

RFID System with Passive RFID Tags for Textiles

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Abstract- Radio Frequency Identification (RFID) technology, by assigning a unique identifier to each product allowed spectacular development of wireless monitoring and control applications. With the advances of tags with passive integrated circuits, operating without a self-contained energy source, extracting the needed energy from the energy of electromagnetic waves generated by an interrogator, RFID applications extended to processes held in harsh industrial environments. For textile articles, in industrial laundries, the RFID system with passive RFID tags involves specific architectures and building solutions. The paper analyses the weak points of actual passive UHF RFID tags and proposes solutions regarding the architecture and the materials used in construction of tags suitable for laundry applications. Thus, new requirements have been established to design passive RFID tags: they should be washable and wearable, robustness enough to operate in harsh environments, with a sufficiently long lifetime, and cost-efficient.

Keywords: passive RFID tag, RFID system, UHF, harsh environment, weak points, textiles, laundry application.

I. INTRODUCTION

In 1873 Maxwell in his famous treaty [1], for the beauty of mathematical equations symmetry, introduced in Ampere's Law, the term:

$$\int_{\text{SR}} \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$$

advancing the theoretical hypothesis of the possibility on electromagnetic field propagation.

After a few years, in 1887, Hertz [2] demonstrated, experimentally, the validity of this hypothesis. The way to the transfer, via electromagnetic field, of energy and especially of information was open. Regarding the transfer of energy through electromagnetic field without electrical wires, wirelessly, the beginning binds the name of Tesla [3,4] and it has become a hot topic nowadays. The wireless transfer of analogue or digital information has begun with Marconi patent in 1896, and continued with a long line of scientists and engineers, leading to ubiquitous and fabulous applications of wireless communications technologies [5].

Radio Frequency Identification (RFID) is one of these wireless technologies which use the property of electromagnetic field to propagate in a complete manner, both in the transmission of information and the transmission of energy.

The theoretical foundation of the process of communication in an RFID system, using the phenomenon of

backscattering has been described in [6]. This operating principle allows RFID systems to be used effectively in tracking and monitoring physical objects [7,8].

A generic RFID system consists of an RFID tag fixed on the object it identifies, a RFID reader and a software application. The reader sends a radio signal to the RFID tag, which, after receiving the signal, responds with a signal containing the tag identifier and other data regarding the identified object [9-11].

The successes in achieving RFID integrated circuits and software development, have led to lower prices, increase performances and RFID systems. As a result, RFID systems are widely used in logistics, defence, space, health [12-14].

Thus, the RFID system for supply chain management applications allows:

- substantiation consumption by analysing the use of objects before they become waste,
- analysis of energy use efficiency for production of goods,
- inventory, objectively and in real time, of monitored goods,
- reducing of consumer or industrial goods by inventory management.

There are still many RFID issues in actual researches: RFID tags miniaturization, reduction of energy consumption required for the activation of RFID tags, the integrity of Reader-Tag communication, possibility to use the tags in harsh environments, mitigation of the susceptibility to electromagnetic disturbances [15-19].

Introduction of the RFID systems in textile articles management raises specific issues related to the wash ability and endurance of RFID tags to harsh environmental conditions and repeated washing, the ways of fixing the RFID tag on the textile support, and the effective reading [20].

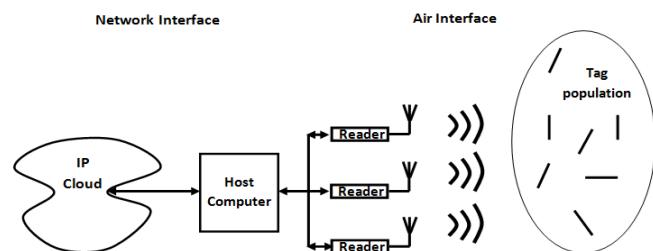


Fig. 1. General structure of a RFID system.

II. RFID TAGS PERFORMANCES

An RFID system includes RFID readers connected to a computer and a population of RFID tags, each tag identifying uniquely an entity (person, place or object) monitored via an inventory, monitoring or security software.

The RFID tag contains a digital electronic device capable of communicating according to the "Air Interface" protocol, by radio frequency electromagnetic waves, with RFID reader. Typically a software application manages several readers (Fig. 1).

Depending on how it is designed the software that controls the RFID system, access to the system can be limited to the local server (Host Computer), or can be allowed from any location with Internet access by Internet Protocols. Different RFID applications establish specific performance levels in terms of communication between RFID reader and RFID tag, and therefore the radio frequency should be specifically established. Ultra High Frequency (UHF) or Super High Frequency (SHF) are used when a high-speed communication and a greater reading distance are needed.

Depending on how extract their power to run, RFID tags are active, passive and semi-passive.

Active RFID tags use energy from their own internal battery, both for the reception of signals from the RFID reader and for the emission of signals from RFID tag, by backscatter, to the Reader. These tags are often compared with minicomputers being able to control proximity sensors, to perform logical operations and even make decisions. RFID systems with active tags operate over long distances. Usually, a RFID system is able to manage a population of thousands of active RFID tags with several RFID readers.

Semi-passive RFID tags, called Battery Assisted Tags, do not need its own power supply for receiving electromagnetic waves emitted by the reader. The formation of the reflected wave (backscatter waves) needs its own power supply.

Passive RFID tags do not use external power from batteries or accumulators. The passive RFID tag power is extracted from the electromagnetic field generated by the RFID reader antenna. Passive RFID tags advantages are directly related to their low cost of production and to the possibility of their easy attaching to the identified objects. These types of systems are widely used in supply chain systems due to low price and a form factor that does not depend on power source. Specific performance of RFID tags are given in Table I.

Applications that need a greater distance of communication is more efficient to work at high frequencies of the order 900 MHz (UHF), considering that with the increase of the frequency, length required for RFID antenna decreases and also increases the directivity of RFID reader antenna.

Thus, for the same RF power radiated by the RFID reader, RFID tag available power at high frequency is higher [10, 21, 22, 23]. However, increased to GHz, increase the complexity of RFID tag design and as a consequence, the price.

TABLE I
CHARACTERISTICS AND PERFORMANCE OF RFID TAGS

Types of RFID tag	Active RFID tag	Semi-active RFID tag	Passive RFID tag
Frequency	433 MHz	860-950 MHz	860 – 950 MHz.
Coupling	Radiation	Radiation	Electromagnetic field; Backscatter
Read rate, tags/second	500 – 1500	500 – 1500	500 – 1500
Read distance	1000-3000 m	100 m	10 m
Storage capacity	+60 kB	+60 kB	+100 B
Battery Lifetime	3 - 5 years	3 - 5 years	-
Cost	10\$ - 100\$	0.1\$ - 30\$.	0.10\$ - 20\$.

A specificity of UHF passive tags is that they transmit information only when they are in the reader electromagnetic field.

Further, efforts are made to improve the structure and functional characteristics of the passive RFID tags.

For communication over distances of several meters, passive RFID tag comprises a UHF antenna and an integrated circuit IC, tiny size, which, in its internal memory, stores the unique identifier of the object to which it is attached, and other information required by the concrete application.

The two fundamental components of the RFID tag are connected via an adaptive impedance structures. This allows resonance between IC and UHF antenna, which provide, on the one hand, a maximum transfer of electromagnetic energy from the reader to tag, and on the other hand, the integrity of transmitted / received data.

There are different various geometries and shapes of passive UHF RFID tags (Fig. 2)

From the constructive point of view (Fig. 2a), the core of the RFID tag is a the so-called "inlay" which comprises an electrically insulating substrate (1) (plastic, paper, fabric) on which there are placed UHF antenna (2) and adaptive impedance structure (3), made from electrically conductive materials (metallic wire, textile electroconductive yarn, nanowires).

Integrated circuit (4) is then bonded with a conductive adhesive to the adaptive impedance structure. Additionally, the "inlay" can be coated with textile or plastics.

Commercial passive UHF RFID tags, shown in Fig. 2b and Fig. 2c, include typical passive tags structure: integrated circuit, adaptive impedance structure and UHF antenna. The differences are given by the UHF antenna geometry (form factor, shape and number of meanders, shape of the tips).

An analysis of power levels handled in a RFID system with passive tags is shown in Fig. 3 [24]. Reader emission signal has a level of 30 dBm / 1W, and only -10 dBm / 0,1mW at 6 m distance, where we assume that passive RFID tag is.

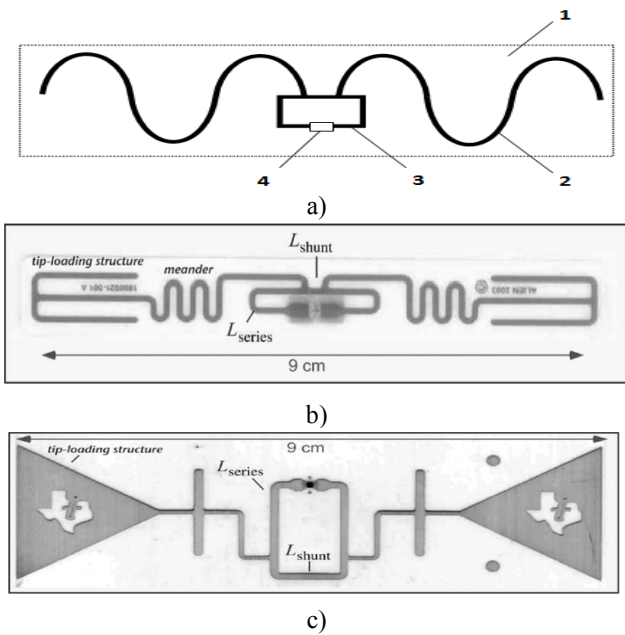


Fig. 2. Structures of passive RFID UIF tags:
a) generic structure; b) with meanders; c) with different shape of the tips.

After reflection (backscattering) on RFID tag, the signal will have the level of $-60 \text{ Bm} / 1 \text{ nW}$ to the RFID reader entry.

Thus, the main requirements that are taken into account in passive RFID tag designing are the reducing power consumption and the increasing degree of workability (constructive forms, increase rectifying efficiency, optimal choice of communication protocols, etc.).

To meet these functional requirements, advanced design and execution procedures of the tags must be correlated with the specific applications and environments where RFID tags will work.

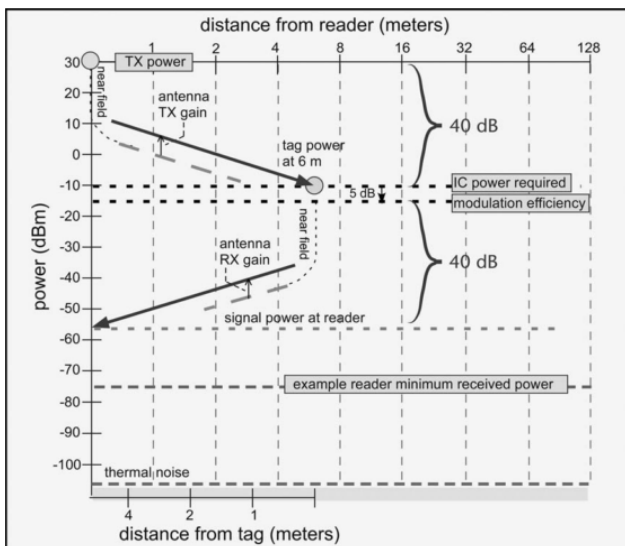


Fig. 3. Power levels in a RFID system with passive RFID tags [24].

III. ASSESSMENT OF WASHABLE PASSIVE RFID TAGS

A. RFID system and work environment description

In the area of Brasov town, an industrial laundry was equipped with a RFID monitoring system of textile objects, which consists in passive RFID tags, RFID readers and the RFID application that uses RFID data.

Readers are mounted in specific interrogation areas, called the read gates, in which are introduced trolleys filled with textiles RFID tagged, at the entry and the exit of laundry. It includes an interface that communicates with the articles monitoring software application that controls the washing procedures, distribution and use to the customer (Fig. 4).

RFID data is processed by operational management system, to fulfil its current tasks (good delivery, packaging, etc.), for data analysis applications, and for top level strategic management decision (Fig. 5).

The working environment for RFID tags embedded in textiles is complex in this case. Textiles, along with RFID tags, are subject to cyclic stress, on the supply chain, to the end user, and then the stage they reach the laundry.

RFID tags are stressed with specific industrial laundry environmental factors:

- washing temperatures of up to 90°C , more than 20 minutes,
- high temperature variations – cold/warm ($8^\circ\text{C}/90^\circ\text{C}$),
- chemical agents included in washing procedures,
- squeezing pressure of 40-60 bars,
- finishing / ironing temperatures of 200°C , tens of seconds.

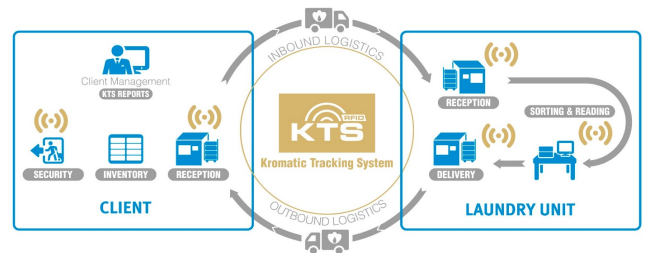


Fig. 4. Flow of information between client and laundry.

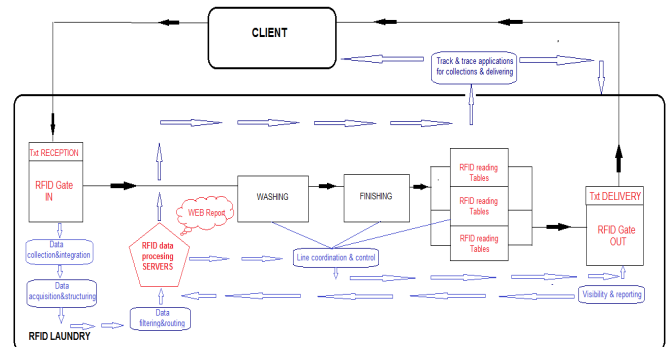


Fig. 5. Scheme of RFID data processed by operational management system.

Contact with water and other substances as detergents, temperature variations and mechanical stresses in the steps of washing, squeezing and ironing, are physical deteriorating RFID tags and decrease the efficiency of communication between reader and tag, but mostly destroy the galvanic connection between the integrated circuit and the adapting impedance structure.

B. The effects of washing cycles on RFID tags

To increase RFID technology efficiency, an analysis of the specific industrial laundries environment impact has been conducted to determine the causes of RFID tags deterioration and to identify optimal constructive/ functional solutions.

A first experiment was done on the samples of passive RFID tags, Fujitsu type, with adaptation impedance structure, which has been subjected to several washing cycles [25].

The inlay is done on a plastic substrate, which were made, by aluminium printed circuit structure, adapting impedance structure common with UHF.

The chip is glued fixed with conductive adhesive on the adapting structure impedance structure (Fig. 6, Fig. 7).

Fig. 6 shows the sample of UHF RFID tag view after the applied stresses, and when the protective silicone coating was removed.

Fig. 7 shows that the insulating substrate, the adapting impedance structure and the UHF antenna are in good state, the samples have resisted to the environmental stress conditions specific to industrial laundries.

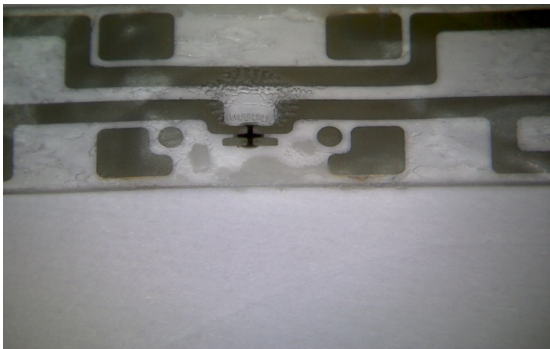


Fig. 6. UHF RFID passive tag - back view.

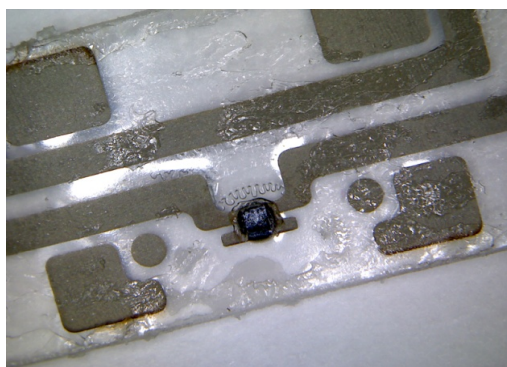


Fig. 7. UHF RFID passive tag - front view.

But the galvanic contact, made of conductive adhesive, between integrated circuit pins and the adapting impedance structure felt to the test. It follows that galvanic contact between integrated circuit pins and the adapting impedance structure have to be much better protected.

In order to establish relevant solutions for increasing the wash ability of passive RFID tags, new tests have been made to establish the impact of washing procedure and laundry environment on RFID tags integrated in textile articles.

In Table II, are summarized the stresses encountered by tagged textiles in different stages of laundry process, and the effects on tags integrity. In the worst case, the tag become no longer functional, the textile item lose its identity and the RFID monitoring system is useless.

The weak points of actual passive UHF RFID tags were analyzed and solutions regarding the architecture and the materials the tags are proposed:

- to develop adequate materials to protect "inlay" support,
- for RFID tag components, to use materials with the same thermal dilatation coefficient,
- for UHF antennas, to use electrical conducting materials with mechanical strength closed with textile article,
- optimization of the design of the UHF antenna,
- establishing new methods for electrical contact between CI pins and UHF antenna.

Regarding the galvanic connection points, there are specific solutions, as:

- reduction to minimum the galvanic contacts of tag architecture, and removal, as it is possible, of galvanic contact with the inductive coupling,
- protection of galvanic contacts,
- achieving more robust galvanic contacts,
- use of materials with flexibility close to the textiles ones when building the UHF antennas. Nowadays, there are related the uses of electrically conductive textile yarns [22] or conductive inks [23].

The result of analysis certified the main way for the passive RFID tags with adaptation impedance structure to withstand the stress specific to industrial laundries is a well protection of the galvanic connection points of integrated circuit pins.

Indeed, the solution that has been imposed for RFID tags used in industrial laundries was to create a small transponder, centimetre range, inductive coupled with the UHF antenna (Fig. 8).

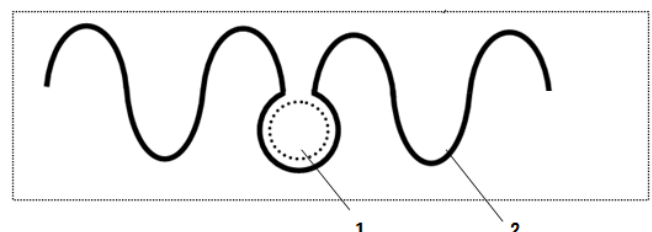


Fig. 8. The structure of a RFID tag with an encapsulated transponder (1) inductively coupled with the UHF antenna (2).

TABLE II
STAGES, STRESS CYCLES AND EFFECTS ON RFID TAGGED TEXTILES IN THE INDUSTRIAL LAUNDRY

No.	Stage	Tag stress	Aspect	Effects
1	Textile reception	- Mixing of textiles results in folding, creasing and random position UHF antennas of RFID tags.		- Transfer of energy RFID tag – reader, and data integrity is seriously affected.
2	Washing procedures	- RFID tag contact with water, detergents, industrial chemicals class. - Washing temperatures up to 90°C, more than 20 min. - Repetitive cold-warm variations (8°C-90°C). - Stress to mechanical forces specifically for the washing process.		Textile article loss of identity due to: - stitches weakening or tearing of the textile material, - breaking in the contact area of the various components (IC, adapting impedance structure, conductive adhesive) which make the galvanic electrical contact.
3	Squeezing procedures	- Stress with pressure of 40-60bars.		- Encapsulated transponder from the RFID tag breaking or its separation from the textile cover.
4	Finishing procedures	- Tens of seconds at about 200°C temperatures, - High pressure.		- Breaking the encapsulated transponder of the RFID tag due to the effect of the pressure, - Destruction in the encapsulated transponder of the textile support, followed by its loss.

The micro-transponder is well protected in a capsule that isolate it electrical, mechanical, thermal and chemical from the environment of the laundry.

Electromagnetic performances are satisfactory, the reading range is 3-5 meters.

Although surpass in reliability tags with adapting impedance structure, in aggressive environments, specific to industrial laundries, even passive RFID tags with encapsulated transponders are destroyed at 15-25% rates.

The weak point, this time, is transferred to the encapsulated transponder, where the galvanic connections between the integrated circuit pins and the conductive loop could be interrupted, leading to loss of textile article identity.

An evaluation of the galvanic connection between the integrated circuit pins and the loop wire, analysis methods of making such connections and materials used, premise

solutions that will lead to the development of even more robust and reliable passive RFID tags.

IV CONCLUSIONS

RFID technology is widely applied in the tracing items throughout their lifetime, being a valuable tool in supply chain management and strategic decisions in energy and materials savings, safety and security.

Effective monitoring process is closely link to keeping the identity of products that can be lost if the tag is no longer functional, either by physical destruction of some of its components or by interruption of electrical contact between them.

This paper identifies the weak points of actual passive UHF RFID tags, and proposes solutions to have passive UHF tags, robust enough to operate in harsh environments specific to

industrial laundries, with a lifetime sufficiently long, and cost-efficient, at the parameters set by the laundry application.

The tag architecture design must minimise the number of galvanic contacts, by removal, as it is possible, of galvanic contact with the non-contact inductive coupling. Passive UHF RFID tags with encapsulated transponders are recommended in textile logistics in aggressive washing processes.

The materials for the tag components have to resist to the industrial laundries harsh conditions, with mechanical and thermal properties close to those of textile materials.

This research was carried for sustaining the implementation of a RFID monitoring system in a modern industrial laundry, built in 2011 within the company PROMAR in industrial park Prejmer, from Brasov County.

Implementing a RFID monitoring system operating in the field of UHF has enabled rapid reading of hundreds of textile articles and formed the basis for the development of high performance computing applications in one of the most modern industrial laundries in the world.

Accumulation of knowledge related to tags for harsh environments made possible the development of the specific passive RFID UHF tags for the laundry.

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