UWB-UHF RFID Tag on Paper for Simultaneous Communication and RF Energy Harvesting

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Abstract
This paper presents the design of a compact integrated UWB-UHF RFID solution enabling simultaneous wireless data and power transfer. The described integrated dual-band antenna is designed to cover the lower European UWB 3.1 to 4.8 GHz band for communication and localization functions and the European UHF RFID 868 MHz band for RF Energy Harvesting. Simultaneous operations are guaranteed by means of a proper feeding and matching network, a three-port diplexer, in a compact, low-profile solution. In order to fulfil eco-compatibility requirements, both the radiating system and the matching network are designed on paper substrate.

Index Terms – Ultra wideband antennas, UHF antennas, Radiofrequency Energy Harvesting, RFID.

I. INTRODUCTION

The evolution of microwave technology is leading toward the introduction of systems more and more distributed in the environment. In this context, the need for autonomy and maintenance-free functions is more than ever fundamental, together with the urgency for new solutions exploiting eco-friendly materials. Moreover, an important role in next fifth generation (5G) cellular networks is expected for a technology able to manage a Simultaneous Wireless Information and Power Transfer (SWIPT) [1].

RF Energy Harvesting and Wireless Power Transfer technologies are able to provide maintenance-free operations for Wireless Sensor Networks, while UWB technology has the advantage of extremely low power consumption, as well as robustness versus fast fading, and thus enabling sub-meter precision indoor localization [2]. Given this background, we developed an original solution, which combines these two technologies and at the same time fulfils the requirements of the national GRETA project [3] (GREen TAgS and sensors with ultra-wideband identification and localization capabilities). The RFID tag here described provides the operations highlighted in Fig. 1, showing the complete GRETA tag architecture.
With this work we present a novel dual-mode antenna, able to efficiently exploit both the European low UWB band (from 3.1 GHz up to 4.8 GHz) for communication and localization purposes and the RFID-UHF band (868 MHz) for Energy Harvesting. The main novelty consists in the compactness and eco-compatibility of the proposed solution, together with its single-port architecture, directly connected to a planar network for matching, filtering and decoupling operations.

![Diagram of GRETA tag architecture](image)

**Fig. 1** – Block diagram of the GRETA tag architecture; the presented tag describes the compact implementation of the highlighted parts.

### II. **Tag Antenna**

As tag radiating element a new, compact, one-port antenna has been designed. The UWB 3.1 to 4.8 GHz frequency band is covered by means of an Archimedean spiral, while the 868 MHz RFID band is covered by the meandered planar dipole obtained from the extension of the spiral outer arms. Common paper has been adopted for the design, having $\varepsilon_r=2.85$, $\tan(\delta)=0.053$ @ 4 GHz and thickness 0.69 mm.

Such co-localization of the two radiating elements leads to a single-port antenna architecture, which has the twofold advantage of reducing antenna area and simplifying direct connection to a future UWB-UHF integrated chip. Fig. 2(a) reports antenna layout with the relative dimensions, while Fig. 2(b) shows antenna radiation patterns in the UHF band and at three different frequencies of the UWB band. Dipole length is selected to provide a $1.5\lambda$ resonance at 868 MHz, where a non-standard behavior is obtained: since the entire spiral path contributes to the total length, no secondary lobes are present. As regards the polarization properties of the antenna, standard dipole and spiral behaviors are achieved: vertical polarization (along the y-axis) in the UHF band and circular polarization (right-handed in the $z>0$ half space, left-handed in the $z<0$ half space) in the UWB band. It is worth noting the satisfying gain performance of the dual-mode antenna, despite of the high losses of the paper substrate: the antenna gain (taking into
account the matching conditions at the antenna port) are 0, 3.4, 3.2, 4.2 dBi, at 868, 3100, 4000, and 4800 MHz, respectively.

![Antenna Layout](image)

Fig. 2 – Tag antenna layout (a) and electric field radiation pattern in linear scale (b) at the operating frequencies of 868 MHz (I), 3.1 GHz (II), 4 GHz (III) and 4.8 GHz (IV).

### III. Diplexer and Tag Architecture

The dual, simultaneous functionalities of the tag can be guaranteed only if a proper matching/filter network is implemented. This diplexing network separates the signal coming from the antenna by means of UHF and UWB filters. The first one, implemented with lumped components, is loaded by the rectifying section for Energy Harvesting purposes, while the second one is realized with distributed elements and will be loaded by the UWB backscatter modulator.

Due to the ungrounded nature of the antenna, the diplexer should have the smallest possible dimensions, especially for not influencing the highest operating frequencies, which are covered by the inner part of the Archimedean spiral. Besides diplexer miniaturization, developed by microstrip meandering and adoption of small size (0402 case) SMDs, the balanced antenna to the unbalanced diplexer microstrip connection has to be taken into account, while guaranteeing low tag profile. Fig. 3 depicts different views of the balun-free [4] connection adopted between the antenna and the diplexer. A volume of only 53x53x6 mm$^3$ is needed for the whole tag.

Despite the lossy paper substrate, the final diplexer shows promising performance: reflection coefficient for both filters is less than -10 dB at the respective frequencies of interest, whereas the insertion loss is about -1 dB and -2 dB in the UHF and UWB bands, respectively. The fundamental strong decoupling between the two paths is always guaranteed higher than 35 dB: this way simultaneous communication and power transmission activities can be effectively implemented.
The rectifying section is realized by means of a voltage-doubler topology, employing two Skyworks SMS7630 Schottky diodes. For the nonlinear optimization of the RF-to-DC conversion efficiency, low power levels have been considered for the incoming UHF signal, typical of RF harvesting scenarios. The simulated results are promising: efficiencies around 50 ÷ 60% are obtained in the range of input available power [-15 dBm ÷ -10 dBm].

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**REFERENCES**


PASSIVE RFID SENSOR NETWORK FOR INDUSTRIAL INTERNET OF THINGS

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Abstract

RFID technology is here applied to the low-level monitoring of critical infrastructures to detect early attempts of physical and cyber attacks. The proposed RFID sensor network provides the detection of complex events ranging from the unauthorized access to a critical area, the human interaction and tampering of electric equipment up to the occurrence of critical environmental events.

Index Terms – RFID sensor, industrial monitoring, IoT.

I. INTRODUCTION

After home automation, leisure and communication, the revolution of the Internet of Things (IoT) paradigms promises to produce changes also in many different industrial scenarios [1]. A key role in such perspective is played by the wireless sensor networks, and in particular to autonomous and reconfigurable monitoring infrastructures capable to sensibly increase the possibility to control systems and predict events, thus optimizing production, security and efficiency.

This contribution introduces for the first time the complete design and implementation of an RFID industrial sensor network (RFID-SN). More particularly, the proposed solution is applied to the empowering of SCADA (Supervisory Control And Data Acquisition) system in critical infrastructures by proper integrating on machinery and environment analogue and digital RFID autonomous sensors. The aim is to improve the defense against cyber-attacks and threats [2].

The work presents the design of both hardware and software components, up to deployment and test in a real environment.

II. RFID SENSOR NETWORK ARCHITECTURE

The proposed RFID-SN inside an industrial area (Fig.1) comprises i) one or more fixed multi-channel reader unit connected to the communication network hub; ii) for each reader unit, one or more surveillance antennas connected to the reader and properly distributed to achieve a uniform radio coverage of the environment or, more in general, a spatial selectivity of the interrogation; iii) a set of standard analog RFID tags to be used as wireless markers, iv) a set of digital sensing boards, hereafter denoted as radio-boards, equipped with
different sensors according to the monitoring to be performed and,  
 Control & Command software living into the reader module and able to 
 dynamically modulate the functions of the network in term of active 
 area, parameters to be measured, power and interrogation frequency.

**Fig. 1** – Possible implementation of the RFID-SN inside an industrial room.

The two types of RFID devices have complementary capabilities and 
roles. The multi-parameter wireless boards provide specific and 
quantitative sensing data while conventional RFID tag produces 
environmental backscattering modulation as a response to a variation 
of the electromagnetic fingerprint of the environment, produced by 
shadowing and scattering effects of humans and moving machinery 
parts (*ambient electromagnetic intelligence* [3]).

### III. Radio-board

The Radio-boards are based on a new family of RFID transponders 
(SL900A by AMS) that, beside the pure identification features, provide a 
native integrated electronics for sensing activities. In particular the 
selected IC includes an Analog-to-Digital Converter (ADC) capable to 
control up to two analog external sensors and an integrated 
temperature with a programmable dynamic range and resolution in the 
interval -40/150°C. This IC can be used in a fully passive mode or in 
battery-assisted mode. The design of the Radio-board was oriented to 
pursue the maximum flexibility in measurement and installation in 
complex environments. Beside the antenna, the matching element and 
the traces for battery and sensors (Fig.2), the board is equipped with 
several tuning elements (trimming points, solderable elements and 
lumped impedances) properly located onto the conductive traces. By 
acting on such elements the performance of the radio-board can be 
customized for the specific application. The read distance ranges from 
2m to 7m in battery-less and battery-assisted mode respectively.
The configurable multi-sensor S-board. Left) (A) Antenna with tuning elements, (B) Matching loop with tuning elements, (C) Chip, sensors and battery (optional) traces. Right) Prototype with measured tuning features.

IV. A FIRST TEST-BED
An early version of the complete RFID-SN was deployed and tested within the Electrical transformer secondary substation of the University of Rome “Tor Vergata”. The configuration of the RFID-SN is sketched in Fig.3. A 3.2W long range RFID reader connected to four surveillance antennas was used to monitor four different zones in the cabin: Cabinets and meters (Antenna 1); Access (Antenna 2); Flooding sensitive area (Antenna 3); Cable harness (Antenna 4). The joint use of radio-boards and conventional tags enables to monitor both authorized and un-authorized access, tampering actions, flooding and humidity changes and, finally, power overloads of wire harness.

Fig.3 shows a subset of the signals recorded by the sensors network when an authorized access to the cabin for ordinary maintenance occurred. In the initial reference condition, the light in the room is off (Radio-board 44 with photo-diode) and the sensors for the access control (Tag F1) and cabinet opening (tag F3) show stable RSSI values. No people are detected inside the ambient (null signal from badge F5). The visible drop in the value of the RSSI collected from sensor F1 reveals the opening of access door. Immediately after, the person entering the room is automatically recognized by the system as authorized personnel through his badge identification (F5). The maintenance technician turns on the light (sensor 44 switches to ON state) and opens the electrical cabinet (sensor on the door F3 is no longer read in the open position) to perform ordinary operations. Finally, he approaches the exit door and turns-off the light; the system detects again his badge and records the exit.

V. CONCLUSION
Early considerations and tests seem to corroborate the feasibility of using RFID technology for multi-parameters monitoring of critical
infrastructures and, more in general, of industrial plants. The proposed sensing network was successfully experimented in a real electric cabin and, as better shown at the symposium, it enabled the detection of a great variety of events by means of a unique and scalable infrastructure, borrowed from logistics.

**Fig. 3** – Electrical transformer secondary substation of the University of Rome “Tor Vergata”. b) Schematic representation of the RFID-SN. c) RFID-SN measurements in case of authorized access to the electric cabin.

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**References**


Modular Antennas for Near-Field UHF-RFID Systems

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Abstract
Several ad-hoc antennas for Near-Field (NF) UHF-RFID applications have been proposed in the last decade. In particular, the authors recently proposed novel antenna configurations, the so-called Modular Antennas. In these layouts, a travelling wave antenna is combined with a low-gain resonating antenna, which share the surface of the desktop reader antenna. Specifically, a spiral Travelling Wave Antenna (TWA) is used to generate a strong and uniform field in proximity of the antenna surface. Then, such a microstrip transmission line is used to feed the resonating antenna in order to extend the reading range up to few decimeters. Also, to make the antenna almost scalable, several antenna solutions have been proposed, so spreading the generated field in a large and arbitrarily shaped area.

Index Terms– Near-field antennas, Radio Frequency Identification, UHF.

I. INTRODUCTION
Radio Frequency Identification (RFID) systems have been widely used in supply chain and logistics applications for wireless identification and tracking of goods, with excellent performance for long-range (up to 4-6m, with passive tags) interrogation of tagged pallets and cases. In particular, Item level tagging (ILT) has also received a lot of attention. In this contexts, Near-Field (NF) Ultra-High Frequency (UHF) RFID systems are largely used in retail and pharmaceutical industry, as for example for desktop readers [1]-[4], smart shelves [5],[6], smart point readers [7]-[9] and printer encoders [10].

Differently from High Frequency (HF) systems, which are largely used for near-field applications, Near-Field (NF) UHF RFID systems represent a valuable solution to implement a reliable short-range (up to a few tens of cm) wireless identification for ILT applications, which can steadily operate with small tags and in scenarios with closely spaced tagged items. However, the NF UHF-RFID system performance is affected by the presence of different materials and closeby tags - the item material the tag is attached to and the mutual coupling among tags in a stacked configuration can compromise the tags readability and reduce the read range [11].

Thus, reader antennas that can exhibit in unloaded conditions a read range larger than that required in operational conditions have been recently proposed [3],[4],[8],[9],[11]. Furthermore, reconfigurable antennas have been considered, which allow for a shaping of the interrogation field in the antenna near-field region, when a simple control of the reader output power is not enough to guarantee high successful reading percentages on the whole antenna surface and for any tagged item and tag topology/orientation.

In other words, antenna reconfigurability is becoming an interesting antenna feature which makes the entire near-field UHF RFID system more flexible to the specific operative scenario. For instance, reconfigurability can be used to change the electric and magnetic field distribution within a confined volume,
also extending the read range up to a specific distance. In this framework, the authors recently introduced the Modular Antenna concept [3]. In particular, to maximize the electromagnetic field in a confined volume within the antenna near-field region (namely, in both the reactive and radiative near-field regions), a travelling wave antenna is combined with a low-gain resonating antenna, which share the surface of the desktop reader antenna. The travelling wave antenna allows for covering the reactive near-field region, with almost uniform electric and magnetic fields up to a few cm from the antenna surface. The low-gain resonating antenna is used to cover the radiative near-field region, up to a few tens of cm from the antenna surface, yet radiating a relatively low field in the antenna far-field region as required by antennas for desktop readers. In this paper, an overview of the recently proposed Modular Antenna configurations is presented, highlighting the advantages of each antenna layout.

II. MODULAR ANTENNAS: A REVIEW

The Modular Antenna concept has been firstly presented in [3]. Then, in [4] a specific design is described. Specifically, in [4] a 50-Ω coaxial cable feeds a spiral shaped TWA at the surface center, which in turn series-feeds a coplanar array of two miniaturized square patches (Fig. 1). Besides, by simply adding a switch, the spiral microstrip line can be either connected to the array (Modular Antenna Configuration) or ended on a matched load to implement a conventional TWA (Spiral TWA Configuration). The latter configuration ensures a strong and uniform field distribution in a small volume just above the antenna surface, which is high desirable for tag writing operations or single-tag readings. On the other hand, the modular combination of radiating elements is effective in improving the tag detection up to few decimeter from the antenna surface, even in presence of stacks of tags (where the mutual coupling effect is not negligible). As described [4], both the Modular Antenna Configuration and the Spiral TWA Configuration have been tested to measure the reader antenna read range. Tests have been carried out by moving the tag away from the antenna surface, with a step of 5 cm. At each distance, the RSSI value has been averaged in an interval of 10 s, for two orthogonal tag orientations. The read ranges (Fig. 1) are around 60 cm and 10 cm for the Modular Antenna Configuration and the Spiral TWA Configuration, respectively, regardless of the tag orientation.

![Fig. 1 – Modular Antenna prototype consisting in a 2x1 array of miniaturized CP patches serially-fed by a spiral-shaped transmission line [4]. RSSI distribution by varying the tag (LABID UH414) distance from the antenna center (along a direction perpendicular to the reader surface), with an input power of 23 dBm, for two orthogonal tag orientations and for both antenna configurations.](image)
The transmission line antenna and the resonating antenna can be also arranged in order to share the same surface in the smart point reader or desktop reader (aperture-shared antennas). In [8], [9], the *Modular antenna* consists of two main elements, that is a spiral-shaped microstrip transmission line which serially-feeds a circularly polarized ring slot resonant antenna (Fig. 2a). However, such a configuration is not a fully-scalable solution, since the resonant ring slot size is strictly dependent on the operating frequency. To make the antenna layout more flexible and scalable, in [8],[9] the spiral transmission line is extended beyond the slot antenna, so covering a larger area and shaping the antenna according to the shape of the reader case.

![Fig. 2 – Two-elements Modular Antenna composed by a spiral transmission line which serially feeds an embedded ring slot antenna.](image1)

As an alternative, the circular ring slot has been replaced by four separated curved slot antennas, placed around the spiral TWA and 90-degree rotated with respect to the antenna center (Fig. 2b). In detail, to achieve a circularly polarized radiated field in the radiative near-field region, the four resonating slot antennas are series-fed by the spiral TWA with the same current amplitude but with a 90-degree phase shift (sequential rotation feeding technique). Sequential rotation feeding is effective to improve cross polarization (circular polarization purity) and radiation pattern symmetry.

![Fig. 3 – Two-elements Modular Antenna composed by a spiral transmission line which serially feeds four curved resonating slot antennas.](image2)
III. Conclusion

In this paper, an overview on the Modular Antenna configurations proposed for near-field UHF-RFID systems is presented. The advantage given by a similar modular combination is twofold. Firstly, a strong field is generated on the antenna surface thanks to the presence of the spiral TWA, which is especially suitable for writing operations. On the other hand, with respect to a TWA antenna alone, a significant field intensity is observed beyond a few decimeters from the antenna surface thanks to the presence of the resonating antennas, which allow tag detection in case of stacked tagged items too. However, since the input power is partially radiated by the spiral TWA, each slot antenna is fed by a smaller power level, so guaranteeing a relatively low radiation into the far-field region and reducing the cross-readings (false positives) out of the read zone required or the NF UHF RFID reader. The presence of switches is also useful to make the antenna reconfigurable and adaptable to the specific application scenarios.

REFERENCES

ENHANCED BATTERY-FREE AUGMENTED RFID TAG

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Abstract

In this work an improved version of a recently published battery-less augmented RFID device enabling a tag-reader cooperative approach is presented. Based on a specifically designed physical layer implementing a logical communication procedure over LLRP, the device is now capable to react to the reader solicitations by reasoning, asking for extra info, taking autonomous decisions, piloting actuators and generating alerts. Tests performed in the building automation context demonstrate the capability of the proposed device of reasoning jointly with the reader and changing its behavior according to logical and physical events occurring in the surrounding environment.

Index Terms – RFID, augmented tags, sensing.

I. INTRODUCTION

RFID-based devices with augmented capabilities have appeared in recent years in the literature [1, 5]. Some of them, including the one recently published and named SPARTACUS (Self-Powered Augmented RFID Tag for Autonomous Computing and Ubiquitous Sensing) [4], conjugate RFID identification with extra functionalities such as sensing, computation, data storing, and actuation. As deeply clarified in [4], SPARTACUS (see prototype in Fig. 1) embeds an RF energy harvesting block which exploits the electromagnetic energy emitted by the RFID reader to power up a microcontroller (MCU), a memory bank, sensors, actuators and alert devices. In this paper, a new version of SPARTACUS provided with a new physical layer implementing a logical communication procedure over Low Level Reader Protocol (LLRP) is presented. In particular, the novel communication procedure makes tag and reader collaborate to solve a common problem based on the local knowledge of the tag and the global knowledge of the reader. Thus, the tag is not seen as a simple “decentralized static memory” accessible only by the reader. Indeed, the tag memory is now thought as mean of communication shared between reader and tag and it is continuously and dynamically updated by both of them.

Fig. 1 – SPARTACUS Prototype.
II. **Improved Battery-Less Augmented RFID Tag**

The implemented communication procedure supporting the SPARTACUS-reader cooperative interaction is shown in Fig. 2. Once energized and interrogated by the reader, the tag continuously sends the EPC by performing a bidirectional low-level communication according to gen2 standard timing. Thus, the tag is identified as long as it is located in the reader antenna radiation area. In the meanwhile SPARTACUS performs two different cyclical and asynchronous operations whose timing depends on both the level of available RF energy and the storage capacitor value: 1) it starts charging the capacitor, and 2) it computes, manages memory, senses the environment and updates its status by exploiting the harvested energy [6]. In particular, let’s suppose that SPARTACUS needs data from the reader in order to perform a certain computation. With reference to the path highlighted in Fig. 1, when its MCU is energized, the tag changes certain memory bits to specify the required data. Then, the reader reads the memory through gen2 commands and, on the basis of data availability, updates the memory accordingly. Once these data are accessed by SPARTACUS, its MCU retrieves them from the memory at the next energization step, performs the computation, and writes the result into the memory. The reader can now use this information for further elaborations or interactions.

Finally, a crucial aspect related to this kind of communication is the timing regulating the SPARTACUS-reader interaction. On the one hand, being SPARTACUS gen2 compliant, the interaction with the reader occurs with the standardized timing specifications, as in the case of a canonical RFID tag. Consequently, when SPARTACUS is in the reader area, it is recognized and can also exchange LLRP commands. On the other hand, the updating of the tag memory done by the device itself is governed by a different timing depending on many factors: amount of available RF energy, computational load, working distance, reader antennas planning, specific application and, finally, on-board storage capacitor. In particular, this last must be set to minimize the computational latency case by case.

III. **Results**

In this Section a validation use case concerning the
implementation of a SPARTACUS-based system capable to control a fan located in an office room when certain conditions are verified is presented. In particular, it is required to switch on the fan only when the following conditions occur: (a) somebody is in the office room, (b) it is daytime, and (c) the external temperature exceeds 28.8 °C.

In order to detect conditions (a) and (b), an infrared sensor (PIR) and a light sensor are mounted on SPARTACUS. As for condition (c), a weather station mounted on the roof of our building is periodically interrogated through a computer. The same computer interfaces an RFID reader. Finally, the GPIO of the reader is connected to the fan through an appropriate hardware driver supporting higher power than GPIO. The reader receives temperature values from the laptop and compares them with the 28.8 °C threshold. Any threshold crossing is communicated to SPARTACUS, when requested. Vice versa, according to the algorithm sketched in Fig. 3, SPARTACUS is programmed to: 1) sense the light level and compare it with a threshold of 2500 Lux (daylight threshold); 2) verify the presence of people in the office room through a PIR sensor; 3) ask the reader about the fan status (ON/OFF); 4) ask the reader whether or not the temperature threshold is exceeded; 5) verify the true/false status of conditions (a), (b), and (c); 6) send to the reader, if needed, a trigger command to switch ON/OFF the fan. The test was performed leaving SPARTACUS in a standard office room for 24 hours, 2-meter away from the reader antenna, and rather close to a window to monitor the light conditions over the course of a day. Fig. 4 shows how sensor measurements performed by the tag are consistent with events occurred over the 24-hour observation period, with light rising around 6:00 and dropping around 19:30. This clearly demonstrates the ability of SPARTACUS to perform RFID-sensing. Also people presence in the office room, revealed by the PIR sensor and known only by the tag, is visible in Fig. 4, along with external temperature and related threshold, known at the reader stage. It can be observed that the fan is correctly activated or deactivated by SPARTACUS according to the occurrence of the mentioned conditions.

**Fig. 3** – Algorithm performed by SPARTACUS.
IV. CONCLUSION

In this paper, an improved augmented RFID tag enabling a tag-reader cooperative approach has been presented and validated in some application contexts which take advantage from several features of the renovated device: the capability of asking for and receiving context data, of sensing a physical value, of reasoning, and of taking decisions, have been exploited at the same time. These functionalities are enabled by the implemented communication procedure.

REFERENCES


CHIPLESS RFID TAGS AND SENSORS FOR WIRELESS SENSOR NETWORKS

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Abstract
Chipless Radio Frequency Identification relies on the modulation of the backscattered signal produced by the tag. Several designs of tags are possible by exploiting the properties of periodic surfaces. An alteration of the physical properties of the chipless RFID tags under variable environment conditions suggest the use of this technology as a sensor. The challenge in designing chipless RFID sensors is how to perform data encoding without the presence of a chip and adding the sensing capability. These new class of low-cost sensors can be advantageously employed in wireless sensor networks and Internet of Things paradigm.

Index Terms – chipless RFID, chipless RFID sensor, wireless sensor network, Internet of Things (IoT).

I. INTRODUCTION

The Internet-of-Things paradigm requires the development of novel, reliable and low-cost wireless solutions. A promising research area regarding this topic deals with Radio Frequency Identification (RFID) systems that employ chip-based RFID tags with sensing capabilities. However, despite the great interest of conventional RFID, the need for an entirely-passive sensing solution is highly desirable in order to fulfill important practical requirements such as: real-time sensing, potentially infinite lifetime, green technology compliant and last but not least low-cost to allow a massive use of tags for environmental monitoring. It is therefore a challenging and necessary task to investigate on chipless RFID technology to reduce the unit cost and provide innovative solutions for realizing a ubiquitous wireless sensor network.

Chipless technology is based on the modulation of the backscattered signal and it has recently gained great attention in the logistic field for tracking objects. The challenge in designing chipless RFID tags is how to perform data encoding without the presence of a chip and a great research effort is ongoing to propose more and more clever encoding, both in frequency and in time domain. In addition to this, the sensing capability has to be added and the chipless RFID tag has to provide an estimate of an environmental entity. Numerous state-of-the-art designs of chipless sensors can be found in the open literature although the
reliability and reproducibility of most of them is critical. Several challenges still wait to be faced and efficiently solved, such as the choice of the materials able to sense an environmental change and the modeling of the relation between the sensed parameter and the change in the sensor response. In this sense, some promising designs of chipless RFID tags have been investigated in order to provide a tag that can also perform sensing operation.

II. CHIPLESS RFID TAG DESIGN

Chipless tags synthesized with metasurfaces are a promising solution which allows different bit-encoding methods. Metasurfaces are a class of two-dimensional metamaterials comprising a periodic arrangement of resonators. To synthesize the chipless RFID tag, the periodic surface is printed on top of an ultra-thin grounded dielectric slab to form a so-called High-Impedance Surface (HIS) [1]. The layout of the structure is represented in Fig.1. Properties of Frequency Selective Surfaces (FSSs) and HIS can be advantageously modelled through simple yet accurate circuital approach [2].

There are three main reasons for using HIS-based tags:
- the structure can be easily analyzed by using a Periodic Method of Moments (PMM);
- the RCS average value is controlled by increasing or decreasing the number of unit cells;
- the presence of the ground plane allows isolating the response of the tag from the one of the surrounding objects.

![Fig. 1 – Stackup of the employed configuration a) and top view of the unit cell of the periodic surface b).](image)

By exploiting the peculiar properties of HIS surfaces various encoding mechanisms are possible. The first method is to synthesize a multi-frequency narrowband absorber [1]. The second approach consists in exploiting the polarization conversion capability of metasurfaces [3], [4]. The third approach relies on the phase encoding [5] whereas another one is based on a differential encoding exploiting a dual-polarized reader [6]. The last approach is more robust with respect to the environment and it
has been proved a viable solution for performing a reading procedure without any type of background subtraction [7].

III. Transforming a Chipless RFID Tag into a Sensor

A chipless RFID sensor can be realized by exploiting the permittivity variation of a Chemical Interactive Material (CIM) placed on a frequency-based chipless RFID. The changing permittivity of the superstrate material determines a variation of the frequency response of the chipless RFID tag. For example, a chipless RFID tag can be transformed in a humidity sensor if the permittivity of the CIM is a function of the relative humidity of the environment. The CIM can be placed on top of the periodic printed surface. It has to be underlined the CIM has to be in the direct contact of the resonator in order to maximize the frequency shift and therefore air gaps have to be accurately avoided. In this case, a sheet of paper has been adopted as the CIM superstrate. The permittivity of the dry paper has been considered equal to 3.5. A progressive increment of the 10% of the initial permittivity has been estimated because of humidity absorption. The increasing water content of the paper layer determines a shift of the absorption peak of the chipless RFID tag (Fig.2). In this case, the information is encoded in the frequency shift with respect to the reference values of the dry paper and it is not related to the peak deepness. Clearly, the most challenging part of this research is to demonstrate the phenomenon in practice and analyze its reliability and reproducibility. The current work is focused on linking the change in permittivity to the relative humidity (RH) by using a controlled climatic chamber developed by the authors. The ongoing experimental research and the most promising results will be presented at the conference.

**Fig. 2** – Shift of the absorption of the chipless tag peak as a function of the dielectric permittivity of the superstrate.
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REFERENCES


EXPERIMENTAL TOOL FOR RFID TAG ELECTROMAGNETIC ANALYSIS

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Abstract
Performance of RFID tags is strongly dependent on the context, so that the selection of the most suitable tag for the specific application becomes a key point. In this work, a cost-effective but accurate system for the electromagnetic characterization of UHF RFID tags is firstly presented and then validated in the challenging case of label-type tag antennas bent around cylindrical structures.

Index Terms – RFID antenna, electromagnetic performance, radiation pattern

I. INTRODUCTION

Thanks to the proliferation of scientific works related to novel layouts and strategies for designing compact and high-performance RFID tag antennas [1], [2], the development of novel kinds of test environments, tools, and methods suitable for UHF RFID tag characterization is becoming a topic of interest for the Electromagnetic (EM) Community. Indeed, at the state of the art, different kinds of methods have been proposed. Some of them are based on direct measurements of some important RFID tag parameters, such as chip or tag antenna impedance. Some others characterize the assembled tags through over-the-air methods by analyzing the backscattered signal [3],[4].

In this work, based on the author’s PhD activity carried out at the EM Fields Group of the University of Salento under the supervision of Professors Tarricone and Catarinucci, an accurate, flexible, and low-cost tool for the UHF RFID tag EM characterization and performance evaluation is presented. Lying on a specific theoretical formulation of the EM problem, the novel system allows for the calculation of a set of metrics characterizing an RFID tag as a function of the tag activation power threshold when varying both tag orientation and interrogation frequency in the 865-928 MHz band. The system has been optimized to estimate radiation pattern (RP) and sensitivity of RFID tags through an over-the-air analysis when chip and antenna are assembled together. Hence, antenna gain, quality of antenna-chip conjugate matching, and substrate are contemporarily taken into account.

Once implemented the novel characterization tool has been validated through comparison with a reference measurement platform. Moreover, an experimental campaign has been carried out aimed at assessing the electromagnetic performance of flexible label-type RFID tag antennas bent around cylindrical structures with different diameters.
II. THEORETICAL FORMULATION AND METRICS DERIVATION

Let us consider the RFID communication system of Fig. 1.a where tag and reader antennas are placed along a straight horizontal line, with reader antenna kept fixed and tag antenna free to rotate around its axes. By using the Friis formula and naming $d$ the tag-reader distance, $\eta_{plf}$ the polarization loss factor, $A_{\text{cable}}$ the cable attenuation and $\tau$ the power transmission coefficient between tag antenna and RFID chip, the minimum power activating the RFID chip, i.e. the chip sensitivity $S_{\text{chip}}$ is:

$$S_{\text{chip}} = P_{\text{tx,ON}}(\theta, \varphi) \cdot G_{\text{tx}} \cdot G_{\text{tag}}(\theta, \varphi) \cdot \tau \left( \frac{\lambda}{4\pi d} \right)^2 \cdot \eta_{plf} \cdot A_{\text{cable}}$$

where the gain of the reader antenna $G_{\text{tx}}$ is assumed to be fixed and the gain of the tag antenna $G_{\text{tag}}$ is assumed to be an angular function of $(\theta, \varphi)$. Consequently, since the chip sensitivity is a constant, the power emitted by the reader in correspondence of the chip activation event, denoted as $P_{\text{tx,ON}}(\theta, \varphi)$, must be necessarily an angle-dependent parameter. It is worth highlighting that the only chip sensitivity $S_{\text{chip}}$ is not sufficient to quantify the goodness of the assembled tag, which definitely depends also on the quality of the tag antenna and on the quality of the conjugate matching between antenna and chip. In its place, a novel and more significant metric can be the “sensitivity of the whole tag” $S_{\text{tag}}$ which as desired accounts chip, antenna gain, and conjugate matching. Starting from (1), the tag sensitivity can be defined as a function of the tag activation power threshold $P_{\text{tx,ON}}(\theta, \varphi)$:

$$S_{\text{tag}}(\theta, \varphi) = S_{\text{chip}} / \tau \cdot G_{\text{tag}}(\theta, \varphi) = P_{\text{tx,ON}}(\theta, \varphi) \cdot G_{\text{tx}} \cdot (\lambda / 4\pi d)^2 \cdot \eta_{plf} \cdot A_{\text{cable}}$$

The tag sensitivity evaluated in (2) is an angle-dependent parameter. Nevertheless, by keeping constant the angles, the frequency-dependent version of the tag sensitivity can be obtained as follow:

$$S_{\text{tag}}(f) = S_{\text{chip}} / \tau(f) \cdot G_{\text{tag}}(f) = P_{\text{tx,ON}}(f) \cdot G_{\text{tx}} \cdot (c / 4\pi df)^2 \cdot \eta_{plf} \cdot A_{\text{cable}}$$

Finally, another important tag characterization can be done in terms of radiation pattern of the tag antenna. Starting from (2) and after some simple steps, the tag antenna radiation pattern can be obtained as:

$$\frac{G_{\text{tag}}(\theta, \varphi)}{G_{\text{tag, max}}} = \frac{S_{\text{tag, min}}}{S_{\text{tag}}(\theta, \varphi)} = \frac{P_{\text{tx,ON, min}}}{P_{\text{tx,ON}}(\theta, \varphi)}$$

It is important to observe that the three metrics (2)-(4), which would allow a complete characterization of any UHF RFID tag both by varying angle and frequency, are directly or indirectly depending on the activation power threshold $P_{\text{tx,ON}}$, once all the other static parameters of Fig. 1 ($G_{\text{tx}}, d, \eta_{plf}, A_{\text{cable}}$) are set. On such basis it is possible to define a novel system that experimentally determines the tag activation power threshold $P_{\text{tx,ON}}$ and then all the proposed metrics, as described below.
III. RFID tag Characterization Tool Implementation

The proposed system for UHF RFID Tag electromagnetic characterization is reported in Fig. 1.b. It is mainly composed of a fully-controllable UHF RFID reader board having its RF interface connected to a patch antenna with known electromagnetic characteristics and its digital output connected to an automatized rotating system. The selected reader board is the ThingMagic Mercury 6e (M6e) which is equipped with four GPIO (General Purpose Input Output) ports and which allows to modify both the emitted power (in the range 5 – 31.5 dBm in steps of 0.5 dB) and the working frequency in the whole RFID band. It is worth highlighting that the wide power excursion along with the good power resolution of this reader allow for the implementation of a measurement procedure based on the iterative research of the tag activation power threshold $P_{\text{on}}$. Besides the M6e, in order to implement the tag rotation with respect to the reader antenna, a stepper motor with minimum angular step of 1.8° has been selected. The stepper motor is controlled by the M6e GPIO ports through driver board.

In order to carry out the performance evaluation of a tag, the main task to be performed by the proposed measurement tool is the individuation of the tag activation power threshold by gradually increasing via software, from zero to the maximum allowed value, the reader emitted power $P_{\text{e}}$ and, contextually, by verifying whether or not the tag is energized and answers to the reader.

IV. Results

In this Section, the capability of the proposed system of performing the EM characterization of RFID tags is verified. First of all, both sensitivity and RP of some UHF RFID tags have been measured in the whole RFID band by using both the proposed tool and the Voyantic platform as described in [5]. The very good agreement of the results demonstrates the suitability of the proposed platform to characterize UHF RFID tags with a high level of accuracy. Moreover, a measurement campaign aimed at creating a taxonomy of label-type RFID tags bent around cylindrical structures has been performed. As observed in Figg. 2.a and 2.b both vertical RP and sensitivity of the tag Alien ALN-9640 for bending diameters of 7.5cm, 5.5cm, and 3.5cm have been preliminarily measured. Performance degradation up to 7 dB can be appreciated as
the diameter is gradually reduced and the dipolar structure of the antenna is consequently modified. On such basis, a performance comparison in terms of measured tag sensitivity of a selection of RFID tags equipped with Higgs 3 chip ($S_{\text{chip}} = -20\text{dBm}$) in both standard position and when placed on a cylindrical structure with diameter of 3.5cm has been carried out. For instance, as shown in the case of in Fig. 2.c, the ALN-9654 exhibits greater robustness in the case of strong curvature with a sensitivity peak of -16dBm and a degradation of about 5dB with respect to the flat case. On the contrary, the ALN-9640 is less efficient than the previous one and, moreover, it is also more influenced by the curvature effect with a sensitivity peak of -11dBm when bent. Presented results jointly to others omitted for brevity confirm once again reliability and robustness of the proposed tool along with its real support in studying and selecting suitable tags for specific applications.

V. CONCLUSION

In this paper an accurate and cost-effective measurement tool for electromagnetic analysis of passive UHF RFID tags has been presented. It is optimized to estimate antenna radiation pattern and sensitivity of tags in different operating environments. Once realized, the system has been successfully validated through a comparison with a reference instrument and through a measurement campaign on label-type tag antennas bent around cylindrical structures. The novel tool guarantees high versatility, robustness and accuracy in characterizing RFID tags.

REFERENCES


