# A Compact-Size Eco-Compatible Solution for Simultaneous RF Energy Harvesting and Data Communication

Marco Fantuzzi, *Student Member, IEEE*, and Alessandra Costanzo, *Senior Member, IEEE*

***Abstract*—This research is dedicated to the study and development of novel antenna system solutions for next generation UWB-based RFID technology, enabling accurate localization at ultra-low power and integrating energy autonomy, sensing, data communication, and real-time localization in a unique, low-cost, compact-size and eco-friendly device. Compatibility with the environment is ensured thanks to the adoption of a paper substrate. The intended scalable design will possibly pave the way to large-scale market adoption, according to specific applications. Finally, the simultaneous RF energy harvesting as well as communication and real-time localization functionalities envisioned by the device, will place it in the front line toward future Simultaneous Wireless Information and Power Transfer (SWIPT) requirements for M2M communications and the 5G architecture.**

***Index Terms*—Radiofrequency (RF) energy harvesting, rectennas, UHF antennas, ultra wideband antennas, RFID.**

## I. Introduction

THE pervasive distribution of technological devices in almost every area of modern society calls for new zero-power solutions for ubiquitous electronics, with a particular focus on the more than ever vital compatibility with the environment. In the microwave area, this applies in particular to radiofrequency identification (RFID) and real-time locating systems (RTLS) technologies [1-2]. The proposed system aims at unifying all these concepts into a unique, novel, compact-size and eco-compatible solution, therefore paving the way to a high number of potential applications.

From the energy autonomy point of view RF energy harvesting (EH) and far-field wireless power transfer (WPT) can be exploited for maintenance-free operations [3]. At the same time, ultra wideband (UWB) radio technology is being adopted for next generation RFID as it offers short-range efficient localization and communication, especially in harsh indoor environments [4]. The presented system combines these two technologies in a unique, compact device. In particular, harvesting capabilities are provided for the UHF RFID 868 MHz band, while communication and localization take place in the European low UWB band from 3.1 to 4.8 GHz. Simultaneous operations are guaranteed by a miniaturized three-port matching and filtering network, named diplexer, directly connected to the novel, one-port, dual-band antenna. In order to provide compatibility with the environment, the whole system is designed and realized on paper substrate.

M. Fantuzzi and A. Costanzo are with the Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi" – DEI, University of Bologna, 40136, Bologna, Italy. (e-mail: marco.fantuzzi3@unibo.it).

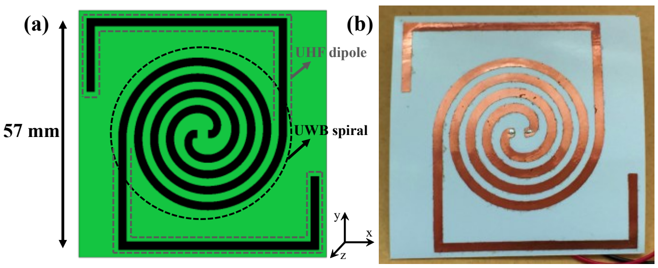


Fig. 1. (a) Integrated UWB/UHF antenna layout and (b) realized prototype on paper substrate. The overall antenna size is 57x57 $mm^3$.

## II. Antenna Design and System Performance

The UWB 3.1 to 4.8 GHz band is covered by means of an Archimedean spiral antenna. By extending the spiral outer arms, a planar meandered dipole is obtained, operating in the 868 MHz RFID band, chosen for the better power propagation with respect to higher frequency ISM bands often adopted for EH applications, such as 2.45 and 5.8 GHz bands. This novel integrated UWB/UHF antenna, reported in Fig. 1, features optimum radiating performance in both bands [5], despite the compact planar dimensions, equal to 0.16λ x 0.16λ at the lowest operating frequency, i.e. 868 MHz. Moreover, the single-port architecture of the antenna is well suited for direct connection to a future integrated version of the matching and filtering network.

In order to provide efficient operations in the two bands, the antenna is connected to a three-port network, called diplexer, which receives the signal coming from the antenna and splits it into the UHF and UWB paths [6]. The first path, responsible for harvesting operation, is loaded by an RF-to-dc rectifier, while the second one filters the UWB signal to be loaded by a UWB modulator for backscatter communication. The diplexer network, reported in Fig. 2, is realized with hybrid lumped/distributed components elements and it is miniaturized

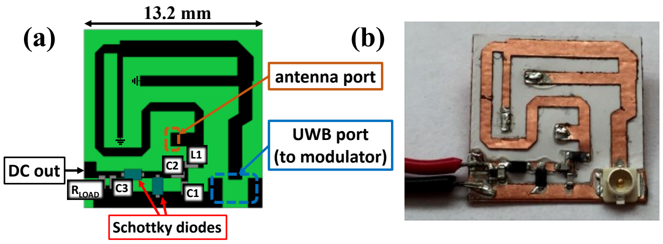


Fig. 2. (a) Layout of the 13.2 x 13.2 mm$^2$ paper-based diplexer network and (b) picture of the prototype on paper substrate.

to a size of only 13.2 x 13.2 mm$^2$. The physical implementation of the system, both for the antenna and the diplexer, is realized by gluing a copper adhesive tape, etched by means of a conventional photo-lithographic process, onto the paper substrate, as described in [7]. This implementation technique has the twofold advantage of a lower cost with respect to silver inkjet printing and to allow conventional soldering directly on the copper layer.

The performance of the rectifying stage are investigated outside anechoic chamber, in different realistic scenarios. The measured results are reported in Fig. 3, for incident power levels typical of indoor environments. The proposed system provides an RF-to-dc conversion efficiency of 45% for an available input RF power of -10 dBm. Excellent agreement is observed between measured and modelled results.

The proposed system demonstrates the effective implementation of eco-compatible solutions for energy-autonomous future tags implementations. The adopted paper substrate guarantees eco-compatibility for more than 93% of the total tag volume, enabling the proposed solution for pervasive, massive market applications. Finally, the high decoupling between the two bands provided by the diplexer network guarantees effective simultaneous data and power transfer operations, endowing the presented tag for next-generation UWB-based RFIDs.

## III. Future Plans and IMS Experience

The possibility to win the distinguished IEEE MTT-S Graduate Fellowship award for 2016 deeply motivated my research activity and further boosted my already great interest in the academia. My short-term plans are focusing on the final period of my PhD, for which the expected graduation is at the end of 2017. After that, I do not have yet clear plans about my next steps. Even though pursuing an academic career is very attractive, the possibility of moving towards industry is still open, since it is seen as the chance to approach the engineering world from a significantly different point of view. The Graduate Fellowship award certainly had a deep impact on my career and could possibly move the odds in favour academia.

Being able to attend my first IMS, in 2016, San Francisco, was a great honor and an immense opportunity that every PhD student in the Microwave area should be able to experience at least once. This is undoubtedly the biggest joint academic and

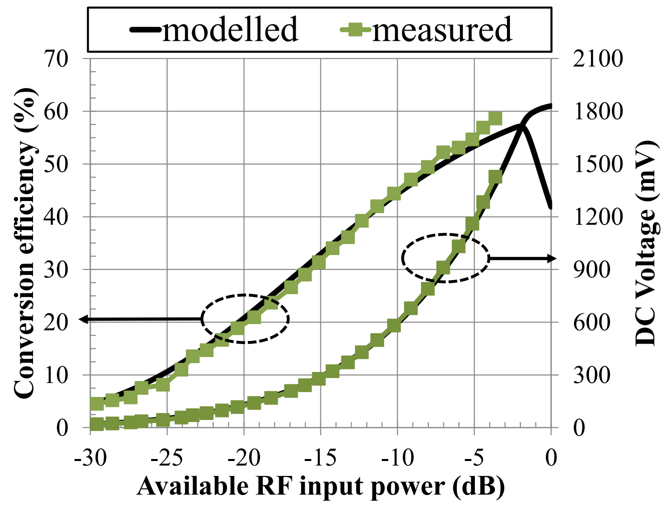


Fig. 3. RF-to-dc conversion efficiency and rectified voltage of the energy harvesting unit, for typically available RF input power levels of indoor scenarios.

industry gathering for RF and Microwave engineers, giving the possibility to meet, talk, share ideas, doubts, possibilities and experiences with most of the distinguished figures in the field, as well as PhD students coming from all over the world.

## Acknowledgment


I would like to sincerely thank the IEEE Microwave Theory and Techniques Society for granting the financial support during my academic career and for IMS 2016 attendance.


## References


[1] N. Decarli, *et al.*, "The GRETA architecture for energy efficient radio identification and localization," *International EURASIP Workshop on RFID Technology (EURFID)*, pp.1-8, 22-23 Oct. 2015.

[2] M. Fantuzzi, D. Masotti, and A. Costanzo, "Electromagnetic prediction of antenna layout impact on UWB localization and sensing," *International EURASIP Workshop on RFID Technology (EURFID)*, pp.16-21, 22-23 Oct. 2015.

[3] A. Costanzo, M. Dionigi, D. Masotti, M. Mongiardo, G. Monti, L. Tarricone, and R. Sorrentino, "Electromagnetic Energy Harvesting and Wireless Power Transmission: A Unified Approach," *IEEE Proceedings*, vol. 102, no. 11, pp. 1692-1711, Nov. 2014.

[4] D. Dardari, R. D'Errico, C. Roblin, A. Sibille, and M. Z. Win, "Ultrawide Bandwidth RFID: The Next Generation?," *IEEE Proceedings*, vol. 98, no. 9, pp. 1570-1582, Sept. 2010.

[5] M. Fantuzzi, D. Masotti, and A. Costanzo, "A Novel Integrated UWB-UHF One-Port Antenna for Localization and Energy Harvesting," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 9, pp. 3839-3848, Sept. 2015.

[6] M. Fantuzzi, D. Masotti, and A. Costanzo, "A multilayer compact-size UWB-UHF antenna system for novel RFID applications," *European Microwave Conference (EuMC)*, pp.255-258, 7-10 Sept. 2015.

[7] C. Mariotti, F. Alimenti, P. Mezzanotte, M. Dionigi, M. Virili, S. Giacomucci, and L. Roselli, "Modeling and characterization of copper tape microstrips on paper substrate and application to 24 GHz branch-line couplers," *European Microwave Conference (EuMC)*, pp. 794-797, Nuremberg, 2013.