

# Concealable, Low-Cost Paper-Printed Antennas for WISP-based RFIDs

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**Abstract** — Paper-based, inkjet-printed antennas are proposed in this paper as replacement for the typical antennas used on the WISP RFID tag. These antennas are designed to be as concealable as possible. The designs presented exploit meandered techniques in order to achieve significantly reduced dimensions. In particular, text-based meandered line techniques are applied to obtain both decreased size and concealment. The inkjet printing has been chosen to provide a substrate, which suits the aim of concealment for the final device. Moreover, this paper shows how the inkjet printing techniques perfectly match the text-based design proposed in terms of high applicability. A comparison with the normal antennas mounted on the WISP is performed.

**Keywords** - Paper-based antennas; text-based antennas; WISP; concealable RFID.

## I. INTRODUCTION

Modern societies are characterized with fast growing demands for ubiquitous cognitive sensing with miniaturized dimensions and improved transparency for the final users. RFID technology is playing a leading role in addressing this need as numerous efforts have already been put into action with the aim being miniaturization [1-2] and adoption in everyday life [3]. The basic concept of the technology resides in the intrinsic simplicity of the object itself, usually made up of an antenna, which realizes the communication interface between the RFID and the reader, and a chipset, which performs the whole set of computation logic needed to successfully establish and carry out the communication. RFID tags are generally classified into three main categories, namely active, semi-passive and passive, depending on the power source that the device makes use of.

### A. Active RFIDs

The active RFIDs are powered by an external source, such as a battery, which means that their operability relies on the capability to provide power by means of an embedded source. In this case all transmission and computational tasks are performed autonomously by the RFID tag itself, meaning that more powerful computational and range capabilities can be achieved. The tradeoffs are the increased cost, limited battery lifetime and subsequent need for disposal and replacement.

### B. Passive RFIDs

The passive RFID tag is characterized for being completely battery-less, with an available power exclusively depending on the reader's energy that is captured (and stored) during the illumination phase. This has led to the idea of a theoretically "infinite" lifetime and perpetual operation as long as the tag is in the near proximity of the transmitter.

### C. Semi-passive RFIDs

The semi-passive RFID tags are a hybrid between the active and passive ones. Semi-passive means that the two RFID tasks are performed with different sources of power. All the communication tasks are performed by using the backscattered energy obtained captured from the reader's transmitted signal, while the computational effort is sustained by an embedded power source. Although the electronics design of this type of tag is more challenging since it has to be energy-efficient, this approach results in a longer lifetime for the device and a lower cost in comparison to the active ones, while featuring a better range than the passive ones,

In this paper we present the design, prototyping and evaluation of concealable, low-cost, conformal paper-based antennas applied on RFID passive devices and RFID-enabled sensors. In particular we propose antennas designed to replace the conventional antennas mounted on the WISP RFID [4] designed by Intel Labs Seattle. A presentation of the tools used for this work, an analysis of the performance and the characteristics of the antennas and a comparison with the commonly used ones is consecutively provided. A discussion of further steps required for the ubiquitous applicability of the proposed antennas concludes the paper.

## II. CONCEALABLE FLEXIBLE RFIDs

As mentioned in the previous section, one of the critical factors for the ubiquitous applicability of RFID technology is to be as concealable, conformal and miniaturized as possible. The idea is to introduce ubiquitous devices in everyday's life that can perform important tasks (e.g. biomonitoring, quality control, anti-counterfeiting, logistics) for the final user, even if he does not realize the presence of the device itself. It is well known that the use of most of the wearable and

biosensing devices, especially for the monitoring of senior or disabled persons, is limited by their large size, cabling and non-conformal large antennas that limits the motion and psychologically disturbs the person wearing them. As a matter of fact, RFID tags have the potential to fit very well to satisfy these requirements. In particular, passive RFID tags perfectly suit a situation in which the device answers only when asked by the transmitter, while remaining mostly unnoticeable and unobtrusive for the rest of the time.

In this framework, the idea is to use paper based antennas that increase the possibility to conceal the final RFID tag. The proposed realization is based on inkjet printing the antenna's shape directly on a paper substrate through the use of a silver nanosphere-based ink [5]. Different antenna shapes have been studied and are presented in the following sections.

The key point of this work is to address the possibility of building a completely ubiquitous device by integrating and joining a computationally powerful RFID-based module, the WISP (more than a simple passive RFID, able to perform computations and basic logic), and a printed antenna, on top of a very common flexible and "green" substrate material (paper), through the use of inkjet printing. The latter can allow for the easy fabrication of arbitrary radiating shapes. The proposed approach could potentially set the foundation for the realization of ubiquitous RFID-enabled sensors with potentially enhanced range, and low-cost and efficient power operation using off-the-shelf components.

To understand how this technology applied to the antenna of a RFID device can help the concealment of the device itself, it is better to give an example. Let's think of a situation in which we want to monitor the quality of food and we assume we have a sensor, which is capable of guessing if the food goes bad. If we apply this situation to our study, we are able to attach the sensor to the WISP platform, getting and computing the information thanks to its MCU capabilities, while on the same time we can hide the antenna used to transmit the information by embedding it for example in the label printed on the packaging of the food itself. Given the meander technique described in the next sections, using text as part of the antenna will make the concealment become even easier.

### III. THE WISP PLATFORM

The chipset used in this work is made by Intel labs Seattle and is called WISP (Wireless Identification and Sensing Platform). The WISP is a tiny computing board composed, primarily, by a rectifier, used to harvest the power needed to complete the sensing or computing tasks. A microprocessor from Texas Instrument, the computing core of the device, and some sensing capabilities are already embedded in the board itself. The advantages of this platform are rather obvious. First, given the fact that this is a completely passive RFID, it features a theoretically infinite lifetime, with no need for battery or replacement or alternative power sources when the battery is exhausted. Since its rectifier circuit is able to harvest enough power (the constant 1.8 V it needs) to feed the low-frequency microcontroller, this device has also the computing capabilities of performing some logic and sensing functions, which allows it to be deployed in several applications, that could also include the astonishing possibility of applying cryptography to the communication



Fig. 1. HFSS design of a dipole with text as meandered line.

[6]. Moreover, the WISP supports the latest and very widely used EPC GEN2 RFID protocol. As a result, for an RFID reader the WISP is just typical RFID tag.

Despite the fact that WISP platforms are not limited by the battery lifetime constraint, other restrictions must be kept in mind. Since the device is passive, it works only in the proximity of a transmitter, or, at least, its operation is strictly correlated to the presence of an illuminating signal from which it can capture the power. Additionally, its computing capabilities are considered to be elementary and each task needs to be considered under the light of a carefully calculated power budget.

All this said, the specification of the WISP assures a reading capability of tens of feet, which varies with the complexity of the required tasks, and a sufficient computing power, which allows performing tasks such as analog to digital conversion, or some forms of simple sensing, such as temperature or motion sensing.

The reason why the WISP platform has been chosen instead of a normal integrated passive chip resides in the number of possible applications we can address through the use of such a device. Whereas for an integrated chip the task performed is merely an identification section, with the WISP the applications aspects that can be taken into account are multiple. As said before, they can range from a normal temperature monitoring up to the embedding of an external sensor for particular sensing purpose. So with the idea of keeping the level of technological capabilities available as highest as possible, and at the same time making the final device as concealable as possible, we decided to pick the most powerful RFID available from the state of the art and work on the part of the device that was possible to be made less visible, the antenna.

Finally, as matter of fact, by investigating its own intrinsic characteristics the WISP RFID module allows us to achieve a longer range [4] than the one provided by a standard integrated chip.

### IV. ANTENNA DESIGN

Due to the electrically small thickness of the conformal substrate design, the antenna structure was chosen to be a set of interconnected printed strip antennas of arbitrary shapes realized with silver ink that is inkjet printed on paper. The tool used for the electromagnetic performance of the composite antenna shapes was Ansoft HFSS. The paper used for this project was a regular photo paper, which has a thickness of around 300  $\mu\text{m}$ . This substrate has an  $\epsilon_r$  of 3.28 and a  $\tan\delta$  of 0.061 [5]. The silver ink has a conductivity that varies from 0.4 to  $2.5 \times 10^7$  S/m [5], depending on the temperature and the duration of the curing of the inkjet-printed structure.

The aim of this paper is to fabricate an antenna, which should be as concealable, masked, and unnoticeable as possible in contrast to the commonly used WISP antennas that are bulky and non-conformal, limiting their applicability to a short range of applications. An extensive effort for the reduction of the antenna dimensions has been carried out,

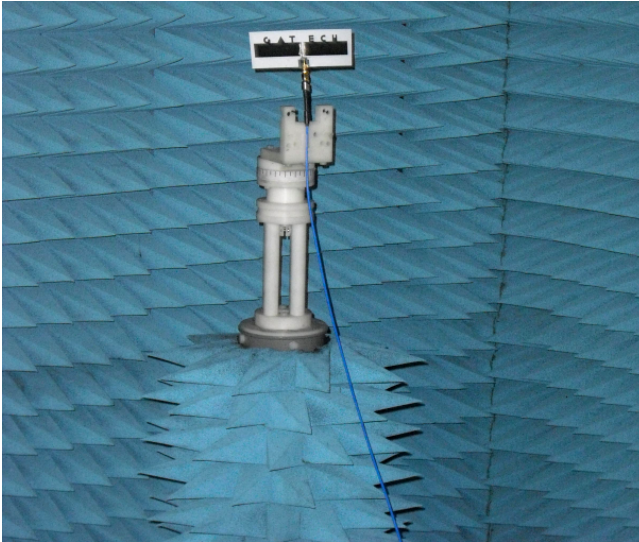


Fig. 2. Anechoic chamber set-up.

starting from a normal slim half-wavelength dipole resonating at 915 MHz with a length of 16.39 cm.

As a first step, two stubs of 0.3 cm in width and 1.7 cm in vertical length have been added, in order to reduce the maximum dimension of the antenna to 11.9 cm. This concept derives from the idea of folded, or more specifically meandered, antenna [2, 7]. The two stubs mostly modify the reactive part of the antenna impedance, allowing a reduction in the horizontal length. Following this idea, increasing the number of stubs allows for a decrease of the vertical length of the antenna. For example, increasing the number of radiating elements up to six, we were able to decrease the vertical length of the antenna to only 1.1 cm by using stubs of dimensions 0.2 cm in width and 0.7 cm in vertical length. Those were equally spaced and symmetrically placed in respect to the two branches, designed to affect as less as possible the radiation pattern and efficiency, which was designed to suit the one previously obtained with the normal, non-meandered, dipole.

Having combined the use of stubs with the idea of text-based antennas [8], the result obtained was a dipole having a set of “stub”-letters on top, which can eventually compose a word with a proper meaning. The design obtained in the simulation can be seen in Fig 1. The dimension of this antenna is 12.6 cm in length, 0.2 cm in width and as far as the letters are concerned, they are 0.9 cm high and between 0.2 and 0.4 cm wide. Obviously, as for the stubs before, more letters can be added. All these changes can lead to different customizable characteristics of the antennas.

This particular type of the antenna design is very significant in our effort to realize an object that can be integrated in a nonintrusive, concealable way within another object; for instance the product label or a food package, printed with conductive ink, could act as very efficient radiating elements.

The antenna is finally mounted, as seen in Fig 5, on the WISP by first soldering two short conductive wires to the board’s antenna output and afterwards sticking these wires on the paper antenna with conductive epoxy, used instead of traditional soldering on heat sensitive components.

These two branches are placed tightly to the paper surface where the antenna is printed. More precisely the connection with the antenna is made exactly where the feeding port has

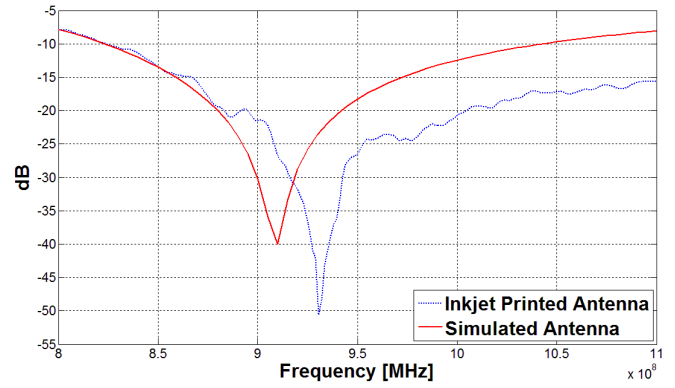


Fig. 3. Example of  $S_{11}$  measure.

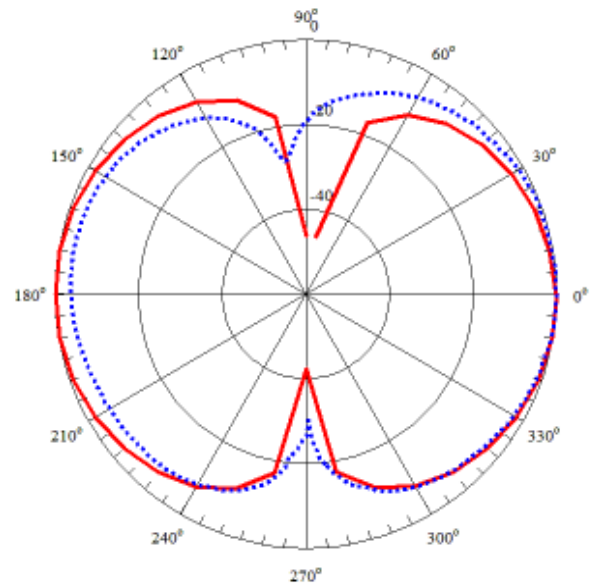


Fig. 4. Example of measured pattern. As before, solid red line simulated, dotted blue line measured.

been decided to be during the design phase. The metal branches are then covered with conductive material, specifically a mixture of equal amount of conductive and hardener epoxy. Combined in the correct quantity, this mixture provides a conductive connection that both allows the signal to flow from the antenna to the metal branches and fixes the branches onto the antenna when cured properly. This means that after applying the conductive epoxy another curing phase in the oven is needed to stick the board to the paper antenna and dry out the solution making the whole device ready to work.



Fig. 5. Printed antenna mounted on the WISP.

## V. EXPERIMENTAL SET-UP

The antennas presented in this paper have been experimentally characterized and compared to the simulations in terms of different antenna parameters. First, the return loss value was measured with an R&S vector network analyzer within a frequency span of 300 MHz, from 800 MHz to 1.1 GHz. The frequency range operation of the UHF band in the United States spans from 902 MHz to 928 MHz, with the center frequency being exactly at 915 MHz, and these have been the boundaries taken into consideration. So, the working frequency is 915 MHz and all the antennas have been tested to be below the -10 dB thresholds in the desired frequency bandwidth. Subsequently, the gain of the antennas was taken in account. The measurements were performed in a small anechoic chamber, 4 m long, 2 meter wide and 2 meter high, shown in Fig. 2, with the tested antenna connected to a signal generator<sup>1</sup> with a signal frequency ranging from 10 MHz to 50 GHz, for signal strength of -10 dBm. The signal emitted by the paper-based antenna was received by a horn antenna with a known gain of 6 dB and sent back to the spectrum analyzer<sup>2</sup> over a frequency range between 30 Hz to 26.5 GHz. The anechoic chamber is equipped with a movable holder for the transmitting antenna, which is able to rotate 360 degrees and, as a result, perform a complete evaluation of the pattern of the antenna. Fig. 3 shows both simulations and measurement results for the text-meandered antenna with a 70 Ohm input impedance, according to the requirements of the WISP matching circuit, which present an output impedance of about 70 Ohm [4], with no imaginary part. Despite the fact that there is a minor shift in the resonant frequency, possibly due to a minor mismatch in the simulated materials' characteristics, both curves feature a similar 10-dB bandwidth that allows for the effective coverage of most UHF RFID applications.

In order to achieve this goal, a wider dipole of 1.8 cm has been created. An example of this kind of antennas adapted to 70 ohm can be seen in Fig. 5. All the other designs made have exhibited similar behavior, with a shift in the return loss value but with a satisfactory pattern. In Fig. 4 the simulated and measured radiation the patterns are compared. Again we can state that the two curves are highly comparable and they can be considered satisfactory for RFID applications.

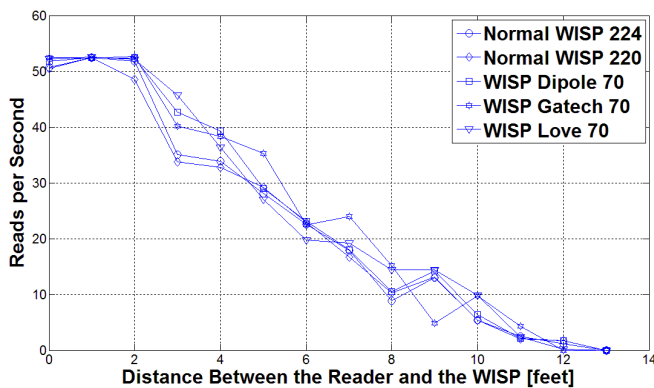


Fig. 6. Performances comparison of the different antennas.

## VI. RESULTS

The final step of the work, after having verified the validity of the prototyping compared to the simulations, is to compare the performance of the WISP when using the commonly used conventional antenna and when using the one proposed in this paper. The results were obtained using the Impinj RFID reader, which has a frequency range that follows the UHF specification, from 902 MHz to 928 MHz. The transmitted power was 30 dBm as from regulations. The WISP was activated by the signal received from this reader with an activation time strictly related to the distance from the reader itself and also related to the number of readings the reader can perform on the tag while changing the distance.

The measurements have been performed in the identical environment for all antennas under test. This means that the results obtained could be affected by the same reflected signal and generic interference, but since the environment did not change during the whole testing phase, their effect is comparable and represents the conditions of a generic real-world application. Obviously, sources of high interference were avoided, and no obstacles were inserted between the tag and the reader.

After connecting the antennas to the WISP, as shown in Fig. 5, we compared, among the whole set of antennas, the rates of successfully repeated read out of the tag ID the reader was able to get in a second of time, while varying the distance of the device from the reader. We chose this metric of comparison because it's clearly demonstrates the ability of the reader to successfully read the information from the WISP. Accordingly, the fewer read outs we get, the less information we will obtain from the tag. Intuitively, because of the passive RFID we are considering, the distance is inversely proportional to the performance. The farther we are from the reader (the power source), the fewer read outs we get from the WISP.

As can be seen in Fig 6, the performance of the WISP platform with the paper antennas is comparable to the one with the normal antennas. Even if there are minor changes in the rate between the different designs, those are not as critical to be considered completely different from the average behavior. Effectively, there are not any evident differences between the normal antennas mounted on the WISP and the ones proposed in this paper.

## VII. CONCLUSION

In this paper a new design solution for the antenna side of the WISP RFID tag has been proposed. The design characteristics and performance of the proposed antennas have been discussed and explained. A performance comparison between the typical antenna design and the paper-based antennas has, also, been conducted.

The aim of the paper is to achieve by the, as effective as possible, marriage of a computationally smart tag, the WISP, with the technology of inkjet printed antennas that enables the realization of a truly possible concealable device based on RFID technology. We can state that the solutions proposed have satisfied all design requirements, and the actual antennas currently deployed in the WISP platform can be directly substituted with the ones proposed in this paper without any performance degrading. On the contrary,

<sup>1</sup> HP 863650L

<sup>2</sup> HP 8563E

deploying a paper-based printed antenna considerably enhances the WISP characteristics and opens a whole new set of applications. The future steps of this work include, first of all, a more precise matching between the simulation and the prototyping that can theoretically increase the range of the device if the correct resonant frequency is perfectly matched.

#### ACKNOWLEDGMENT

The authors would like to thank the IFC/SRC Center for their support and Intel Labs Seattle for providing the WISP samples used in the framework of this work.

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