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Integrated RF-DC converter and PCB antenna for UHF wireless powering applications

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Abstract. In this work, a broadband differential RF-DC CMOS converter realized in CMOS 130 nm technology with a customized PCB antenna with inductive coupling feeding for RF energy scavenging is presented. Experimental results show that output DC voltage higher than 1V from 800MHz to 970MHz can be obtained with a load of 1k Ω .

1. Introduction

Scavenging the electromagnetic energy radiated in the ISM band [1], [2] is a fascinating option for the development of remote power supply solutions for ultra-low power devices like, bionic implants [3] WSN nodes [4], [5] and RFID active tags.

Rectification circuits of the RF-EH systems must be optimized to reduce the minimum power-threshold needed for the system to operate. Usually to get that target, chips containing rectifier circuits exhibit a complex input impedance with a small resistance, and a high capacitive reactance. Since matching networks cannot be used in order to minimize power loss, an impedance matching between chip and antenna is required. Broadband antennas play a key role in the RF energy harvesting if the frequency of the electromagnetic waves impinging on the system is not known *a priori*. Moreover broadband allows to compensate for the frequency shift due to the presence of unknown dielectric materials nearby the antenna.

In this work we present the results of an energy harvester module composed by a balanced RF-DC power converter and a matched broadband printed antenna [6]. No matching networks are used since the antenna is designed to match the highly capacitive chip input impedance [7]. The overall performances of a prototype have been measured in an anechoic chamber. Results show that output DC voltage higher than 1V from 800MHz to 970MHz can be obtained with a load of 1k Ω .

2. System

The RF energy harvester we developed is shown in Fig. 1. It is composed by the following block: custom differential antenna; reconfigurable RF-DC voltage rectifier (VR); the voltage regulator; the energy storage capacitor. By combining the reconfigurable VR and the custom antenna avoids the use of a dedicated matching network benefiting the efficiency of the whole system. The voltage rectifier is based on a differential reconfigurable architecture which improves the efficiency and the sensitivity of



the circuit on a very large input power range compared to typical solutions [7]. The voltage rectifier is comprised of two rectifier blocks that can be connected either in series or in parallel through the M_X , M_Y and M_Z switches, which are controlled by the control logic signal V_{CTRL} . The two modular VR blocks are derived from the classical 2-stages Dickson voltage rectifier/multiplier [8].

The antenna is composed by a printed biconical radiating dipole inductively coupled with the chip by means of a rectangular loop. The real and imaginary parts of the input impedance can be adjusted independently by acting on the loop size and its distance from radiating dipole [9]. This makes very easy to achieve the target value of Z_{ANT} . Fig. 2 shows the layout of the antenna.

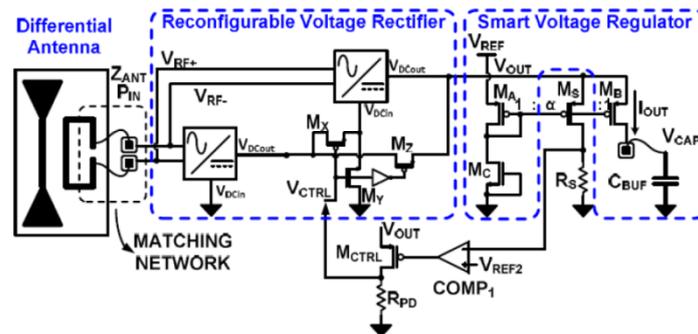


Figure 1. RF energy harvester module composed by custom differential antenna, two differential voltage rectifiers, the voltage regulator and the energy capacitor.

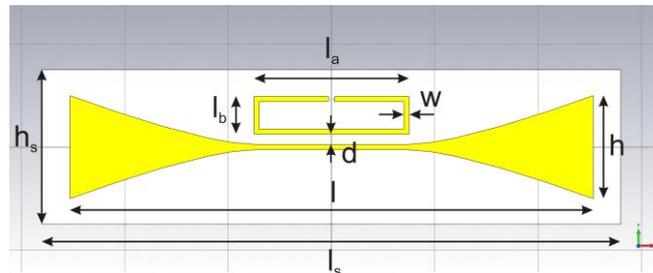


Figure 2. Layout of the differential antenna, realized on a FR4 substrate. Geometrical parameters of the antenna are reported in Table I.

The maximum power transfer from antenna to chip is obtained when the complex matching condition is satisfied:

$$Z_{ant} = Z_{chip}^*$$

being Z_{ant} and Z_{chip} the input impedances of the antenna and of the chip respectively.

The above condition makes very challenging the design of broadband antennas because usually the input chip impedance is highly capacitive and frequency dependent. In fact, as demonstrated in [10], the rectification circuit exhibits an input impedance that can be represented as the parallel of a capacitance C_{IN} and a resistance R_{IN} . C_{IN} accounts for the rectifier transistors parasitic capacitance, while the active power flowing into the rectification circuit depends on R_{IN} .

In the chip input impedance model shown in Fig. 3 also the bond wire parasitic resistance R_{BOND} and inductance L_{BOND} are included. The antenna has been designed by considering $R_{IN}=10k\Omega$, $C_{IN}=500fF$, $R_{BOND}=2\Omega$ and $L_{BOND}=1nH$ and a substrate of FR4 with relative dielectric permittivity $\epsilon_r=4.3$ and thickness of 0.8mm. The electromagnetic software CST Microwave Studio has been used for the design. The geometrical parameters of the designed antenna are reported in Table 1. The numerical values and the measured ones of the antenna input impedance $Z_{ant} = R_{ant} + jX_{ant}$ are reported in Fig. 4 and they are compared with Z_{chip}^* . The changing of the slope of X_{ant} around the resonance frequency of the radiating body $f=900MHz$ allows to follow the conjugate chip reactance over a broad frequency

range. The antenna resistance crosses the chip resistance at $f=840\text{MHz}$ and is higher than R_{chip} at $f=900\text{MHz}$. This does not allow to obtain a perfect matching condition at a given frequency but broadens the antenna bandwidth [3].

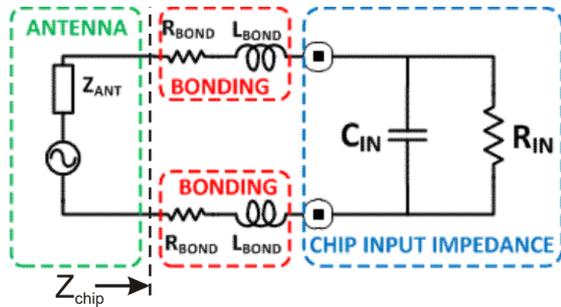


Figure 3. The equivalent circuit of the chip and antenna.

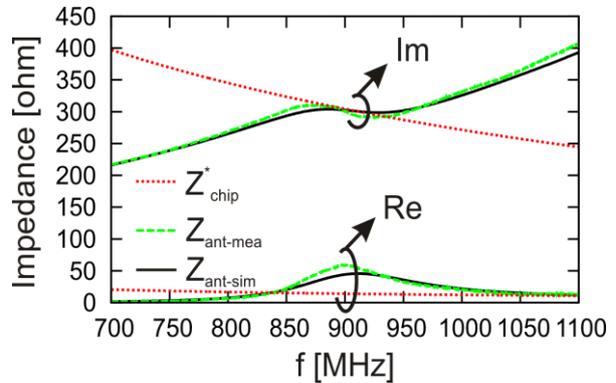


Figure 4. Antenna and chip conjugated input impedances.

Table I. Geometrical antenna parameters.

Parameter	Value
l_a	30 mm
l_b	20 mm
d	2 mm
w	1 mm
l	101 mm
h	20 mm
l_s	110 mm
h_s	30 mm

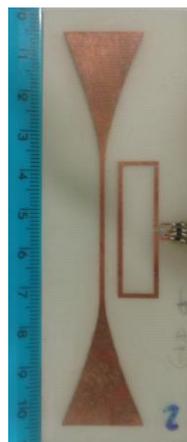


Figure 5. Left: Photograph of the PCB differential antenna realized on a FR4 substrate with bonded chip. Right: Measurement set-up.

3. Experimental results

Up to present the performances of the antenna and IC converter have been measured separately. In particular an efficiency peak of 60% has been measured for the chip [10]. Here, to test the overall

performances of the energy harvester module, a prototype of the antenna with bonded chip has been realized in it is shown in Fig. 5 (left). The performances have been measured in an anechoic chamber. The set-up is shown in Fig. 5 (right). The module has been connected to a resistive load R_L and fed with a log periodic antenna in the frequency range 800-1000MHz. The impinging electric field has been measured at the receiving antenna position in the absence of it through a probe. Results are shown in Fig. 6. They show the DC voltage on R_L versus the frequency for different values of the load and the impinging electric field. With $R_L=100k\Omega$ a DC voltage higher than 1V is obtained both at 868MHz (RFID UHF UE standard) and 920MHz (RFID UHF USA standard). With $R_L=10k\Omega$ a voltage higher than 1V is obtained over a frequency range wider than 150MHz, from 800MHz to 970MHz showing the very broadband behaviour of the developed module.

Results are shown in Fig. 6. They show the DC voltage on R_L versus the frequency for different values of the load and the impinging electric field. With $R_L=100k\Omega$ a DC voltage higher than 1V is obtained both at 868MHz (RFID UHF UE standard) and 920MHz (RFID UHF USA standard). With $R_L=10k\Omega$ a voltage higher than 1V is obtained over a frequency range wider than 150MHz, from 800MHz to 970MHz showing the very broadband behaviour of the developed module.

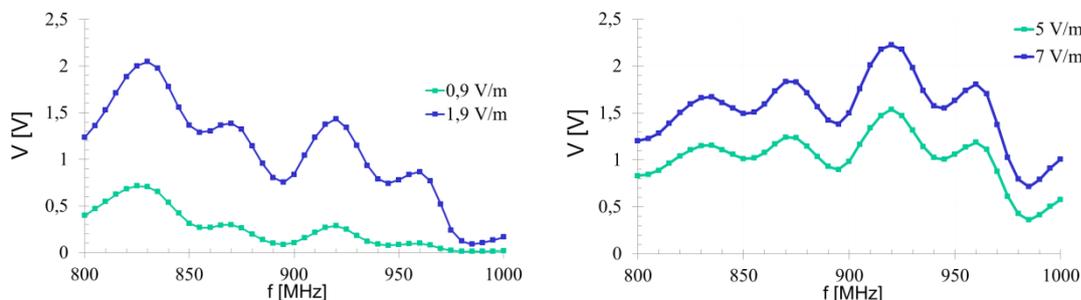


Figure 6. DC voltage on R_L versus the frequency of two different values of R_L : 100k Ω (left) and 10k Ω (right) and two different values of the electric field.

4. Conclusions

In this work we have presented the experimental results of an energy harvester module composed by a balanced RF-DC power converter and a matched broadband printed antenna. The overall performances show that output DC voltage higher than 1V from 800MHz to 970MHz can be obtained with a load of 1k Ω .

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