Alimentation par énergie RF d'une Wake-Up Radio ultra faible consommation

Jesus Argote-Aguilar, Florin Hutu, Guillaume Villemaud, Matthieu Gautier, Olivier Berder

Alimentation par énergie RF d'une Wake-Up Radio ultra faible consommation

Jesus Argote-Aguilar*†, Florin-Doru Hutu*, Guillaume Villemaud*, Matthieu Gautier† and Olivier Berder†
* University Lyon, INSA Lyon, INRIA, *prenom.nom@insa-lyon.fr*
† Univ Rennes, CNRS, IRISA, *prenom.nom@irisa.fr*

***Abstract*—Nowadays, the efficiency of the Radio-Frequency (RF) energy harvesting circuits is continuously increasing and, at the same time, the energy consumption of connected devices is drastically decreasing. Despite that, collecting, storing and delivering such kind of harvested energy to the device in an appropriate manner is still a challenge. This paper focuses on a strategy of harvesting energy in an efficient way from both low and high levels of the RF field. The objective is to power an ultra-low power consumption wake-up radio requiring a regulated voltage. The starting point is the characterization of a commercial power management integrated circuit which operates with ultra-low power levels. Then, some design guidelines of the RF power rectifiers, specifically designed for our envisaged application are given.**

***Index Terms*—rectifier, RF/DC, wireless power transfer, power management integrated circuit, ultra-low power wake-up radio.**

I. Introduction

In a context of an increasing deployment of the Internet of Things (IoT), replacing the battery of billions of connected devices is an expensive and exhausting task. Powering low power connected devices with energy available in the environment avoids the use of a battery or increases its lifetime. For example, [1] allows a Wireless Sensor Node (WSN) to efficiently use the energy harvested from ambient sources (e.g. solar, wind, vibration). Moreover, the WSN power consumption is reduced by using ultra-low power Wake-up radios (WURx), avoiding the unnecessary activation of the main transceiver. The present paper has the main goal to power a WURx consuming hundreds of nW and requiring a Direct Current (DC) regulated input voltage by RF energy harvested from different power levels of the RF field. An architecture combining two RF rectifiers, each one optimized for a specific power level, with a Power Management Integrated Circuit (PMIC) is considered. The RF/DC conversion is performed by the former and the supply of a regulated voltage is assured by the latter. The paper is organized as follows: Section II introduces the proposed architecture, Section III presents the features of a PMIC and presents measurement results of the commercial PMIC BQ25570 from Texas Instruments and Section IV describes the rectifier design considerations for our application.

II. Proposed architecture

Aiming to harvest RF power from Wireless Power Transfer (WPT) and from Self Energy Recycling (S-ER) during the transmission state of the main transceiver [2], knowing that each of the mentioned sources of RF energy have different power levels (lower than -20 dBm for WPT and around -10 dBm for S-ER) the design of a rectifier for each power level is considered. The received power levels may considerably vary (depending on the propagation channel). Since the output voltage of a rectifier depends on its input power, the use of a voltage regulator is mandatory and the use of a PMIC appears as an appropriate solution. A PMIC provides an output regulated voltage independently of its input power and power consumed by its load. The schematic of the proposed architecture is depicted in Fig. 1. The proposed architecture consists in the association of two rectifiers, each one optimized for a specific input power level, in series with a PMIC. The latter, allows to appropriately load a rectifier as explained in Section III. Moreover, as explained in [3], in this architecture, the PMIC efficiently loads the rectifier with the highest output voltage at a given moment.

III. Power Management Integrated Circuit Measurements

In the context of the envisaged application, three functionalities offered by a PMIC are identified. The Maximum Power Point Tracking (MPPT) which enables a PMIC to efficiently load a rectifier for maximizing its RF/DC conversion efficiency, the management of the collected energy (among the WURx and a storage element) and the functionality that ensures to supply a regulated output voltage to the load. These functions are enabled when the PMIC is in its Normal Mode (NM) state after exiting its Cold Start (CS) state which harvests energy in a less efficient way, although necessary to collect the minimal energy required by the former state. In this paper the measured features of the BQ25570 in NM are presented.

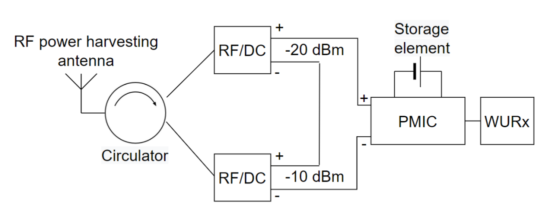

Fig. 1. Proposed architecture for energy harvesting from WPT (-20 dBm) and for harvesting during the transmission of the main transceiver (-10 dBm).

In [4], the authors claim that a rectifier may be modeled by a voltage source in series with its internal resistor R_{int} and conclude that a maximum transfer of power occurs when the rectifier load has the same value as R_{int}. Aiming to study the influence of R_{int} in the minimal voltage $V_{pmic\text{-}in}$ and power $P_{pmic\text{-}in}$ required by a PMIC in NM while powering a load $P_{pmic\text{-}load}$ emulating the consumption of an ultra-low power WURx, the BQ25570 is connected to a voltage source in series with two different values of resistors. These elements are modeling the RF rectifier. To load the rectifier model with the same value of R_{int}, MPPT is set to 50 % implying the output voltage of the rectifier model is fixed at half its open circuit voltage. Furthermore, a ceramic capacitor C_{store} of 100 μF is used as storage element and its voltage V_{store} is set to 2.5 V (to limit leakage currents). The output voltage of the PMIC is set to a regulated voltage of 1.8 V. Results are summarized in Table III. Using (1) the equivalent load $R_{rect\text{-}load}$ at which the PMIC loads the rectifier model is calculated as

$$R_{rect-load} = \frac{V_{pmic-in}^2}{P_{pmic-in}}. \quad (1)$$

$R_{rect\text{-}load}$ of 2.4 kΩ and 52.6 kΩ are obtained for a R_{int} of 2.2 kΩ and 47 kΩ respectively. Furthermore, it is observed that higher R_{int} require higher voltages, however decreasing the power absorbed by the PMIC. Actually, a minimal $P_{pmic\text{-}in}$ of 4.12 μW and 2.7 μW and a minimal $V_{pmic\text{-}in}$ of 99.1 mV and 376.8 mV were obtained for a R_{int} of 2.2 kΩ and 47 kΩ respectively. These results give design considerations for the RF rectifier at input power levels of -20 dBm, since at low powers rectifier efficiencies are reduced and thus obtaining high voltages is difficult.

R_{int} (kΩ)	$V_{pmic\text{-}in}$ (mV)	$P_{pmic\text{-}in}$ (μW)	$P_{pmic\text{-}load}$ (nW)
2.2	99.1	4.12	324
47.0	376.8	2.7	324

TABLE I
IMPACT OF THE RECTIFIER IMPEDANCE ON THE MINIMAL INPUT POWER AND VOLTAGE OF THE BQ25570

IV. Low Power Rectennas

In [5], the authors show that Schottky SMS7630 diodes are well suited for low power rectifiers. Using this technology, voltage doubler, series and shunt topologies are compared in simulation at 868 MHz using Keysight ADS software. Design considerations are mainly given at -20 dBm, since a rectifier design is more critical at low powers. The strategy adopted is to design a rectifier having a high R_{int} in order to limit $P_{pmic\text{-}in}$ and able to supply the minimum $V_{pmic\text{-}in}$ and $P_{pmic\text{-}in}$ required. Consequently, the three aforementioned topologies were optimized to have a maximum efficiency at 47 kΩ. The matching circuit employed for all the cases is a L-C topology where the reflection coefficient S_{11} was optimized to values inferior to -25 dB for a power of -20 dBm, a central frequency of 868 MHz and a bandwith of 6 MHz. Fig. 2 shows the voltages and efficiencies of the rectifiers in function of their input powers $P_{rect\text{-}in}$ when loaded with their optimal loads. At -20 dBm, single diode topologies (Series and Shunt) slightly outperform the Voltage Doubler, having an output voltage of 492.6 mV and an efficiency of 49.5 % which implies an output power of 4.9 μW and a R_{int} of 49 kΩ. With regards to the rectifier optimized at -10 dBm, since the minimal $V_{pmic\text{-}in}$ and $P_{pmic\text{-}in}$ are not a constraint, the optimization was performed favoring efficiency. At -10 dBm, it was found the shunt rectifier has higher performance with an efficiency of 77.5 % and an output voltage of 859.4 mV.

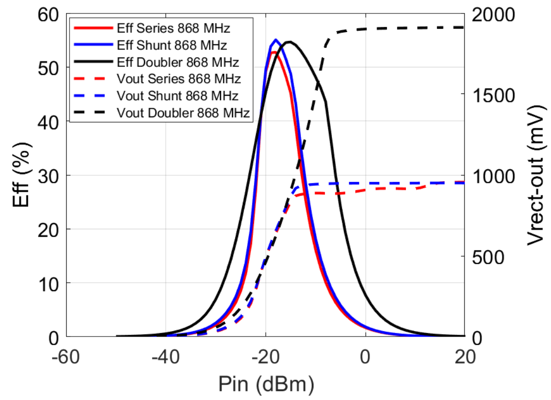

Fig. 2. Rectifier Efficiencies and output voltages when loaded with their optimal loads.

Conclusions

The use of a PMIC is an appropriate solution to power ultra-low power consumption devices requiring regulated voltage supply. Although, in our application, the quiescent power of a PMIC is one order of magnitude higher than the targeted load power consumption, current voltage regulators have even or higher quiescent power consumption when operating at low powers. Moreover, a PMIC allows to maximise the RF/DC power conversion efficiency of a rectifier. After characterizing the PMIC features for the architecture proposed in this paper, it was determined that at low powers, the design considerations are mainly oriented by the rectifier impedance to limit the quiescent power of a PMIC, and at relatively higher powers, efficiency needs to be fostered.

References

[1] F. Ait Aoudia, M. Gautier, M. Magno, O. Berder, and L. Benini, “Leveraging energy harvesting and wake-up receivers for long-term wireless sensor networks,” *Sensors*, vol. 18, no. 5, p. 1578, 2018.

[2] Ö. T. Demir and T. E. Tuncer, “Optimum qos-aware beamformer design for full-duplex relay with self-energy recycling,” *IEEE Wireless Communications Letters*, vol. 7, no. 1, pp. 122–125, 2017.

[3] M. Piñuela, P. D. Mitcheson, and S. Lucyszyn, “Ambient rf energy harvesting in urban and semi-urban environments,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 61, no. 7, pp. 2715–2726, 2013.

[4] S.-E. Adami, V. Marian, N. Degrenne, C. Vollaire, B. Allard, and F. Costa, “Self-powered ultra-low power dc-dc converter for rf energy harvesting,” in *2012 IEEE Faible Tension Faible Consommation*, 2012, pp. 1–4.

[5] A. Fumtchum, P. Tsafack, F. D. Hutu, G. Villemaud, and E. Tanyi, “A survey of rf energy harvesting circuits,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 10, no. 7, pp. 99–106, 2021.