Body-matched Slot Antennas for RadioFrequency Identification

Cecilia Occhiuzzi[1], *Claudio Calabrese*[1] *and* *Gaetano Marrocco*[1]

[1] University of Roma Tor Vergata, Via del Politecnico,1, 00133 Roma, Italy, marrocco@disp.uniroma2.it

Abstract

This paper addresses the design of transponder antennas for Mobile Healthcare Networks based on the RFID technology involving the human body as the object to be tagged or bio-monitored. A new planar tag family based on a suspended patch fed via a shaped nested slot, and able to host sensors and electronics, is here introduced. Three different layouts have been investigated through numerical simulations and fabricated prototypes. The achieved results are promising toward the possible application of such antennas for the bio-monitoring inside hospital or domestic rooms.

1. Introduction

Radio Frequency IDentification (RFID) of objects and remote control of devices has become very popular in logistics, inventory management and bio-engineering applications. Various kinds of data can be contactless transferred to a local querying system (reader) from a remote transponder (tag) including the antenna and a microchip transmitter. A new frontier is the wireless monitoring of people within Mobile Healthcare Services [1] with the purpose to reduce the hospitalization of patients, to support disaster relief or to get an epidemic under control. An RFID system could provide real-time bio-monitoring and localization of patients inside hospitals or domestic environments, as well as in extreme conditions like a Space Capsule. In these cases the tag should be placed on the human body and equipped with bio-sensors (temperature, blood pressure, glucose content) and, when activated by the reader, tag ID and bio-signals could be transferred to a remote units and then stored and processed (Fig.1).

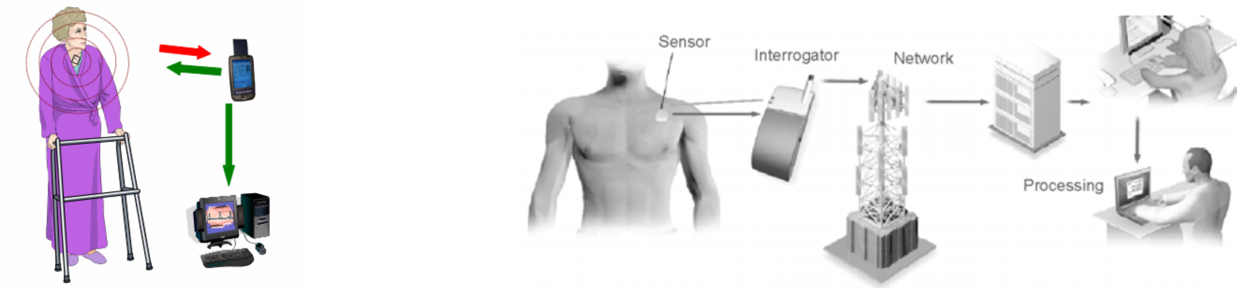

Fig. 1. Typical scenarios for a Mobile Healthcare Network.

These devices could be *passive*, harvesting energy from the interrogating system, *semi-active* when a battery is included only to feed the sensors, or fully *active* where a local source directly feeds a microcontroller as well as the transmitting radio. However, the large battery packs required for active techniques, in addition to the use of protruding antennas, are suboptimal for medical use and additional issues have to be considered, such as the compromise between a long battery-life and a miniaturized design. Moreover, when active tags are attached onto the human body, or implanted, the resultant RF power deposition inside tissue must be compliant with safety regulation.

Focusing on passive or semi-active systems, many RFID tag antennas, for on-body application or implants, conventionally work in the HF band (13.56 MHz) or below. These devices are typically fabricated as multi-turn coils, just in the case of wristbands or insulated capsules. At this frequency the antenna performs well around liquids and human tissues but the activation range is generally smaller than 1m due to the fast attenuation of the magnetic field with the distance. On the other hand, UHF devices (860-960MHz), although more influenced by high dielectric targets, may in principle promise larger activation ranges.

Together with the microchip sensitivity, the tag antenna plays a key role in the RFID system performance, such as the reading range and compatibility with the tagged object. In the case of RFID with sensing capability, the antenna should be additionally suited to electrical and physical integration with sensing electronics.

Conventional general-purpose tags are designed in free space, but when on-body applications are required, the strong pattern distortion and the efficiency loss, caused by human body dissipation and scattering, need to be taken into account in the first stage of the design. Although considerable publications are available about on-body antennas used for microwave heating as well as for radiometric and radar sensors and for implanted devices, the design of UHF RFID antennas for on-body applications is not a common topic since it involves conjugate impedance matching to microchip transmitters having high capacitive input reactance.

This contribution considers the design of planar slot antennas placed onto the human body working in the UHF RFID band. In particular, it is of interest to investigate on the possibility to design *passive* or *semi-passive tags*, e.g. such to be directly activated by the reader radiation itself, within the existing technological and energetic constraints and to find a well suited antenna layout. The research focuses on tags to apply on the thorax and on the legs, eventually combined with sensors and electronics.

2. Technological and energetic constraints

Having fixed the effective power ($EIRP_R$) transmitted by the reader, the tag antenna gain (G_{tag}) and the sensitivity (P_{chip}) of the tag microchip, e.g. the RF power required to the microchip electronics to turn on and complete its tasks, the maximum activation distance of the tag along the (θ,ϕ) direction is therefore given [2] by

$$d_{\max}(\theta,\phi) = \frac{c}{4\pi f}\sqrt{\frac{EIRP_R}{P_{chip}}\tau G_{tag}(\theta,\phi)}\ , \qquad \tau = \frac{4R_{chip}R_A}{|Z_{chip}+Z_A|^2} \le 1 \qquad (1)$$

where P_{chip} is the microchip's sensitivity, G_{tag} the gain of the tag's antenna and τ is the power transmission coefficient [3] which accounts for the impedance mismatch between antenna ($Z_A=R_A+jZ_A$) and microchip ($Z_{chip}=R_{chip}+jZ_{chip}$). Since the microchip includes an energy storage stage, its input impedance is strongly capacitive, and therefore the antenna should be designed with inductive reactance in order to achieve a conjugate matching. Beyond d_{max} the power collected by the tag decreases under the microchip sensibility and the tag is unreachable.

The presence of the human body, with its high permittivity and conductivity, will favour the antenna miniaturization but nevertheless will induce a strong power absorption. The antenna gain, and hence the link distance, will be sensibly reduced with respect to the free space. The maximum transmitted power allowed to the reader is constrained to local regulations. In Europe the relevant standards for UHF RFID applications are the ETSI EN330-220 and Draft TESI EN302 208-2. In particular within the 865.6-867.6MHz the maximum EIRP is 3.2W, which overcomes the previous limit 0.8W. In the U.S.A. the FCC allowed band is 902-928MHz with maximum transmitted EIRP=4W.

Microchip power activation threshold is continuously improving, reducing from 1mW in the year 2001 to some microwatts in today current products or even less in the state of the art ASICS [4].
From equation (1), antennas with averaged realized gain ($G_{tag}\tau$) not less than -10dB could be in principle compatible with reading distances of the order of 5m if the microchip sensitivity is less than 10µW.

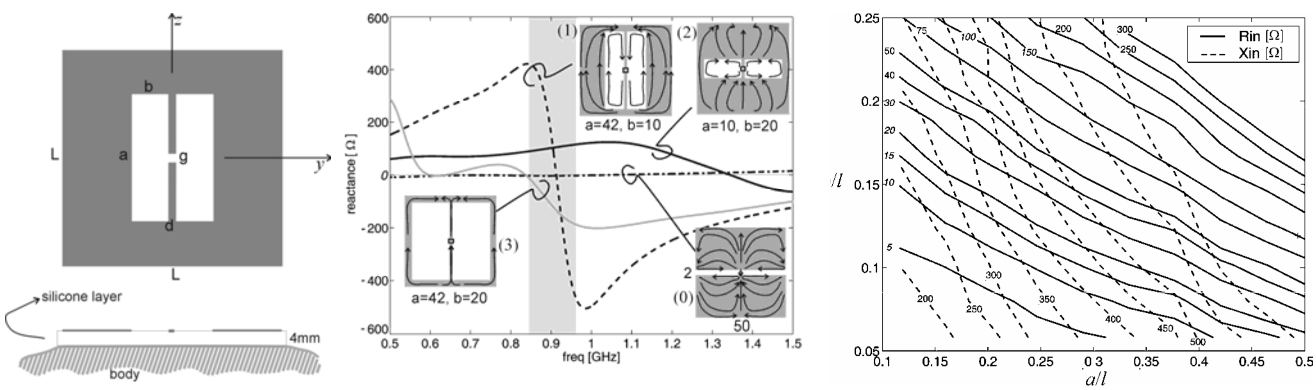

Fig. 2. *left*) Parameters of the proposed planar slot antennas. The microchip transmitter should be placed in the central gap of size *g* x *g*. *middle*) Typical antenna input impedance for some choice of the H-slot parameters (in mm). In all the case the patch size is L=50mm. *right*) matching chart to design the H shape factor to match the particular microchip's impedance.

3. The Nested-Slot Suspended Patch (NSSP) Antenna

The tag antenna family here described, is a nested-slot suspended-patch (NSSP). Small size slot antennas are naturally inductive and therefore appear more suited than dipoles to achieve conjugate impedance matching [5]. The basic geometry is visible in Fig.2. Since the slot sizes are comparable with the patch surface, the radiation features are related to both the objects. In particular, the maximum antenna gain is mainly fixed by the patch side *L*, while the impedance tuning can be changed by acting on the slot size *a* and *b*. Depending on the shape of the internal slot, the antenna mainly radiates either as a *dumbbell H*-slot or as a pair of rectangular loops sharing the sourced conductor.

All the presented results are calculated by a Finite-Difference Time-Domain solver, having considered the antenna placed onto stratified elliptical-based cylinder simulating the tagged body district.

The computer simulations (Fig.3) and also the early measurements on fabricated prototypes, have demonstrated a relevant impedance tuning agility and a read distance suited to small or even average room.

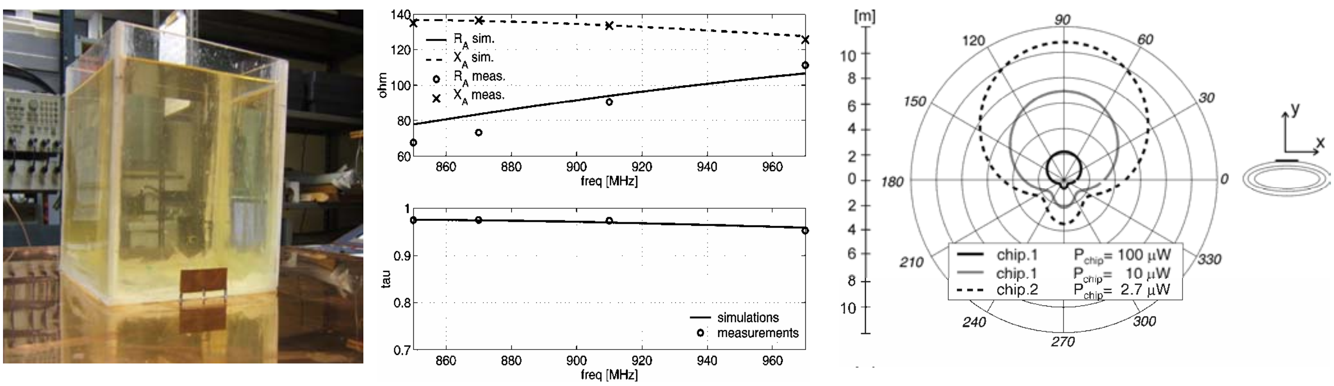

Fig.3: *left*) Fabricated Half-plane NSSP antenna in front of a Perspex cubic phantom filled with tissue-equivalent solution made of deionised water, saccharose and sodium chloride. The antenna and the box are placed over a 1m x 1m copper image plane. *middle*) Measured and computer-estimated input impedance. *right*) Estimated read distance for different kind of microchip and 3.2 W EIRP emitted power.

4. The Meandered Slot Antenna (MSA)

The previously considered NSSP antennas are symmetric with respect to both the *x* and *z* axis. However this geometry offers additional degrees of freedom in the position of the slot and in the connection to the microchip provided that a larger number of slot discontinuities (Fig.4) are considered. This new layout similar to a meandered slot, when properly optimized, could permit to fulfill several electrical and geometrical constraints, such as the impedance matching to a particular microchip, dual-frequency operations, the embedding of a sensor stage of given size, and a stable response over a large variety of tagged dielectrics. The slot profile can be seen as a slot-line impedance transformer [6], where each discontinuity (tooth) provides energy storage and radiation. A Genetic Algorithm optimization problem is hence formulated to shape the transformer layout, within input impedance and size requirements. As an example, Fig.4 shows the shape and the power transmission coefficient τ for some 870MHz slot-line antennas optimized to occupy only a fraction of the overall metallization, and preliminary experimental prototypes on FR4.

5. The Slot Inverted L antenna (SILA)

A further evolution of the slot-driven patch comprises an L-type patch folding (Fig.5) with the purpose to increase the antenna radiation and in particular to reduce the power dissipation into the body district where the tag is placed. The folded region acts as a ground plane which partly isolates the antenna from the body. The radiation is now due to the H-slot itself, as in the previous layouts, but also to the current discontinuity in the folding and especially to the patch truncation. When attached onto a leg-like layered cylinder, this layout produces a larger gain than the NSSP, with maximum value of the order of 0dB (it was -6÷-8dB in the case of the NSA) with back radiation ranging within -5÷-10dB. The read distance results sensibly improved. This antenna is intended for the monitoring of legs' movement in neuroscience applications.

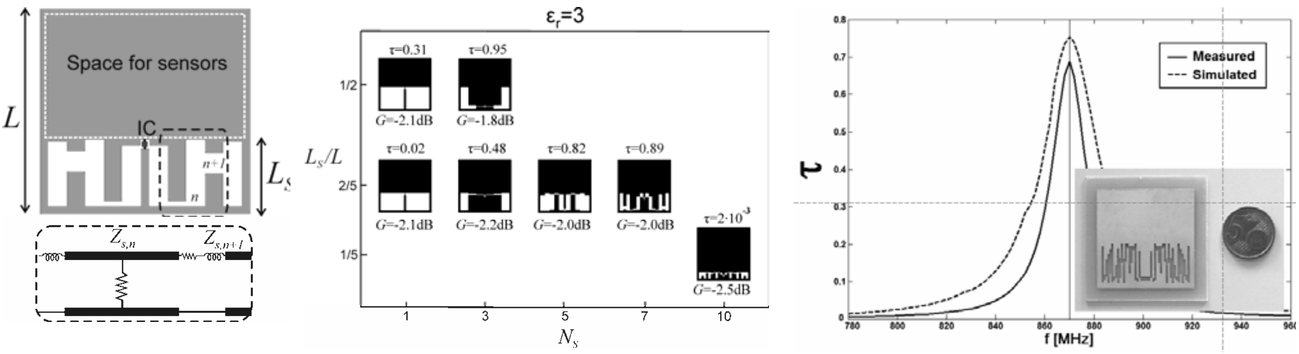

Fig.4: *left*) Layout of the meandered slot family and slot-line model. *middle*) Examples of antennas with L=5cm, placed over a ε_r=3 dielectric half-space, which have been optimized for an IC with Z_{IC}=15-j450Ω, for different sizes L_s of the antenna region and for different number N_s of slot-line sections. It is assumed a symmetric layout and therefore N_s represents half the overall slot transitions. G is the maximum gain in the air half-space. *Right*) Fabricated 5cm x 5cm prototype and in-air measurement of the power transmission coefficient.

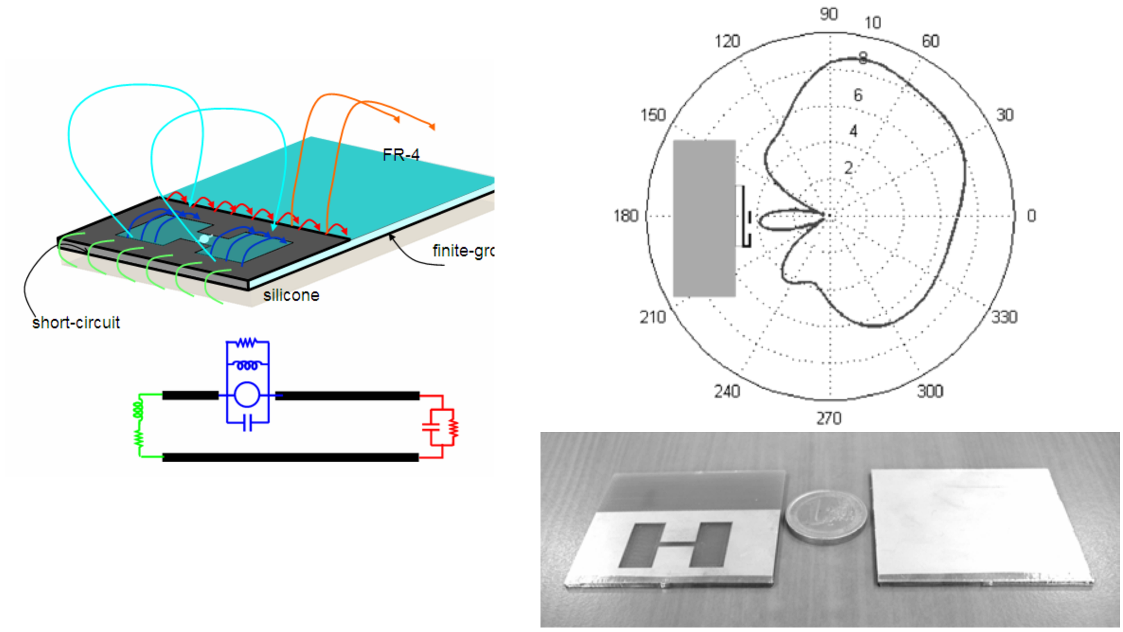

Fig.5: left) Layout of inverted slot antenna and its transmission line equivalent. Right) estimated read distance for reader power 3.2 EIRP and microchip sensitivity P_{chip}=10mW.

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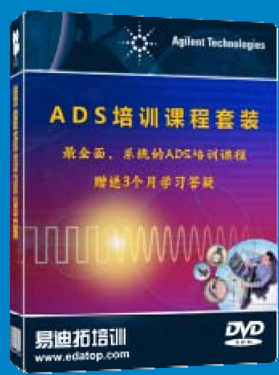

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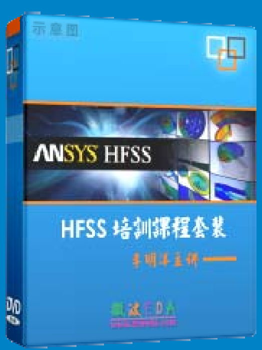

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