF-DC boosting circuit, the power conversion efficiency η (%) and DC voltage - RF power transfer function (mV/mW) could be reported for variable input power. In the following study, the FR4 dielectric could be replaced by Plexiglas substrate, not only to reduce the dielectric losses, but also to realize prototypes on transparent substrates, such as building glasses with invisible conductors. Others stages of voltage doublers can be added to obtain the required DC voltage, or array of rectennas to improve the RF power.

ACKNOWLEDGMENT

The circuits have been designed thanks to Computer Simulation Technology software (CST) that is available in Electrical Engineering School - ENSEIRB-MATMECA.

The authors would like to thanks CST for their soft- ware licence, Jean-Marc Micouleau, David Bedenes and Jerome Le Gall, ENSEIRB-MATMECA INP Bordeaux, France for the circuits realization and their technical assistance, especially with anechoic chamber

REFERENCES

[1] S. Kim, K. Niotaki, A. Georgiadis Ambient RF Energy-Harvesting Technologies for Self-Sustainable Standalone, IEEE Proceedings of the IEEE, Vol. 102, No. 11, November 2014, pp. 1649-1666.

[2] ANFR, Etude de lexposition du public aux ondes radiolectriques, 2014.

[3] H. Takhedmit, L. Cirio, F. Costa and O. Picon, Transparent Rectenna and Rectenna Array for RF, IEEE EuCAP 2014, pp. 2970-2972.

[4] K. Gudan, S. Shao, J. J. Hull, J. Ensworth, and M. S. Reynolds, Ultralow power 2.4GHz RF energy harvesting and storage system with - 25dBm sensitivity, in 2015 IEEE Int.Conf. on RFID, San Diego, CA, USA, Apr 2015

[5] A. K. Ermeey, Aiguo Patrick Hu, Morteza Biglari-Abhari, and Kean C. Aw, Indoor 2.45 GHz Wi-Fi Energy Harvester with Bridgeless Converter, IEEE Journal on selected areas in communications, Vol.34, No.5, May 2016, pp. 1536-1549.

[6] S-E. Adami, P. Proynov, G. S. Hilton, G. Yang, C. Zhang, D. Zhu, Y. Li, S. P. Beeby, I. J. Craddock, B. H. Stark, A Flexible 2.45-GHz Power Harvesting Wristband With Net System Output From 24.3 dBm of RF Power, IEEE Trans. On Microwave Theory and Techniques, Vol.44, No.1, January 2018, pp. 380-395.

[7] H. Kanaya, S. Tsukamoto, T. Hirabaru, D. Kanemoto, Energy Harvesting Circuit on a One-Sided Directional Flexible Antenna, IEEE Microwave and Wireless Components Letters, Vol. 23, No. 3, March 2013, pp. 164-1665.

[8] D. Masotti, A. Costanzo, M. Del Prete, V. Rizzoli, Genetic-based design of a tetra-band high-efficiency radio-frequency energy harvesting system, IET Microwaves, Antennas Propagation, vol.7, no. 15, June 2013, pp. 12541263.

[9] G. Vera, A. Georgiadis, A. Collado, and S. Via, Design of a 2.45GHz rectenna for electromagnetic (EM) energy scavenging, in Proc. IEEE Radio and Wireless Symp., 2010, pp. 6164.

[10] U. Olgun, C. Chen, and J. Volakis, Investigation of rectenna array configurations for enhanced RF power harvesting, IEEE Antennas Wireless Propagation. Letter, vol. 10, Apr. 2011, pp. 262265.

[11] R. Bergs, L. Fadel, L. Oyhenart, V. Vigneras, T. Taris, A dual Band 915MHz/2.44GHz RF Energy Harvester, IEEE EuMC 2015, pp. 307-310.