Autonomous Wearable RFID-Based Sensing Platform for the Internet-of-Things

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***Abstract*—An autonomous wearable radio-frequency identification (RFID) tag with sensing, processing, and decision-taking capability is presented for operation in the 2.45-GHz RFID band. The tag relies on a dedicated textile shorted circular patch antenna with tailored radiation pattern for operation in a smart floor/ceiling environment. By means of an holistic design strategy, the textile antenna's functionality is augmented by reusing its surface as an integration platform for sensing, computing, transceiver, and light-energy-harvesting hardware. Special attention was paid to align the tag's power consumption profile with the power generation profile of the energy harvester. Measurements under free-space conditions and in a realistic indoor scenario demonstrate excellent wearability, very high read range, enhanced functionality, and extended system autonomy.**

I. Introduction

The Internet of Things (IoT) is currently the main force driving a massive change in industry and society. Fueled by the adaption of novel key-enabling technologies such as radio-frequency identification (RFID), wireless sensor networks (WSN) and energy-harvesting techniques, an ever-increasing number of everyday objects are augmented with sensing, processing, and wireless communication capabilities, enabling a far-reaching integration into the Internet.

However, to fully exploit the potential of the IoT, multiple, complementary key-enabling technologies should be combined. Incorporating WSN, energy-harvesting and RFID functionality within a single enhanced RFID tag that also enables unobtrusive integration within a garment will revolutionize many aspects of our daily lifes. Such a tag will leverage pervasive monitoring of the wearer's physiological parameters during his/her day-to-day activities, by wirelessly migrating gathered sensor data to the internet via a question-and-reply protocol, and this without the discomfort of frequent battery recharging or carrying additional, heavy equipment. The realization of such a autonomous wearable tag, however, imposes a challenging set of design requirements [1]. First, the tag must be flexible, low profile, and light weight in order not to affect the wearer's comfort. Second, a high and stable read range, even in the presence of the human body, is necessary. Finally, low-power and energy-efficient operation is requisite to allow self-powering from scavenged ambient energy.

In this work, we propose a wearable, enhanced RFID tag with integrated energy harvester that features an unprecedented combination of excellent wearability, very high read range, enhanced functionality, and extended system autonomy with respect to other similar tags in literature [2], [3]. Moreover, our tag is optimized for communication with a smart floor/ceiling in the 2.45-GHz RFID band. In this concept, the RFID reader(s) are integrated into the ceiling/floor of the building in which the wearer is located.

II. System Architecture and Implementation

Fig. 1, (a) and (b), depicts the architecture of our autonomous wearable RFID-based sensing platform and shows the holistic design approach. A textile circular patch antenna, designed for optimal performance in the 2.45-GHz RFID band, forms the base of the tag and serves as an integration platform for flexible light-energy-harvesting, sensing, processing and transceiver hardware. Such a design approach yields excellent results by relying on the textile antenna to obtain peak performance and by minimizing the amount of lossy and fragile interconnections between the diverse subsystems of a smart textile system by using the antenna as an integration platform.

The circular patch antenna consists of four shorting vias, connecting the patch to the ground plane, and a probe feed in the center to excite the TM22 mode. This particular mode gives the antenna a monopole-like radiation pattern, providing

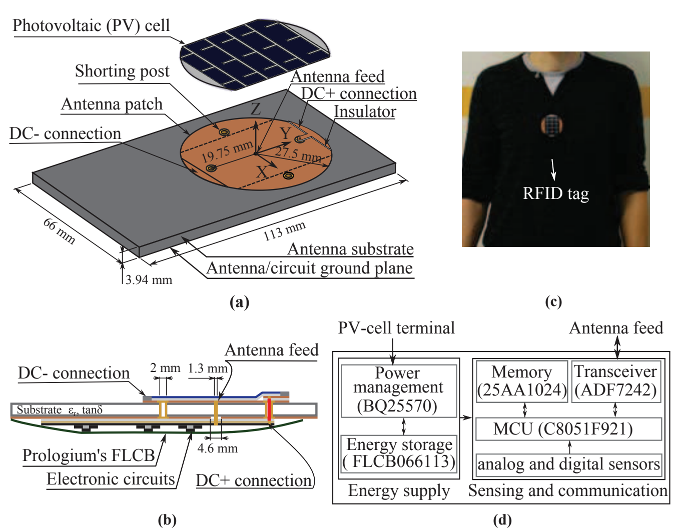

Fig. 1. Autonomous wearable RFID-based sensing platform. (a) Top 3D view. (b) Cross-sectional view. (c) Prototype worn on the chest of a test person. (d) Block diagram of the hardware integrated onto the antenna's backside.

reliable communication between a body-worn node (Fig. 1(c)) and an interrogator located in a smart floor/ceiling. A low-cost textile foam (ϵ_r = 1.42 and tanδ = 0.016 at 2.45 GHz [1]) is selected as antenna substrate to obtain a low-profile, flexible and light-weight antenna with sufficient bandwidth. Conductive textile with a surface resistivity R_s = 0.18 Ω/sq [1] is used to fabricate the antenna patch and ground plane. Both layers are laminated to the antenna substrate by means of thermally-activated glue, while hollow, brass eyelets are used to realize the shorting posts. The antenna is optimized in CST Microwave Studio for maximum -10 dB impedance bandwidth around the 2.45 GHz center frequency. The final dimensions are shown in Fig. 1 (a) and (b).

Next, a flexible and ultrathin (200 μm) Powerfilm SP3-37 a-Si:H photovoltaic (PV) module is fixed on top of the antenna patch, whereas dedicated power management (including energy storage), sensing, processing and transceiver hardware is integrated onto the antenna backside. Fig. 1(d) shows the block diagram of the hardware integrated on the antenna's feed plane and denotes the main component of each subsystem. These components are carefully selected for low power consumption and are implemented on a flexible polyimide circuit board (FCB) to maintain flexibility. In the integration process, the FCB's ground plane is bonded with the antenna ground plane (Fig. 1(a)), which allows using the antenna as a common DC ground and provides excellent shielding between the antenna patch and the active circuitry. Hence, the negative DC terminal of the PV module may now be directly connected to the antenna patch and only the positive DC terminal needs to be routed through one of the hollow eyelets (Fig. 1(b)). In a final step, Prologium's 066113 Flexible Lithium Ceramic Battery (FLCB) is integrated as depicted in Fig. 1(b). It allows the tag to remain fully operative in the absence of light.

Finally, our tag features flexible sensor interfacing via a I2C bus and via an embedded 10-bit analog to digital converter. This allows our tag to be used in diverse real-life applications by connecting the appropriate sensor(s).

III. System Performance

First, the antenna performance is validated by measuring its input reflection coefficient $|S_{11}|$ and radiation pattern under diverse operating conditions. First, these parameters are measured before and after the integration of the additional hardware. Afterwards, they are measured when the tag is worn on the human body. Measurements in an anechoic chamber demonstrate that the $|S_{11}|$ (with respect to 50 Ω) remains lower than -10 dB over more than 150 MHz around the 2.45 GHz center frequency, irrespective of the operating condition. Fig. 2 shows the simulated and measured radiation pattern in the XZ- and YZ-plane (Fig. 1(a)) at 2.45 GHz for the same operating conditions. It can be seen that the antenna exhibits a stable monopolar radiation pattern with most of the radiation directed towards the ceiling and the floor (YZ-plane), when worn as depicted in Fig. 1(c). In fact, the antenna exhibits a maximum gain of 2.7 dBi and a radiation efficiency of 65 % under any circumstance.

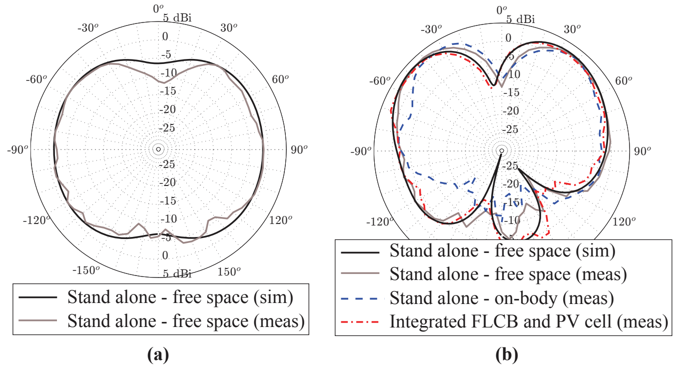

Fig. 2. Radiation pattern at 2.45 GHz. (a) XZ-plane. (b) YZ-plane.

Furthermore, measurements in an indoor scenario show that our tag features a read range up to 23 m when three brick walls are in between both link ends. Moreover, it allows interrogation by a reader at an overhead floor, through a reinforced concrete floor. Hence, a very high read range is achieved by combining excellent antenna perfomance with a state-of-the-art transceiver.

Finally, our tag's system autonomy is analyzed. On the one hand, our node implements a low-power algorithm in which the system is primarily in sleep mode (consuming 48 μA) and only periodically (every wake-up period T_{sleep}) switches to its active state for 5 ms to perform sensing, processing and to listen if its interrogated by a RFID reader. In its active state, our tag's current consumption increases up to 35 mA. Hence, the average current consumption of the tag is determined by T_{sleep}. Measurements show that in case T_{sleep} is set to 60 s, our node only consumes 168 μW of power, guaranteeing a system autonomy of at least 138 days in complete absence of light (provided the battery was fully charged). For this setting, sensing and processing are performed every 60 s and the system will answer within maximally 60 seconds. On the other hand, measurements have shown that our node is capable of harvesting 50.1 mW under full sunlight (107 527 Lux) and approximately 250 μW under typical office lighting (330 Lux), thereby further extending system autonomy. In fact, measurements show that, under typical office lighting, T_{sleep} can be reduced to 20 s without using battery power.

IV. Conclusion

We have presented the design and realization of an autonomous wearable RFID-based sensing platform for operation in the 2.45-GHz RFID SHF band. The adopted holistic design approach yields a RFID tag that features excellent wearability, enhanced functionality, flexible sensor interfacing, very high read range and extended system autonomy.

References

[1] S. Lemey, S. Agneessens, P. Van Torre, K. Baes, J. Vanfleteren, and H. Rogier, "Wearable Flexible Lightweight Modular RFID Tag With Integrated Energy Harvester," *IEEE Trans. Microw. Theory Techn.*, vol. 64, no. 7, pp. 2304–2314, Jul 2016.

[2] R. Colella, L. Tarricone, and L. Catarinucci, "SPARTACUS: Self-Powered Augmented RFID Tag for Autonomous Computing and Ubiquitous Sensing," *IEEE Trans. Antennas Propag.*, vol. 63, pp. 2272–2281, 2015.

[3] T. Kaufmann, D. C. Ranasinghe, M. Zhou, and C. Fumeaux, "Wearable Quarter-Wave Folded Microstrip Antenna for Passive UHF RFID Applications," *Int J Antennas Propag*, vol. 2013, pp. 1–11, 2013.