RFID Tag Antenna Embedded in Concrete Structures for Construction Industry

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***Abstract*—The activity to which the present work belongs aims at the realization of an RFID-based indoor localization system utilizing ink-jet printing on organic substrate. A person, moving within a building, is localized and tracked by using an RFID system consisting of a nomadic reader interrogating an array of passive tags embedded in the floor tiles. The project described in this paper will be focused on the RFID tag development, and mostly on the antenna design and the relevant environmental influence on the antenna radiating characteristics and performances.**

I. Introduction (Heading 1)

Currently ink-jet printing technology finds its focus on the realization of active and passive components (resistors, inductors, capacitors and more recently basic diodes and transistors) or radiating elements (antennas), in order to improve component and circuit functionalities together with manufacturing techniques and costs [1]. Considering the present development of ink-jet printed electronics and of the related technology it seems that it's time to think "out of the box". Ever since its appearance in fact, this technology stimulated the fantasy of many scientists because of the enormous potentialities of enabling new solutions to many problems of the daily life. The disruptive concept enabled, in a few words, consists of the possibility to embed electronic systems in all those situations where paper or alternative very cheap materials (PET for instance) are present or simply can be extensively used.
Thinking in terms of "extensive electronics" based on conventional (ink-jet for instance) printing technology, RFID seems to be one of the most suitable approaches to cope with the present societal needs. To this purpose however, several major challenges existing in today's RFID technologies need to be faced before they can march into everyone's daily life along with ink-jet printing on paper systems. Some of the challenges are certainly related to: i) the design of tag antennas with effective impedance matching to passive RFID IC chips to optimize the power performance; ii) the fabrication of ultra-low-cost RFID tags compliant with massive production of very large circuits and systems; iii) the realization of battery-free active and semi-active RFID tags [2] as well as battery-free reader to avoid maintenance. On the other side, a challenge is growing in the RF world: the need for fast, low cost and reliable new systems for localization purposes.
In this research an indoor UHF-RFID localization, system based on ink-jet printing technology is envisioned. The aim is to prove the feasibility of realizing a completely self-powered

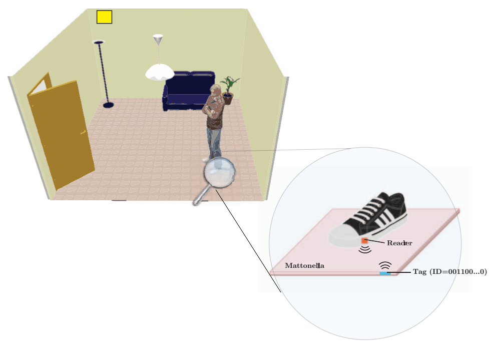

Fig. 1: Localization System Concept.

RFID system for such an indoor localizer fully implemented on paper or paper-like substrates.
To this purpose the localization system is realized by embedding into the pavement of a room a matrix of previously mapped RFID passive tags; each tag can be placed in a tile and the reader can be made wearable and self powered so that, when a person, wearing the reader, is in the reading range of a restricted number of RFID passive tags placed in the floor (at least one), his position can be identified. Data collecting is not an issue here (Body Area Networks and Wireless Area Networks WAN such as WiFi in general are possible solutions).
As a first step the focus was on the tag antenna design for an ink-jet printing solution compatible with floor embedding. To facilitate the fabrication and first prototyping, the tag antenna was realized on paper substrate with the use of copper tape. The final prototype will be realized with ink-jet printing technique of silver nano-particle ink. Simulation results are compared with measurements showing a very good agreement while a feasibility analysis of the tag antenna is also provided, focusing on the tile and screed effects.

II. Antenna Tag Development

As stated previously the tags are located under the tiles and they form a matrix of localization (Figure 1). Considering a single tile and assuming that its side is about 30 cm, we choose for the antenna design, a square loop shape [3] realized on paper substrate, so that it can be stick on the tile bottom surface.

The antenna was properly sized to obtain the 50 Ω matching at desired frequency while keeping the dimension within the

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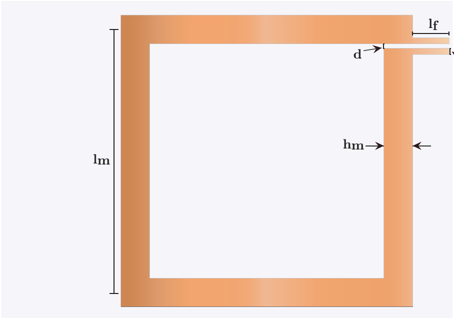


Fig. 2: Square Loop Shape Antenna; the dimensions are: $l_m = 17.34$ cm, $h_m = 1.9$ cm, $l_f = 2.4$ cm, $d = 0.3$ cm, $h_f = 0.4$ cm.

30 cm side reference tile.

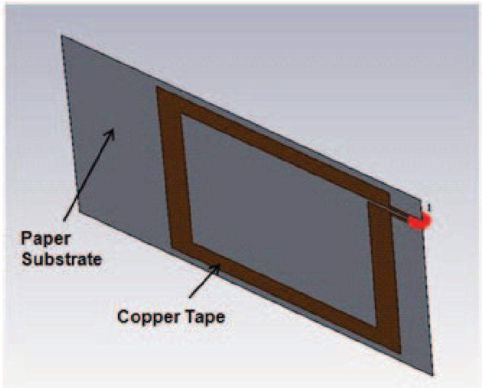
A. Antenna Simulations

The geometric and electrical parameters used to run the full wave simulations have been set on the basis of already known values [4], that are: 3.3 for the relative dielectric constant (ε_r) of paper, 0.088 for loss tangent ($tan\delta$) of paper and 5.96 S/m for copper electrical conductivity (σ). It is worth noticing that the use of copper tape applied on the sheet of paper to realize metallization is alternative to ink-jet printing for prototyping; in the industrial phase silver nano-particle ink-jet printing technique can be adopted for faster production without significant performance degradation. In Figure 3 the simulated structures and the corresponding Return Loss are shown. The results in Figure 3(b) demonstrate that the antenna in air resonates at 865 MHz, as desired. Figure 3(c) shows the structure simulated to study the tile effect on antenna behavior. The Return Loss in Figure 3(d) shows a shift of about 15 MHz in the resonance frequency caused by the tile.
In Figure 4(a) is inserted the antenna radiation pattern in air: according to the theory of loop antenna which perimeter is comparable with the operative wavelength [3], the directivity is approximately orthogonal to the pavement. Figure 4(b) shows the effect of the tile on the radiation pattern. It is important to underline that in both cases there are not evident nulls and that the radiation efficiency is close to 0 dB (about -0,28 dB in air and about -0,17 dB with tile).

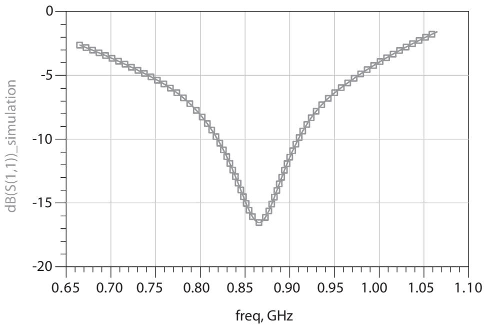
The antenna behavior is also influenced by the screed. A study of the structure composed by the screed, the antenna and the tile is proposed. As found in literature the dielectric constant of the screed varies between 4 and 10. An example of the simulated Return Loss is inserted in Figure 5, where the dielectric constant is set to 4. The screed causes a mismatch of the antenna, that can be compensated with an opportune transformation impedance network.

B. Antenna Fabrication

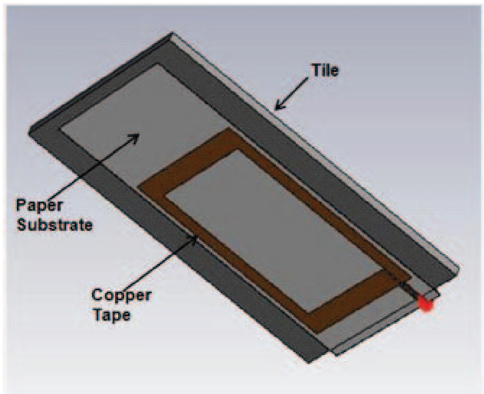
The antenna has been fabricated through some steps: layout printing on photographic paper with common ink-jet printer, copper tape sticking, separated copper segment soldering and



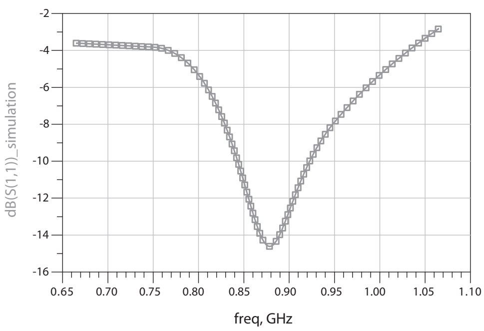
(a) Antenna in air



(b) Return Loss of antenna in air

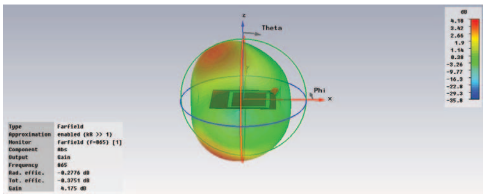


(c) Antenna with tile

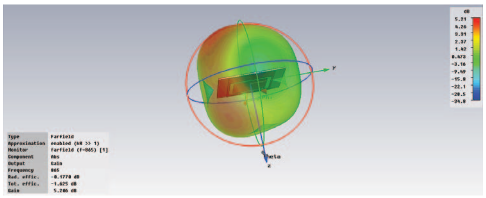


(d) Return Loss of antenna with tile

Fig. 3: Simulated structure and corresponding Return Loss.



(a)



(b)

Fig. 4: Simulated antenna radiation pattern in air (a) and with tile (b).

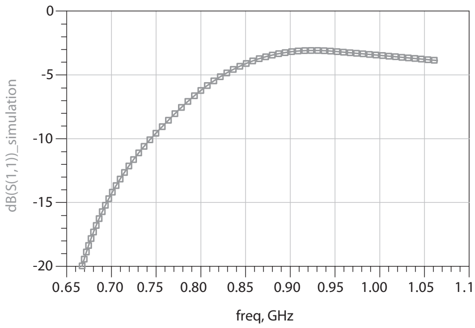


Fig. 5: Simulated Return Loss of the complete structure (screed+antenna+tile), where the dielectric constant of screed is 4.

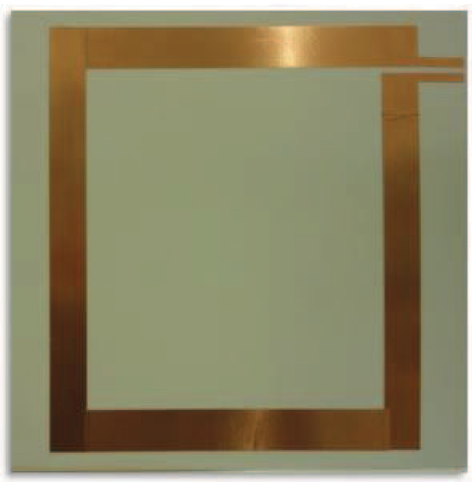


Fig. 6: Picture of the fabricated prototype.

SMA connector soldering. Figure 6 shows the fabricated prototype after the second step.

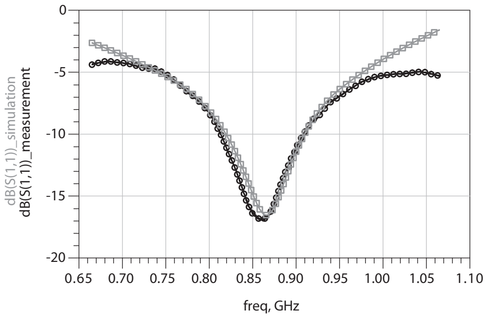


Fig. 7: Simulation and measurement comparison of the antenna Return Loss in air.

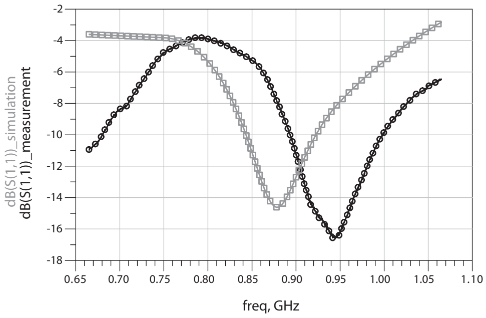


Fig. 8: Simulation and measurement comparison of the antenna Return Loss when the antenna is stick on the tile button surface.

C. *Measurement Results*

Measurements have been performed by using a Vectorial Network Analyzer (VNA). The antenna was placed on a polystyrene slab in order to provide mechanical support without affecting the results.

The measured and simulated reflection coefficients of antenna in air are compared in Figure 7 showing good agreement at the resonant frequency. Figure 8 shows the comparison between the simulation and measurement of the reflection coefficient in the case of tile, which depth is 6 mm, placed on the antenna prototype. A shift between the resonance frequency of about 75 MHz can be observed. The only uncertain parameter used in the EM simulation was the dielectric constant of the tile. The set value was guessed to be 6 after a bibliographic research.

D. *Tile dielectric constant determination*

To determine the actual dielectric constant of the tile used in the measurements the structure was simulated several times by varying the dielectric constant in order to obtain good agreement. Figure 9 shows simulation and measurement after setting the tile dielectric constant equal to 4,38.

E. *Impedance Matching*

Figure 8 and 9 show that the tile influences the resonance frequency causing a frequency shift. As a consequence it was necessary to implement an impedance matching network to make the structure resonating at 865 MHz. This network allows the antenna to directly match the impedance of the

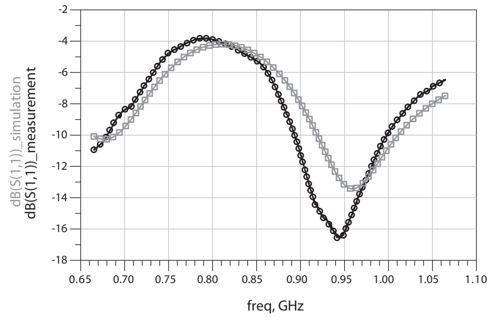


Fig. 9: Simulation and measurement comparison of the antenna Return Loss considering the tile dielectric constant.

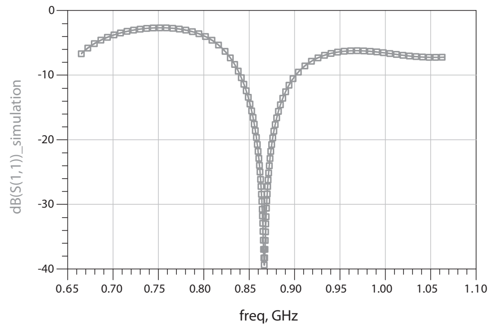


Fig. 10: Simulation of the structure (antenna+tile) Return Loss, matched to the impedance of the tag integrated circuit.

tag integrated circuit (Z_{IC}), chosen in the early phase of the design. Figure 10 shows the simulated return loss of the structure composed by the IC matched antenna and the tile.

III. Conclusion

In this paper the feasibility of a localization system based on a very extensive use of paper electronic in combination with nomadic autonomous RFID system is proven. Although the conceived application is valuable by itself, it is worth underlining that the adopted approach of embedding very low cost tags in concrete structure enables new horizons not only for the solution of indoor localization, but for many problems foreseeable in light of future Internet of Thing and Ubiquitous Electronics evolutions.

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