Single-Ended Broadband Antenna for Radiofrequency Energy Harvesting

L. Vincetti[1], M. Maini[1] M. Bompani[1] L. Larcher[2] S. Scorcioni[2] A. Bertacchini[2] D. Grossi[3] A. Tacchini[3]

[1] University of Modena and Reggio Emilia - Engineering Department "Enzo Ferrari",
Via Vignolese 905b, 41124 Modena, Italy, tel.: +39 059 2056189, fax: +39 059 2056129.
[2] University of Modena and Reggio Emilia – Science and Methods of Engineering Department ,
Via Amendola 2, 42122 Reggio Emilia, Italy, tel.: +39 0522 522625, fax: +39 0522 522609.
[1]e-mail: luca.vincetti@unimore.it, [2]e-mail: luca.larcher@unimore.it
[3] Reggio Emilia Innovazione scarl, EMC&RF Research Group
Via Sicilia 31, 42122 Reggio Emilia, Italy, tel.: +39 0522 922238, fax: +39 0522 513772.
e-mail: tacchini@reinnova.it

***Abstract* – A single-ended broadband UHF antenna with high inductive input impedance for radiofrequency energy harvesting is here presented. It consists of a small feeding loop and a conical radiating monopole. A prototype has been fabricated on a FR4 substrate and tested. Experimental results show a -3dB power transmission bandwidth of about 130MHz (860MHz–990MHz).**

I. INTRODUCTION

In the last years, energy harvesting (EH) technique based on radio frequency (RF) electromagnetic waves has gained many research interest in many fields such as RF identification (RFID), wireless sensor networks [1], [2], and bionic implants [3].

The development of efficient RF-EH systems is a very challenging task. 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 can not 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-EH. Often the frequency of the electromagnetic waves impinging on the system is not known *a priori*. Broadband also allows to compensate for the frequency shift due to the presence of unknown dielectric materials nearby the antenna. Moreover in RFID applications it allow to operate irrespectively to the used UHF standard: 868 MHz (Europe), 910 MHz (America), and 952 (Asia).

In this paper, a printed single-ended antenna with high inductive input impedance over a broad band is presented. It is derived from a differential broad-band antenna recently proposed [4]. The single-ended interface allows to connect it with a highly efficient, low threshold voltage RF-DC circuit proposed in [5]. The antenna is composed of a small feeding loop and a monopole radiating body placed over a printed ground plane. The input resistance depends mainly on loop-radiating body distance, while the inductive reactance on the loop size allowing a easy design. The radiating body consists in a conical shaped printed monopole. The terminal of the loop and the ground plane are directly connected to the chip of the RF energy harvesting without any matching network. Experimental results about a prototype fabricated on a FR4 substrate show an antenna bandwidth of about 130 MHz from 860MHz to 990 MHz.

II. RF-EH SYSTEM

Fig. 1 shows the block diagram of a RF-HE system. It is composed by an antenna, a voltage rectifier, which allows to convert the incoming RF signal captured by the antenna into a DC voltage, a energy storage block which feed the application.

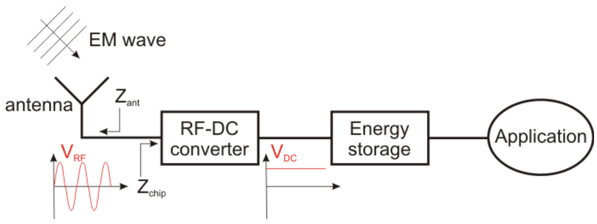


Fig. 1 Block diagram of a RF-HE system, comprised of antenna, voltage rectifier, and energy storage.

Since power efficiency and fabrication requirements do not allow to use matching networks, the antenna must be directly matched to the voltage rectifier in order to maximize the power transfer from antenna to chip. The maximum transfer of power from antenna to chip is obtainable when the two impedances are complex-conjugated:

$$Z_{ant} = Z^{*}_{chip}. \tag{1}$$

The condition (1) 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 [5], 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. 2 also the bond wire parasitic resistance R_{BOND} and inductance L_{BOND} are included.

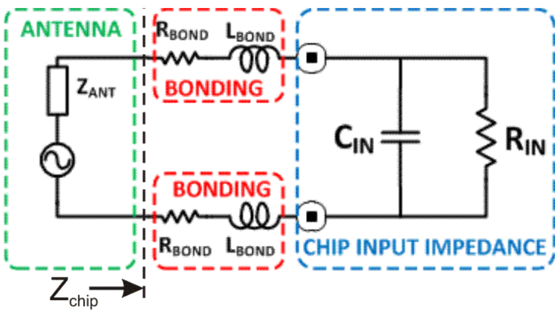


Fig 2 The equivalent circuit of the chip and antenna.

This allows to take into account the frequency dependence of the chip input impedance which is very important in broadband antenna design.

III. ANTENNA DESIGN

The structure of the developed antenna is shown in Fig. 3. It consists of a conical radiating monopole inductively coupled with the chip by means of a rectangular loop. By varying loop size and its distance from radiating dipole, the required value of the antenna input impedance can be easily obtained [6].

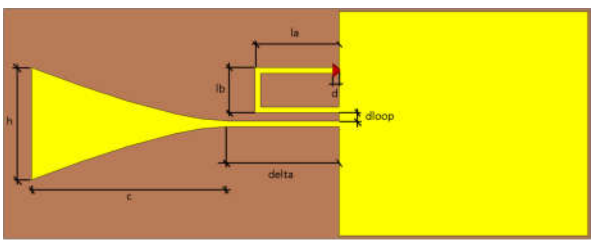


Fig. 3 Antenna Layout.

Parameter	Value
l_a	16 mm
l_b	8.7 mm
dloop	1.4 mm
w	1 mm
delta	16.2 mm
h	32.5 mm
c	35 mm

Table 1: Antenna parameters and their values.

The antenna was designed for a CMOS RF-DC converter recently proposed [5]. It exhibits an input impedance $Z_{chip} = R_{IN} + jX_{IN}$ with R_{IN}=4kΩ, and C_{IN}=870fF. The bond wire parasitic are R_{BOND}=2Ω, and L_{BOND}=1nH. The substrate antenna is FR4 with ε_R=4.3 and thickness = 0.8mm. The antenna was designed by using CST Microwave Studios software. The parameters of the optimized antenna are reported in Table 1. The overall size of the PCB is 41mm by 101 mm. The numerical values of the antenna input impedance $Z_{ant} = R_{ant} + jX_{ant}$ are reported in Fig. 4 and are compared with Z^{*}_{chip}.

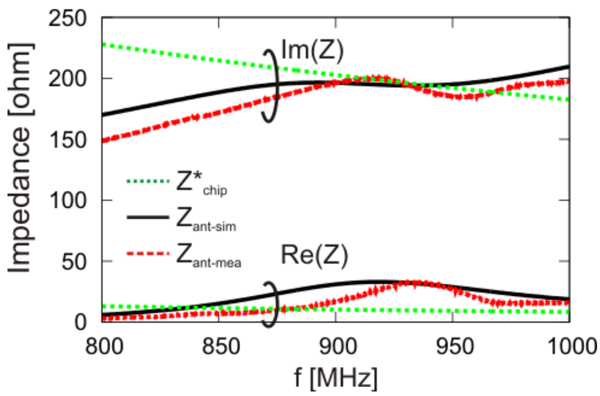


Fig. 4 Antenna and chip conjugated input impedances.

The changing of the slope of X_{ant} around the resonance frequency of the radiating body *f=920MHz* allows to follow the conjugate chip reactance over a broad frequency range. The antenna resistance crosses the chip resistance at *f=840MHz* whereas the reactance crosses the chip one at *f=940MHz*. This does not allow to obtain a perfect matching condition at a give frequency but broadens the antenna bandwidth.

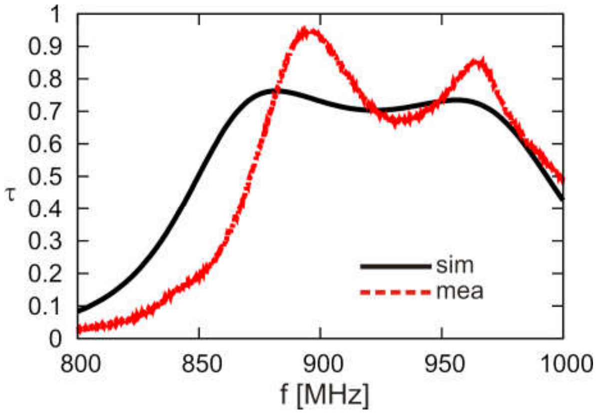
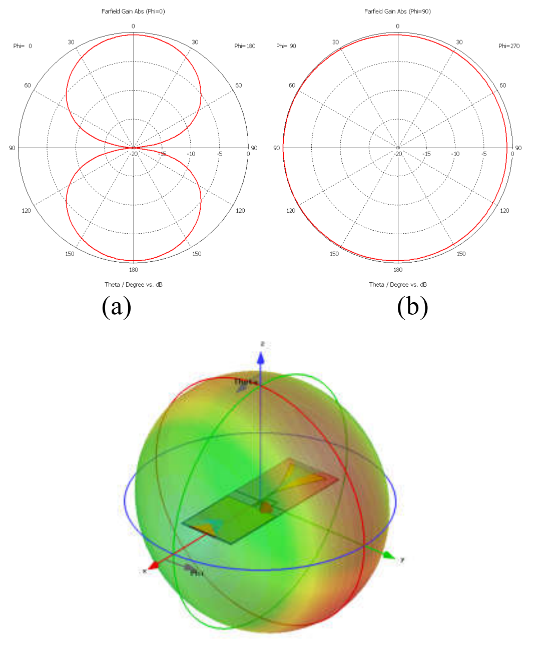


Fig. 5 Simulated and measured power transfer coefficient τ.

Figure 5 shows the power transfer coefficient τ [7]:

$$\tau = \frac{4R_{chip}R_{ant}}{|Z_{chip} + Z_{ant}|^2} .$$

By assuming a minimum acceptable value of 0.5, corresponding to a reduction of 3dB of the transferred power with respect to its maximum value, the bandwidth of the antenna is about 140 MHz. Simulated radiation patterns in E- and H-plane computed at *f=900MHz* are shown in Fig. 6.



(a) (b)

(c)

Fig. 6 Simulated radiation pattern at 900MHz. (a) E-plane, (b) H-plane, and (c) three dimensional.

Despite the ground plane, on the E-plane the pattern is a typical dipole-like pattern. On the H-plane the antenna exhibits a omni directional pattern. The 3D pattern is very close to an anisotropic one, which allow to the system to operate irrespectively to the impinging wave direction.

IV. ANTENNA MEASUREMENT

A photograph of the prototype is shown in Fig. 5. Accurate impedance measurement plays a crucial role in RFID antenna designs. Most of the UHF RFID tag antennas use balanced structures [4], this allows to to use just one half of the antenna placed above a conducting grounded plane [4]. In the present case single-ended interface do not allow this avenue. A coaxial cable with an end connected to a Vector Network Analyzer (VNA) was soldered with the antenna. A small extension of the inner conductor was soldered to the input antenna while the outer conductor was soldered to antenna ground plane. The calibration plane was shifted to the tip of the cable in order to reduce phase error.

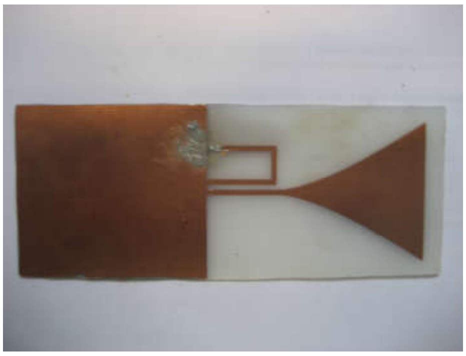


Figure 7: Fabricated antenna.

The measured input impedance is shown in Fig. 4 and it is compared with the numerical one and with the conjugate chip impedance whereas the comparison of the numerical and experimental results about power transfer coefficient τ is shown in Fig. 5. The spectral shift toward higher frequencies is probably due to a different value of the real dielectric permittivity of the substrate with respect to the data sheet value (give with 20% of tolerance). A new antenna taking into account the real value of the permittivity is now under design. Despite that, the prototype exhibits a power transfer coefficient higher than *0.5* from *f=860MHz* to *f= 990MHz* corresponding to a *-3dB* band of *130MHz*. This range covers *866-869MHz* (Europe), *902-928MHz* (America), and *950-956MHz* (Asia) UHF RFID bands, as well as the up (*890-915MHz*) and down (935-960MHz) links of Europe GSM-900 and the down link of the USA GSM-850 (869- 894MHz).

V. CONCLUSIONS

A simple broadband single-ended antenna for radiofrequency energy harvesting has been presented. By using an inductively coupling feeding structure the proposed antenna allows a easy way to match antenna and chip impedances. The conical radiating monopole has been used to broaden antenna bandwidth. Experimental results show that the propose antenna exhibits a bandwidth of *130MHz* covering the three bands of the European, American, and Asian UHF RFID standards as well as the up and down links of the Europe GSM-900 and the down link of the USA GSM-850.

ACKNOWLEDGMENTS

The work has been supported by the END project cofunded by the ENIAC Joint Undertaking under the SUBPROGRAMME SP7 – Design Methods and Tools ENIAC JU Grant Agreement n. 120214

REFERENCES

[1] J. Yin, J. Yi, M. K. Law, Y. Ling, M.C. Lee, K. P. Ng, B. Gao, H. C. Luong, A. Bermak, M. Chan, W.H. Ki, C.Y. Tsui, and M. Yuen, "A system-on-chip EPC Gen-2 passive UHF RFID tag with embedded temperature sensor", *IEEE J. Solid State Circ.*, vol. 45, pp. 2404-2420, Nov. 2010.

[2] T. Le, K. Mayaram, and T. Fiez, "Efficient Far-Field Radio Frequency Energy Harvesting for Passively Powered Sensor Networks", *IEEE J. Solid State Circ.*, vol. 43, pp. 1287-1302, May 2008.

[3] H. Chiu, M. Lin, C. Lin, I. Ho, W. Lin, P. Fang, Y. Lee, Y. Wen, S. Lu, "Pain Control on Demand Based on Pulsed Radio-Frequency Stimulation of the Dorsal Root Ganglion Using a Batteryless Implantable CMOS SoC", *IEEE Trans. Biomedical Circ. Syst.*, vol. 4, pp. 350-359, Dec. 2010.

[4] L. Vincetti, M. Maini, E. Pinotti, L. Larcher, S. Scorcioni, A. Bertacchini, D. Grossi, A. Tacchini, "Broadband Printed Antenna for Radiofrequency Energy Harvesting", *International Conference on Electromagnetics in Advanced Applications (ICEAA12)*, Cape Town, South Africa, 2-7 September 2012.

[5] S. Scorcioni, L. Larcher, A. Bertacchini, "Optimized CMOS RF-DC converters for remote wireless powering of RFID applications", *RFID (RFID), 2012 IEEE International Conference on* , pp. 47-53, 3-5 April 2012.

[6] H.-W. Son, and C.-S. Pyo, "Design of RFID tag antennas using an inductively coupled feed", Electron. Lett., vol. 41, pp. 994-995, Sept. 2005.

[7] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna Design for UHF RFID Tags: A Review and a Practical Application" IEEE Trans. Antennas Prop. vol. 53, pp. 3870-3876, Dec. 2005.