

Experimental Characterization of Bodycentric Passive RFID Systems.

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Abstract—Recent progresses in the design of wearable RFID tag antennas stimulate the idea of passive bodycentric systems wherein the required power to drive the wearable tags is directly scavenged from the interrogation signal emitted by the reader unit. While active bodycentric links have been extensively investigated, the feasibility of passive systems is still questionable due to the poor sensitivity of the tags and to the modest read distances. This paper describes an articulated measurement campaign with textile wearable low-profile tags in the UHF RFID band. It is demonstrated that both on-body and off-body links are feasible with a power budget fully compliant with the available technology. The experiments permits to identify the most efficient tag placements and to propose some quantitative and general guidelines useful to characterize and design this kind of new systems.

I. INTRODUCTION

The RadioFrequency Identification (RFID) technology is increasingly adopted in Logistics, Manufacturing and Security, while pioneristic applications are currently experimented in Sensor Networks, Personal Healthcare and even Entertainment and Social Arts ([1]-[7]). Thanks to the advances in low-power electronics, battery-less (passive) devices are particularly attractive: in these systems the RF power required to the transponder element (the tag) to respond to the query device (the reader) is scavenged from the interrogation signal by the tag itself. Since passive RFID tags do not require regular recharging, they are particularly suited to disposal usage and to the pervasive and long-term distribution within environments.

In some applications the tag device, comprising an antenna integrated with a microchip transponder and eventually with additional sensors or actuators, needs to be worn onto the human body ([8]-[13]). Tags integrated into clothes could work as a *body-centric* passive RFID system able to track people's position and/or to monitor life parameters every time and everywhere. Compared with active bodycentric systems, RFID solution could furthermore offer a higher degrees of pervasivity than the active systems due to lower cost and to the absence of local power supply. These kind of systems deserve additional challenges since RFID antennas do not transmit but *backscatter* the power received by the reader and hence they need to achieve efficient energy scavenging in presence of

the very lossy human body while keeping the antenna size small at the involved frequency (UHF: 866-970 MHz including European, US and Asia sub-bands). Up to now, however, the true feasibility and reliability of these class of devices is still questionable, especially concerning the achievable read ranges in real environments in case of real body motion and postures.

As in the more mature active bodycentric systems, interesting RFID communication modalities are *on-body* and *off-body* links. The off-body communication could be useful for example to locate and monitor people inside buildings by means of fixed readers placed in different rooms or by a wearable reader and ambient-disseminated tags [21]. A possible application could be the access control in dangerous or restricted areas. The on-body communication is instead typical of unusual scenarios where a fixed communication infrastructure is missing. It could be the case of a sportman or a fireman equipped with different RFID sensors (inside his garment) interrogated by his hand-held standard communicator in harsh environments [22],[23]. Starting from our recent experience with wearable RFID tags ([8],[9],[24]), this paper discusses the feasibility of a bodycentric system including passive RFID textile tags, derived from a previous teflon prototype. Now, an articulated experimental campaign is aimed to understand the achievable read ranges, the minimum number of required tags and their most suitable positions over the body for reliable on-body and off-body links. Activity and shadowing effects will be also taken into account in order to understand the possibility to establish robust and safe communications.

II. ANTENNA DESIGN AND CHARACTERIZATION

A 3mm thick synthetic felt sample has been chosen as substrate for the wearable antenna. The electromagnetic features of the felt have been experimentally evaluated by means of parameter identification techniques using numerical models of planar test antennas. The achieved permittivity and conductivity at 870MHz, which is the European frequency for RFID systems, are $\epsilon = 1.17$ and $\sigma = 2 \cdot 10^{-4} S/m$.

The resulting fabricated prototype, of overall size 7×9 cm, is shown in Fig.1. The electromagnetic tag's performances have been experimentally characterized with respect to the

realized gain, e.g. the radiation gain of the antenna reduced by the impedance mismatch, which directly imposes the tag's read distance. The realized gain, $G_{T\tau} \equiv \hat{G}_T$ (Fig.1), is measured by means of the turn-on power method [25], using a customized UHF long-range reader based on the ThingMagic M5-e ASIC. Especially around $869MHz$, simulation and measurements are in a significant agreement, with less than $0.5dB$ difference.

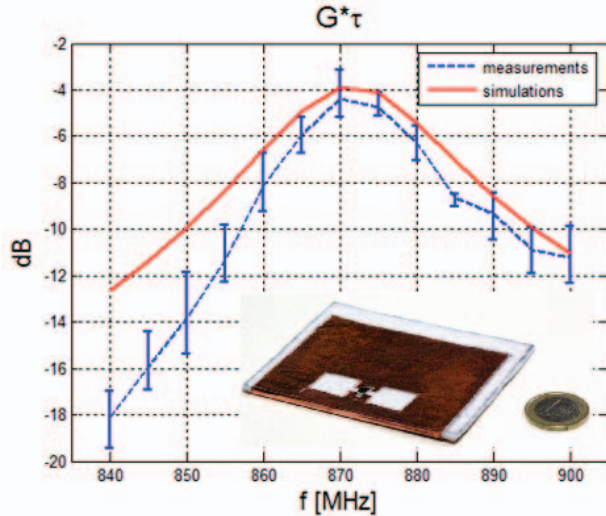


Figure 1. Prototype of body-worn felt antenna matched to $Z_{in} = 15 - j135 \Omega$ microchip and measured realized gain (along the antenna boresight) for the tag placed on the human torso

III. EXPERIMENTAL CHARACTERIZATION

The tag's radiation performances have been experimentally evaluated within a $5.5m \times 5.5m \times 3m$ office room (Fig.2) with desks and computers all around the side walls. The experimental setup included the same reader and antenna as before.

A. Off-body RFID link

For the characterization of the *off-body* RFID link, the reader's antenna was placed in the middle of a side wall, $1.3m$ from the floor. The Effective Isotropically Radiated Power EIRP emitted by the reader was $3.2W$, e.g. the maximum value allowed by the European Regulation.

A volunteer, equipped with one or more wearable tags, walked freely within the room with the purpose to test the effective reading range of the proposed tags and to find their minimum number and preferred locations to achieve the maximum coverage of the space independently from the human-reader mutual position. Four different tag placements have been studied (torso, arm, back and shoulders), each in three different polarizations (orientation of the tag).

In most configurations the maximum frontal distance is about $d_{max}(\phi = 0^\circ) = 4.5m$, and drastically falls to zero in the rear direction. So, in none of the considered tag placements it is possible to achieve a nearly uniform coverage with just a



Figure 2. Experimental setup. The volunteer equipped with a wearable tag walks away from the reader's antenna which is placed onto the wall of a $5.5m \times 5.5m \times 3m$ room, at $1.3m$ from the floor. The experiment is repeated for four orientations of the body with respect to the reader's antenna, e.g. for $\phi_n = 0, 90, 180, 270$ degrees.

single tag. By a combined use of tags it is however expected to achieve a reliable RFID link, for instance by placing one tag over the torso and the other over the back or a single tag over each arm. The combined result for a tag placed on the torso and another one placed on the back is shown in Fig.3 where a nearly isotropic bodycentric interrogation region is visible. This diagram represents the area in which wherever a reader emitting $3.2W$ EIRP in front of the person is placed, it is possible to monitor the subject independently from his position and orientation. Even better results may be achieved by using three tags: over both the arms and one over the chest.

In conclusion, a single reader permits to establish a reliable RFID link with a person equipped with a two- or three-tags within a room of $4m$ by $4m$ size. Four readers, each placed onto each side wall, would instead enable the continuous interrogation within a four-times larger ($9m$ by $9m$) room.

B. On-body RFID link

The *on-body* RFID link characterization has been here performed by means of a remotely controlled short range wearable CAEN A528 reader connected to a quarter-lambda patch (PIFA) with maximum gain $3.3dB$ and placed on the waist, slightly on the left side of the body (Fig.4up).

Five different communication links are considered, with five wearable tags placed on the torso, forearm, head, leg and wrist respectively [26]. During the measurements the volunteer assumes twenty different static and "moving" postures, illustrated in Fig.4down. The reliability of the link is in fact strictly connected to the reader-tag mutual position/orientations and to the body postures.

The RFID link is analyzed according to a statistical approach. The wearable tags are interrogated by means of a fixed power $P_{in} = 20dBm$ and the percentages of answer, α , defined as

$$\alpha = \frac{N_T}{N_R} \times 100 \quad (1)$$

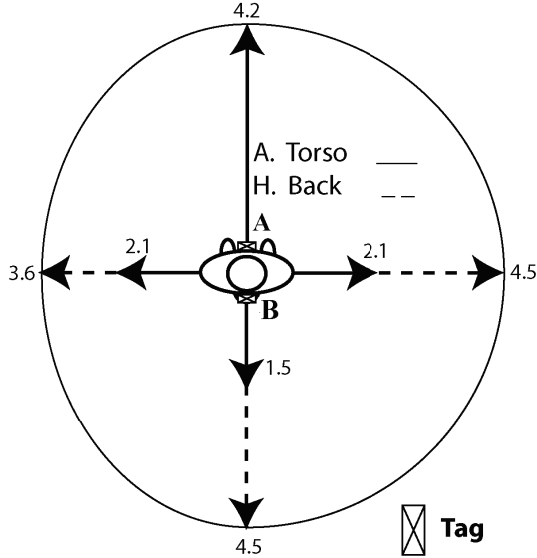


Figure 3. Bodycentric reading regions for two couplet of tags placed on the human body: one tag over the torso (A) and another one over the back (B). Continuous and dashed arrows indicate the maximum read distance $d_{max}(\phi_n)$ of the two tags in the specific direction and the ellipse-like regions gives the estimate of the overall resulting bodycentric reading region for the combined two-tags system.

is collected for each posture.

The reader performs 9 polls per second, each interrogation period is 10s and hence $N_R = 90$, while N_T is the count of responses to those polls.

The aggregated results are shown in Fig. 5 for the particular case of vertical polarization. The waist-torso channel (first row) is the most robust one, with a percentage of answer better than 70% for all the 20 positions. The other links results more sensitive to the human activity, with lower percentage of answer sometimes close to zero.

IV. CONCLUSION

The presented experimentations demonstrate that passive bodycentric RFID links are feasible within a regular indoor room with the today available technology. Actually, the on-body link may be established using a query power of the order of just 10dBm, in case of the tag placed over the torso and the reader's antenna on the waist. This small power budget is compatible with pico-readers as well as with conventional hand-held radios and even with smartphones. Moreover, the continuous improvement in microchip sensitivity will permit to extend the reading distance or, conversely, to reduce the required powers. New pervasive applications may be therefore envisaged where low-cost and even disposable wearable tags will interact with multi-services radio devices.

V. ACKNOWLEDGEMENT

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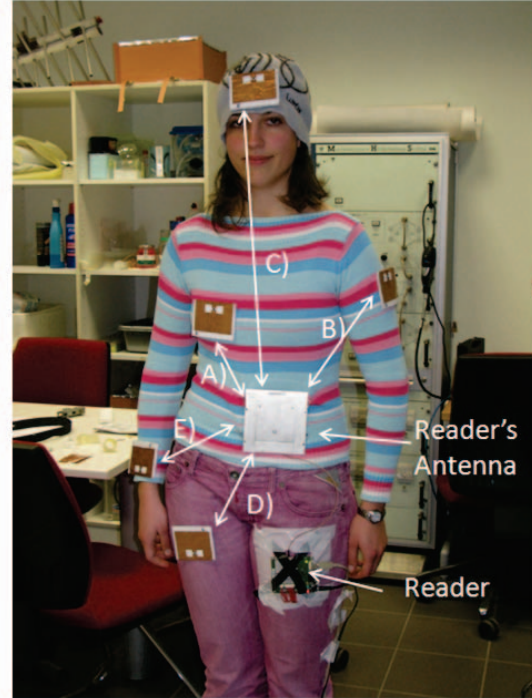


Figure 4. up) Antenna positions on the body. Five different body channels are here considered. The reader is placed in the waist slightly on the left. down) Postures assumed by the subject during the measurements. In the first fourteen the subject stands or sits in different positions according to typical human activities. Two postures (15 and 16) are in motions while in the last four the subjects lies on the floor simulating healthy and pathological conditions, such as the later safety position.

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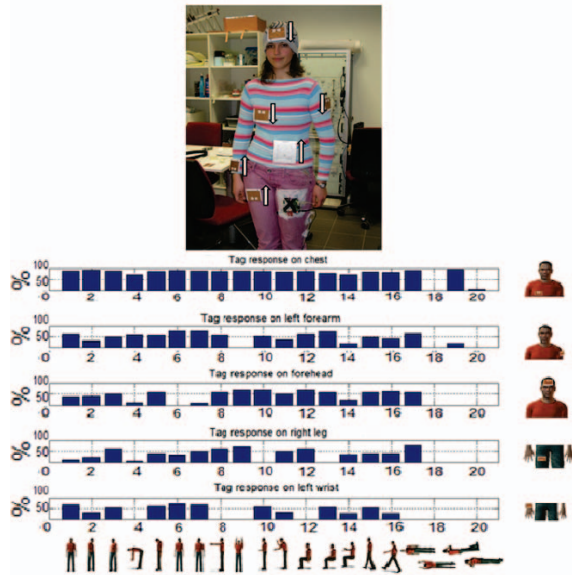


Figure 5. Channel robustness in term of percentage of answer with the antennas in vertical polarization.

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