Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 120 (2015) 655 – 658

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2015

Power efficiency maximization of an RF energy harvester by fine-tuning an L-matching network and the load

Josep Jordana, Ferran Reverter, Manel Gasulla*

e-CAT Group, Universitat Politècnica de Catalunya, C/ Esteve Terradas 7, 08860 Castelldefels (Barcelona), Spain

Abstract

L-matching networks have been proposed for boosting the power efficiency of radiofrequency (RF) energy harvesters. This paper shows that power efficiency is maximized by fine-tuning the components of the L-matching network and the load. Simulations at 868 MHz with commercial components and a Rogers substrate resulted in maximum power efficiencies of 10.9 %, 30.7 %, and 55.2 % for input powers of -30 dBm, -20 dBm, and -10 dBm, respectively. Experimental results showed efficiencies of 31.8 % and 52.0 % at -20 dBm and -10 dBm, respectively, close to the simulation results, but at a frequency of 814 MHz.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: L-matching network; RF energy harvesting; autonomous sensors.

1. Introduction

Passive UHF RFID tags are remotely powered from nearby RFID readers [1,2]. The reader sends radiofrequency (RF) waves that the tag uses to power its internal circuitry and send back a code. Further, some tags also incorporate sensors. On the other hand, powering sensors from RF waves has been widely proposed in the literature [3-5].

RF energy can be harvested either from dedicated sources, such as in the case of RFID systems, or from the RF energy already present in the ambient and coming from unintentional sources such as TV, FM radio, cellular, or WiFi emitters. Fig. 1(a) shows the block diagram of a conventional RF energy harvester, consisting of an antenna, an impedance matching network, and a rectifier. The rectifier provides a suitable DC voltage that powers the load, e.g. an autonomous sensor, and the matching network matches the antenna to the rectifier. As the available power at the

* Corresponding author. Tel.: +34-934137092; fax: +34-934137007.
E-mail address: manel.gasulla@upc.edu

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.698

antenna decreases so does the generated voltage. Whenever this voltage is not high enough to properly bias the diodes of the rectifier, power efficiency severely decreases. Several techniques have been proposed to increase the efficiency at low power levels, among them that based on L-matching networks, which passively boost the voltage coming from the antenna [2,3]. However, in order to achieve a high efficiency, an accurate selection of the matching network and the load is required. This process is usually underestimated in the literature. Here, we propose a threefold tuning process (of the load and the two components of the L-matching network) to maximize power efficiency. Tuning a fixed-value load can be automatically achieved by using maximum power point tracking (MPPT) techniques at the output of the rectifier [5]. In this work, the implementation of MPPT techniques will not be addressed and the load will be manually tuned.

2. RF harvester

Fig. 1(b) shows the circuit schematic of the proposed RF energy harvester. The signal at the antenna is modelled by an AC voltage source v_a and a radiation resistance R_a. A high-pass L-matching network composed of C_m and L_m is following. Next, a half-wave rectifier formed by a Schottky diode and a filter capacitor C_L is found. Finally, R_L models the load to be powered. In addition, v_{in} is the rectifier input voltage whereas Z_m and Z_{in} are defined as the equivalent impedances at the input of the matching network and rectifier, respectively.

The peak voltage of v_a is related to the available power at the antenna (P_{av}) by [4]

$$\hat{v}_a = 2\sqrt{2R_a P_{av}} \tag{1}$$

and the power efficiency is defined as

$$\eta = P_L / P_{av} \tag{2}$$

where P_L is the power transferred to R_L. From (1), at low values of P_{av}, the generated voltage will be small and insufficient to surpass the forward voltage of the diode and thus achieve a high efficiency. So, here we use an L-matching network for boosting v_{in} while matching Z_m to R_a in order to maximize the transferred power. The theoretical gain of the L-matching network is given by [6]

$$G = \frac{\hat{v}_{in}}{\hat{v}_a} = \frac{1}{2}\sqrt{\frac{R_{in}}{R_a}} \tag{3}$$

where $\hat{v}_{in}$ is the peak voltage of v_{in} and R_{in} is the real part of Z_{in}, which directly depends on R_L. In turn, the values of C_m and L_m depend on R_{in} [6]. Higher values of R_{in} and thus of $\hat{v}_{in}$ and G should lead to higher efficiencies. Further, a a higher G should be used for a lower P_{av} in order to compensate the lower value of $\hat{v}_a$. However, the nonlinear behavior of the diode as well as the parasitic components of C_m, L_m, the diode, and the circuit layout will alter and degrade the achieved gain and efficiency. Thus, as will be shown in section 3, a threefold tuning process of C_m, L_m, and R_L is necessary in order to achieve maximum power efficiency.

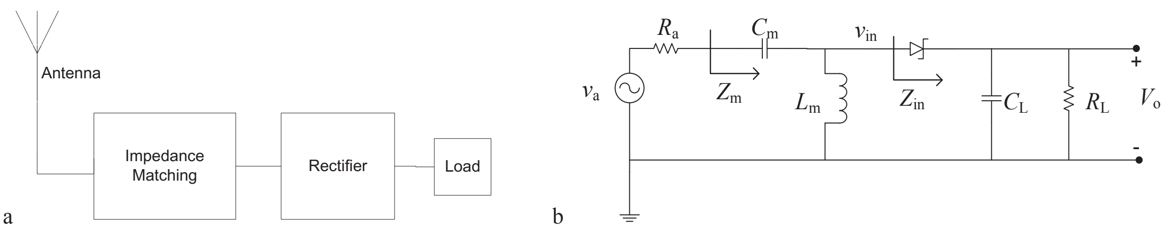

Fig. 1. (a) Block diagram of an RF energy harvester; (b) RF harvester circuit used for the simulations and the experimental tests.

3. Simulations

Simulations of the circuit of Fig. 1(b) were carried out using the Agilent ADS software. We used Harmonic Balance Analysis to compute the steady state solutions. The following parameters and devices were selected: R_a=50 Ω, C_L=1 nF, a Schottky HSMS-2850 diode, input signal frequency of 868 MHz, and input RF power levels from -30 dBm to -10 dBm. As for C_m, L_m, and R_L, an analytical derivation was used for obtaining an initial guess [6]. Then, a threefold tuning process of those values was performed to achieve the maximum η (η_{max}) in the following way: for particular values of P_{av} and C_m, curves of η versus R_L were obtained for different values of L_m. Then, the process was repeated for a range of C_m values. The values of C_m, L_m, and R_L that lead to η_{max} are named as $C_{m,opt}$, $L_{m,opt}$, and $R_{L,opt}$. Finally, the whole procedure was reiterated for different values of P_{av}.

As an example, Fig. 2(a) shows simulations of η versus R_L performed with ideal components, except the diode, at 868 MHz, P_{av} = -10 dBm, and $C_{m,opt}$ = 0.22 pF, where η_{max} = 76.6 % was achieved for $L_{m,opt}$ = 86 nH and $R_{L,opt}$ = 25.4 kΩ. Fig. 2(b) shows η versus R_L at P_{av} = -30 dBm, -20 dBm, and -10 dBm with the appropriate values of $C_{m,opt}$ and $L_{m,opt}$ at each power level. The nonlinear behavior and parasitic components of the diode limit η, particularly at low power levels. Further, as R_L deviates from $R_{L,opt}$, so does Z_m from its optimum matching value, which decreases P_L. Table 1 summarizes the results for the case of Fig. 2(b). Simulations were also performed by using commercial components for the matching network and a PCB Rogers substrate (ε_r = 3.55, tg(δ) = 0.0021). The same as Fig. 2(b) and Table 1, Fig. 3(a) shows η versus R_L and Table 2 summarizes the results. In Fig. 3(a), P_{av} = -15 dBm has been added, as will be used for comparison with Fig. 3(b) in section 4. As can be seen from Table 2, a significant decrease in η_{max}, $R_{L,opt}$, and $L_{m,opt}$ and increase of $C_{m,opt}$ are observed with respect to those of Table 1, which can be mainly attributed to the parasitic components of L_m and the layout.

4. Experimental results

The circuit was physically implemented using a Rogers substrate (RO4003C) and for C_m and L_m the commercial components shown in Table 2 for -10 dBm (which are the same that for -20 dBm). An RF signal generator (Rohde-Schwarz, SMB100A) was used at the input to emulate the antenna and a 50 kΩ potentiometer was used for R_L. The potentiometer was tuned so as to achieve the maximum P_L, which was estimated from the measured output voltage. Fig. 3(b) shows η versus R_L for P_{av} = -20 dBm, - 15 dBm, and – 10 dBm. As can be seen, the experimental curves nearly match the corresponding simulation curves of Fig. 3(a). Maximum efficiencies of 31.8 %, 43.3 %, and 52.0 % and optimum loads of 3.56 kΩ, 3.56 kΩ, and 3.27 kΩ were achieved at -20 dBm, -15 dBm, and -10 dBm, respectively. However, an experimental frequency of 814 MHz had to be used. The deviation with respect to 868 MHz must be investigated.

5. Conclusions

An RF harvester mainly consists of the antenna, a matching network, and a rectifier. This work has proposed and tested the use of an L-matching network and a threefold tuning process, which includes the components of the network and the output load, in order to achieve maximum power efficiency. Harmonic Balance simulations have been performed with ADS software at a frequency of 868 MHz. Power efficiencies of 10.9 %, 30.7 %, and 55.2 % have been achieved for input powers of -30 dBm, -20 dBm, and -10 dBm, respectively, when using commercial components and a Rogers layout. A hardware prototype has also been implemented, resulting in maximum efficiencies of 31.8 % and 52.0 % at -20 dBm and -10 dBm, respectively, close to the simulation results, but at a frequency of 814 MHz.

Acknowledgements

The authors wish to thank the technical staff of the EETAC for the fabrication of the PCB. This work was supported by the Spanish Ministry of Economy and Competitivity under Project TEC2011-27397.

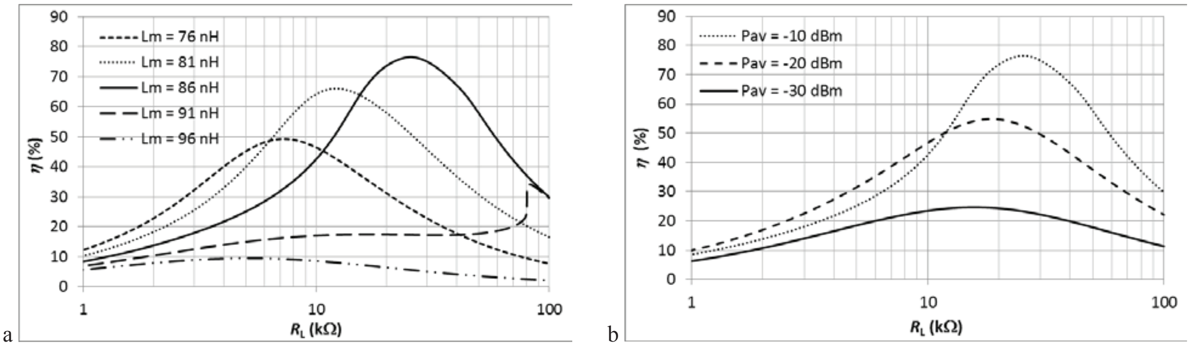

Fig. 2. Simulations with ideal components except the diode of η versus R_L at: (a) P_{av} = -10 dBm with $C_{m,opt}$ = 0.22 pF and different values of L_m (only steps of 5 nH represented); (b) P_{av} = -30 dBm, -20 dBm, and -10 dBm with the corresponding values of $C_{m,opt}$ and $L_{m,opt}$.

Table 1. Simulation results for the circuit of Fig. 1(b) using ideal components except the diode.

P_{av}(dBm)	$C_{m,opt}$(pF)	$L_{m,opt}$(nH)	$R_{L,opt}$(kΩ)	η_{max}(%)
-30	0.26	66	15.7	24.7
-20	0.25	72	18.6	54.7
-10	0.22	86	25.4	76.6

Table 2. Simulation results for the circuit of Fig. 1(b) using a PCB layout and commercial components.

P_{av}(dBm)	$C_{m,opt}$(pF)	$L_{m,opt}$(nH)	$R_{L,opt}$(kΩ)	η_{max}(%)
-30	0.3	30	8.6	10.9
-20	0.5	27	4.6	30.7
-10	0.5	27	4.0	55.2

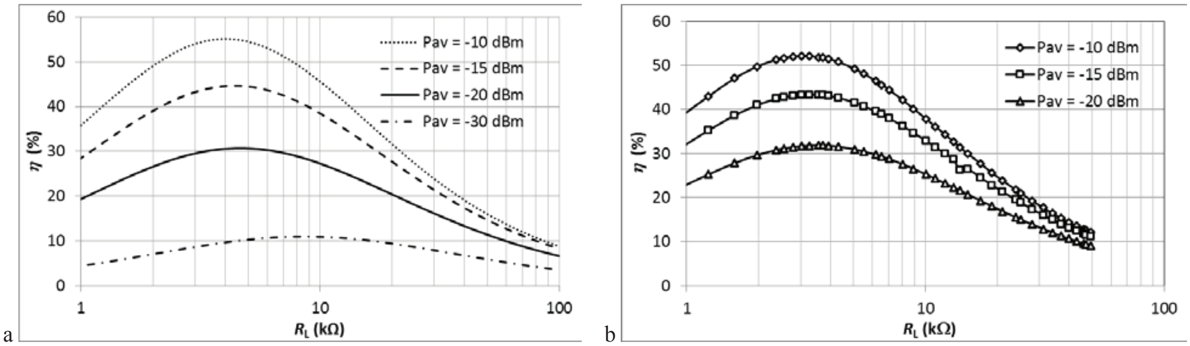

Fig. 3. η versus R_L for: (a) simulations with $C_{m,opt}$ and $L_{m,opt}$ at P_{av} = -30 dBm, -20 dBm,-15 dBm, and -10 dBm using commercial components and a PCB layout; (b) measured data for P_{av} = -20 dBm, -15 dBm, and -10 dBm.

References

[1] R. E. Barnett, J. Liu, S. Lazar, A RF to DC voltage conversion model for multi-stage rectifiers in UHF RFID transponders, IEEE J. Solid-St. Circ. 44 (2009) 354–370.
[2] A. Shameli, A. Safarian, A. Rofougaran, M. Rofougaran, F. De Flaviis, Power harvester design for passive UHF RFID tag using a voltage boosting technique, IEEE T. Microw. Theory 55 (2007) 1089–1096.
[3] N. Soltani, F. Yuan, A high-gain power-matching technique for efficient radio-frequency power harvest of passive wireless microsystems, IEEE T. Circuits-I 57 (2010) 2685–2695.
[4] J. P. Curty, N. Joehl, F. Krummenacher, C. Dehollain, M. J. Declercq, A model for µ-power rectifier analysis and design, IEEE T. Circuits-I 52 (2005) 2771–2779.
[5] A. Dolgov, R. Zane, Z. Popovic, Power Management System for Online Low Power RF Energy Harvesting Optimization, IEEE T. Circuits-I 57 (2010) 1802–1811.
[6] I. Anchustegui, D. Jimenez, M. Gasulla, F. Giuppi, A. Georgiadis, A high-efficiency matching technique for low power levels in RF harvesting, in PIERS Proceedings, Sotkholm, Sweden, Aug. 12-15, 2013.