Project IST-034144: SToP
Stop Tampering of Products

Deliverable 4.3

Report on Integration of Smart/Intelligent Tags in Products

Leading Partner: SPC

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Executive Summary

The mission of SToP is to develop secure, comprehensive, usable, cost effective and convenient product authentication mechanisms to reduce the trade of illicit products. The project's main objective is to develop a distributed and collaborative ambient intelligence-based network-oriented system, enabling enterprises, e.g. producers and distributors, as well as customers to securely manufacture, deliver and purchase secure and authentic products, respectively.

The key component of any RFID based anti-counterfeiting solution is the RFID tag. Tasked with carrying authentication data, and to provide this when requested with 100% reliability and accuracy irrespective of the environment, product, or process, the RFID tag is the most crucial component of the system. It is the entry vehicle for the authentication process, without which the process cannot be started and in fact becomes non-functioning and irrelevant.

Given this importance then, it is essential that the selection, integration, and deployment of RFID tags within a company's products is done correctly and securely in a cost efficient yet failsafe manner. This document provides background information on integration of RFID tags, and then goes into detail regarding the analysis, testing, integration, and go-live stages of RFID solutions for real world applications in real companies.

The outcome is a template driven process detailing and suggesting each step followed, and to be followed, by companies when deploying RFID for anti-counterfeiting solutions. The process has been validated in real live pilot settings with successful outcomes, thus proving the approach and its applicability to other companies and industries.

1 Introduction

1.1 Project description

SToP is an EU subsidised project aimed at developing an anti-counterfeiting solution for companies concerned with, or affected by fake products, including luxury goods, pharmaceutical and aviation companies.

This solution will comprise the evaluation and development of advanced smart identification technologies (such as RFID, and other technologies) together with the design of suitable and scalable software and architecture components as part of a comprehensive secure network infrastructure. The project, development, and final solution will be driven by the requirements of the end users within the project consortium.

The SToP consortium of companies comprises leading technology vendors and end user companies, as well as academic institutions committed to achieving the objectives of developing a sound anti-counterfeiting solution for use in the European Union and, by natural extension, globally.

SToP recognises the key and central role of companies in the anti-counterfeiting initiative, and ultimately that for the solution to be feasible and successful it needs to satisfy the diverse business sector requirements and also make economical sense. Legitimate businesses bear the brunt of counterfeiters' operations, and it is the dedicated intention of SToP to eliminate as far as possible counterfeiting and its adverse consequences on the companies' sales, market share, revenue, operating profit, litigation costs, and working capital. Moreover reducing or eliminating fake goods ensures that the brand is not eroded and confused with counterfeit copies, and company reputation is maintained and enhanced. For society, the most important benefit is product safety - counterfeiters do not respect quality standards to ensure user safety or benefits. Bogus products such as pharmaceuticals, aviation spare parts, toys, etc can be potentially dangerous or even lethal. There have been numerous cases worldwide where counterfeiting of products resulted in serious, life-threatening or even fatal results for the consumer.

SToP deliverables will enable immediate implementation and integration into the particular company's product portfolio and offerings - luxury goods, pharmaceuticals, security documents, aviation components, etc - and the related manufacturing and packaging, as well as inventory control and logistics processes, to eliminate counterfeiting and its consequences for the respective companies and their customers. Furthermore, using software related results these partners will be able to provide web-based product authentication services for the respective distributors, wholesalers, consumers and also for national authorities in different countries. For the EU the project is seen as a cornerstone initiative and deliverable in its fight against illicit trade.

1.2 Objective of Deliverable 4.3

Deliverable 4.3 is the third report generated in Workpackage 4 which relates to Solution Engineering and hardware research and development to achieve SToP anti-counterfeiting objectives.

This deliverable is specific in its focus on intelligent RFID tags and their integration into end user products. The objective is to inform companies of options available in respect to tags, what needs to be considered when identifying and selecting tags, and how to successfully integrate those tags into products. A template of real live trials by consortium members is suggested to guide companies in their approach.

1.3 Relation to Tasks, Deliverables and Workpackages

Deliverable 4.1 created the foundation for Workpackage 4 by researching and analysing existing smart/intelligent devices that are conformant to the requirements of SToP. Deliverable 4.1 scrutinized existing and emerging anti-counterfeiting technologies, their relevance and applicability to consortium companies and industries, and proposed potential approaches to implementation as stand alone or combination technologies. The most promising approaches from a SToP perspective included RFID as a cornerstone technology in any anti-counterfeiting system - with or without other laser, digital and/or printing technologies. Deliverable 4.2 builds on this to identify approaches and considerations for deployment and implementation of RFID specifically, and prepares for WP 5 where the practical applicability of RFID (already selected via Deliverable 4.1) is evaluated by integrating RFID into real life products and processes. Deliverable 4.3 takes outputs from the aforementioned deliverables, combines this with the learning from the live trials, and outlines specific requirements and approaches for successful integration of RFID tags into products. Deliverable 4.4 will then revisit the production and manufacturing of the smart enabled final product originally discussed (prior to live trials) in Deliverable 4.2.

Other Workpackages: From a project process perspective, the outputs of WP 4 support and direct practical implementation and requirements for WP 5. Moreover, WP 4 enables the outputs of WP3 and the PVI i.e. it provides the hardware for the software functionality developed in WP 3.

1.4 Document Structure

This paper begins with an overview of important aspects of tag selection, integration, and deployment. This is then followed by applying such tag considerations to real live trials conducted by and for the consortium partners in luxury goods, aviation and pharmaceuticals. The knowledge, learning, experience and results is then combined into a template approach for use by other companies and industries looking to implement RFID based anti-counterfeiting solutions.

2 Overview

RFID smart tags are an essential component of any RFID system. Without optimally designed tags and their integration into products, the functioning of all the other components of the RFID system is debilitated and in fact irrelevant since the primary data carrier (i.e. the tag) is compromised.

There are more RFID tag types, design and integration permutations than can be counted, including coupling principles, transmission frequency, and form factors such as size, shape and materials. Tags can be integrated into products or their packaging, or merely affixed/applied to products or packaging. With this amount of choice available it is confusing yet essential to select both the correct tag solution as well as the correct integration/attachment method. Moreover, the integration/attachment method crucially must maintain a product's integrity as well as its aesthetic appeal.

Although RFID is usually an IT or logistics department driven initiative, it is essential companies consider and finalize tag selection, product design and tag integration both early and substantially in the project and prior to adopting the technology. These considerations have to be concluded prior to adopting the technology since if done incorrectly can jeopardize any rollout of the technology and its acceptance by companies.

Having a technology that works is one thing, making it work in a product is an entirely different thing.

3 Tag Selection and Deployment

In selecting and integrating RFID tags into products, many tag parameters essential to successful use must be analyzed in detail. These are listed and discussed briefly in this section, and in more detail further in the paper within the context of the SToP project and consortium partners' process.

3.1 Tag Performance

Tags are the most important component of RFID implementation – it is the foundation and the entry point to effective anti-counterfeiting RFID solutions. Important considerations, in no special order, when using and deploying a tag for supply chain use include [KCSJ04]:

- sensitivity: whereby a chip must both receive sufficient power from the reader, and at the same time transmit a signal of sufficient strength to the reader
- placement and orientation: whereby read rate is affected by the orientation of the tag on a box or pallet relative to the reader
- tag intra/inter position relative to other tags: whereby tags can interfere with each other when stacked too close together
- tag form factors: whereby in general, larger tags have longer ranges; but ., products often only have a specific place of set size and shape for label placement
- read speed: whereby the amount of time required by the tag to be within read field e.g. in the carton on a moving conveyor, or a tagged pallet on a moving truck
- data requirements: whereby tags can contain different types and amount of information according to requirements
- environment: whereby RF interference affects read rates due to sources of RF noise, proximity to other tags, and the composition of packaging materials and surrounding surfaces such as metal
- conditions: whereby steam, corrosive chemicals or extreme cold will affect antenna chip connections, or the adhesive on a tag, etc
- re-use: whereby re-use requires modification to information on a tag, or to form factors and adhesive used, etc
- regulations: whereby tags may have different read range and sensitivity depending on their different global rules on power, frequency etc
- data collision: whereby tag replies from many tags read simultaneously are managed to avoid interfering with each other
- readers: whereby available readers to support different tag types may influence the decision on what tags to use
- security: whereby some applications such as anti-counterfeiting warrants data encryption and other measures that may not be supported in all tag types

In considering performance specifications, a company may need to consider a number of trade-offs between performance, cost, read range, read speed, product components such as metal, tag placement such as overt versus covert etc. Some common trade offs include:

- read only versus read write: tags can be read only, write once/read many times or read-write. Data on a read only tag cannot be changed unless the chip is electronically reprogrammed and they are often used to track assets that will have a unique ID over their lifetime such as for medications, luxury goods, and aircraft parts. Read-write tags on the other hand contain dynamic data memory that can be written to and read from, combined with a permanently encoded algorithm for communicating with the reader. A read-write tag will allow changes to the stored data and they are used to track items through the supply chain. Read-write tags provide a living history of the item being tracked and therefore increase transparency in the supply chain. Some of these read-write systems come with cryptographic functions for reciprocal authentication and for encryption of data traffic. However, read write functions and security additions come at a cost as well as reduced performance in terms of read range, read speed, and anti-collision functionality. Moreover, while RFID tags have read/write capability, it can be argued from a practical perspective there are few processes that should ever change the RFID tag data. The same concept can be applied to tags - while a local tag could have its data stored directly on it - the future of RFID tags / tag data will likely be as beacons into a central database. Central databases will store the complete tag history and data.
- higher frequencies versus lower frequencies: higher frequencies are faster and longer, but have reflection problems and are negatively impacted by metal, liquid, glass and moist environments. Low frequencies are not impacted by the presence of metal and can even read through some non-ferrous metals [WIDE04]. Consequently, Ultra High Frequency has a long read range and high read speed but when operating in metal or organic environments the performance reduces dramatically; low frequency on the other hand has a lower read range and read speed but excellent performance in the presence of metal or organic material. Memory size ranges from 2 kilobits, which is typical for inductive systems, up to 256 kilobytes for systems in the UHF and microwave ranges.
- active versus passive tags: active tags are more costly since they contain a battery that provides power so the tag can transmit a signal, up to 50 meters, to a reader. Passive tags do not contain a battery and hence are much cheaper than active tags and therefore can be used more cost effectively to track at the item levels. Furthermore, the longevity of passive tags is not limited by the shelf life of batteries, and disposal of the batteries does not need to be considered. Passive tags are read when they pass through the electromagnetic field of a reader.
- security versus performance: increased security but reduced tag performance such as read range and anti-collision capability (the ability to read many tags simultaneously).
- simple versus complex antenna design: on a passive tag, the most important design characteristic is the antenna. A multi-directional antenna is less orientation specific and hence performs better than a single-directional antenna, but at a higher cost [WEI04].
- health risk: reader range and speed of data transfer increase as frequency increases, but so does the health risk to workers due to radiation.

No single RFID frequency can ubiquitously satisfy all customer requirements. Pure physics defines differences between the various frequencies that results in different frequencies being better suited to different applications.

RFID system performance requirements must be clearly understood and defined by companies implementing RFID. The anti-counterfeiting objectives of end users are likely to be best served by passive tags. The main reasons include i) performance – i.e. adequate read range, read speed, and reliability; ii) integration size – i.e. smaller form factors since no battery attached; iii) cost – passive tags are cheaper than active tags iv) longevity – the lifespan of passive tags are not limited by battery life and v) environmental concerns – the disposal of batteries from active tags is a sensitive, time consuming and costly process. Read-write functionality may be required for the pharmaceutical and aviation companies in the consortium, while read only functionality will likely be required for the luxury goods industry.

3.2 Tag Cost

Most users have limited insight as to how much engineering goes into the design and manufacture of an RFID tag - a great deal more than just volume determines price. There are so many variables that affect price and, consequently, performance. Thus for purchases of more than a few hundred tags, it is important to understand that tags are not created equally. Tags (like readers) require planning to purchase. The amount of time it takes to manufacture a finished RFID tag may be up to 18 weeks, thus it is important to identify different sources for tags, and in addition to the primary manufacturers it is worthwhile contacting several selected RFID label converters.

Depending on performance and integration requirements, current costs for passive tags can be anything from €0.10 to €1 which when applied to an enterprise wide rollout could be prohibitive to adoption. However, the cost of RFID tags (and other components of RFID systems) continues to fall - passive tags have fallen from about €1 per tag in 2000 to about €0.10 in 2008. As volumes in the market increase, companies can continue to expect substantially lower per unit costs for tags and readers.

The cost and performance of RFID tags are also a function of the level of radio frequency waves produced by the reader. Low-frequency tags require a larger antenna that increases the tag size and cost. High-frequency tags can be smaller and cheaper, but require a more expensive reader.

Given the global coverage and high volumes of products shipped by companies; tag costs will need to be maintained at acceptable levels. In addition, as covered in Workpackage 2, costs must be considered from a total cost perspective (rather than on individual tag unit costs) and the threshold level at which positive NPV and ROI is generated.

3.3 Tag Standards

Standards can be applied to various aspects of tags including format and content of the codes on the tags, protocols, security and tamper resistance. Two main RFID standardization bodies exist – EPCglobal and ISO where a number of standards have been developed. RFID tags can be manufactured from a variety of these chip and code formats e.g. the Electronic Product Code (EPC) uses a 96-bit scheme advocated by EPCglobal. In certain applications, standard tags are important so that they can be used beyond the confines of a company's processes and walls. Moreover, the establishment of a standard will force costs to drop as RFID suppliers can all produce compatible chips and tags in much higher volumes (and thus at lower costs).

In many applications however, proprietary applications may be required to fulfill customer's requirements for the following reasons:

- standards do not meet all customer requirements.
- item level tagging is not currently adequately addressed by standards
- standards do not achieve full and reliable operation in harsh environments such as metal, organic material, liquids, close proximity, multiple orientations
- No single tag can ubiquitously satisfy all RFID requirements.

Because of this, many industries and companies require solutions now that are not technically feasible under existing standards. Thus companies need to focus in the first instance on what technology works the best in their environment, and then on whether it is a standardized or proprietary solution.

Moreover, anti-counterfeiting RFID solutions may best be served by non standard technologies to minimize the amount of information and know how that counterfeiters can access with standardized solutions. There are currently no specific global anti-counterfeiting standards in place or under development (and likely will not be)-representing the inherent conflict between making solutions widely available for end-users on one hand, while on the other needing to keep the solution from being exploited, undermined and breached by counterfeiters. Companies will obviously err on the side of keeping solutions secure and private.

3.4 Tag Integration

Products and product packages come in all sizes and types, and tags must be able to fully deliver the performance requirements within the integration constraints, as well as physically survive the full production and distribution processes and environments including shipping wear, temperature extremes and material handling machinery.

Integration is often the single biggest concern for managers [FER04]. It is essential to ascertain how and where tags will be added to products:

- integrating tags into the product packaging or products themselves at manufacture
- adding tags to products using adhesive label application on the production line
- adding tags to products only at the point of sale

The trade-off between the three options is that cost decreases as one moves down the list above since less infrastructure adaptations and investment is required (e.g. production line machinery, production line speed, infrastructure changes etc), but at the same time the supply chain is less secure due to the audit trail being less extensive due to tags – and thus data capture - introduced further along the supply chain. In addition, tags are not irrefutably linked to products since they are only applied after the fact at distribution or retail levels.

There are several different categories of finished, passive RFID tags:

- labels: typically are affixed to corrugated cardboard, paper, or plastic.
- laminated cards or cardboard tickets: are usually carried by a person.
- plastic injected molded tags: these can address any number of applications, including rugged environments and metal mounting issues
- tags that can be integrated: use different approaches to facilitate integration directly into the respective products

End user companies with anti-counterfeiting as their primary goal need item level tagging to occur as early as possible - to ensure the ability to identify and authenticate individual products securely. Obviously the earlier in the supply chain that RFID based anti-counterfeiting solutions are implemented, the more secure the supply chain and the more control can be exerted over products to reduce illicit trade.

3.5 Tag Security

RFID may pose security risks to organisations. Unprotected tags run the risk of eavesdropping, tampering, lifting, cloning, etc and data obtained from RFID tags can be misused in a variety of illegal ways including legitimising fake goods, reducing the price of expensive items, theft, corporate espionage, etc. RFID technology used at the item level can be used to obtain information about customers and to track their movement without their knowledge. Some steps to reduce the privacy concerns of consumers include for example using RFID only on pallets, cases and shelves for streamlining the inventory and supply chain handling systems, but not at the item level. If tags are used at the item level, they could be deactivated after the Point Of Sale (POS), or various Public Key Infrastructure encryption and access techniques can be used (and are being used) [JUE05]. Next generation tags could incorporate additional blocking and encryption systems, designed to protect privacy and unauthorised reading. Also, programmable read-write tags can be encoded with security features that limit access, and to identify and record unauthorised reads.

More detailed discussions on security are provided in Deliverables 3.1 and 4.1

3.6 Tag Disposal and Recycling Requirements

A standard commercially available tag in the form of a smart label contains a number of metals, semiconductors and plastics: The antenna typically contains copper, the chip consists of silicon and the substrate includes polyester. Active tags even have a battery containing a substance such as lithium. The question of material composition and disposal comes up for RFID systems as it does for other electronic components composed of many of materials, some of them environmentally harmful

Generally, only RFID tags that are directly integrated into an electrical device must be disposed of (along with the device) in compliance with EU Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE). If the tag is part of the packaging or is affixed as a label, it belongs in ordinary household waste (considered relatively unproblematic, since their chemical composition does not represent a major hindrance for today's incineration plants). .The same holds true when the tag is integrated into non-electronic products (see EC 2005). Even though disposal may not be an urgent consideration now, it may eventually become necessary for companies to examine disposal and recycling in more detail as the quantities of RFID tags in consumer goods and other ordinary objects increases substantially.

Companies should thus plan to minimize the burden of disposal. In this regard active tags could pose substantial challenges and is one reason for companies selecting passive tags that do not impose heavy requirements for disposal of tags and that are broadly speaking in compliance with current directives. This compliance would need to be confirmed for the finally selected and/or developed products. Consideration may need to be given to setting up reverse supply chains to recycle or reuse tags, especially when the proliferation of tags spreads to lower cost individual items and the number of RFID tags in use increases massively.

4 Tag Integration Template

This section outlines in detail the process followed in the SToP project by both end user and provider companies in selecting and deploying RFID tags in their products. The process described serves as a robust yet easy to follow template for all companies considering deploying RFID as an anti-counterfeiting solution.

4.1 Phase I: Research and Analysis

Taking into account the analysis above, and in order to determine the finished tag's requirements for SToP consortium members, a series of questions were addressed prior to selecting and testing the final solution for the respective end user companies.

- what size finished tag is necessary?
- will the tag be overtly or covertly placed?
- will the tag be flat or bent when attached to the product it is tagging?
- what is the maximum read range from the products being read?
- will multiple tags need to be read simultaneously and if so, how many?
- are products on conveyor belts: what is the minimum time available to read?
- how will the tag be applied; manually or automated applicator, or integrated?
- what are the typical environmental conditions in which the tag must operate, including minimum & maximum temperatures and humidity? will the tag encounter water, chemicals, solvents (ie washing), certain spectrums of light, or mechanical impacts? what conditions will be encountered during any shipping/delivery processes)
- does the tag need to be read only or read-write?
- does anything need to be printed on the tag? what printer is being used?
- what is the anticipated tag life required?
- must the tag be permanent or removable?
- what volume of tags are required and over what period of time?

The answers to these questions dictated i) what tags were required, ii) what material components were used in tag construction, including: inlay type, facing, backing, adhesives, dimensions of facing/backing, inlay placement, finished roll size, roll core size, iii) quality assurance tests required, and iv) robustness and scalability of the solution

The detailed analysis of these questions for each end user company yielded the following outcomes:

4.1.1 Pharmaceutical goods

The requirements were solicited for the RFID tags and the 2D barcodes used in the pharmaceutical trial by providing the following answers to the questions above:

- The tags should be printed on the external packaging, and should be applied both to bottle or cardboard packaging.
- The tags do *not* need to be covertly placed.
- The tags should support both modes of application to the packaging: flat (for cardboard packaging) and bent (for bottle packaging).
- There are no requirements for bulk reading in the context of the pharmaceutical trial.
- The tags will be automatically applied on the production lines.
- The tags should be initialized and verified at production lines with speeds up to 250 units per minute, so the read and write speeds should match this.
- There are no environmental conditions that need to be accounted for, e.g. extreme temperatures, washing, etc.
- The tags should be read-only tags since the only information expected to be stored on them is a unique identifier that shouldn't be modified after production.
- The only information stored on the tag should be an Electronic Product Code (EPC) in the SGTIN 96 format.
- The tag life required is one year after the expiry date of the product – which is up to 6 years.
- The tag should not be removed without damaging the external packaging.

The RFID technology used can be either HF or UHF – the deciding factor should be the performance in a production environment. Namely, different tags from different suppliers should be compared on production lines with current speeds. The tags – pertaining to a specific technology and supplier – that perform best will be recommended for the SToP trials. The main performance indicator that the tags will be evaluated against is the error and thus the reject rate. The results of the detailed tests are provided in section 304.2.1. As the experiments show the UHF tags provided a lower percentage of encoding errors and thus rejects, therefore they were the chosen technology of the pharmaceutical trials.

4.1.2 Luxury goods

In this industry the tag integration study can be split in two families: tag integration into a watch and tag integration into leather goods. Two studies need to be completed due to the complexity of the final product. In the case of watches, they are mostly made in metal and this material causes a lot of difficulty for the anti-counterfeiting radio frequency (RF) signature reading. In the leather good case, the reading environment is less difficult but security of the RF signature must be improved along the supply chain.

4.1.2.1 Watch Use Case

The study is about two different watches - a big watch with a back cover made of two materials (glass and metal) and a small watch with a fully metallic back cover.

Figure 1 : Back case of the watch

The goal is to embed a RF signature into both watches and to read the signature one by one throughout the lifecycle of the watch which would typically comprise of manufacturing, distribution, point of sale and customer service.

In deliverable 4.2, we demonstrated the theory of the magnetic and electrical field and some electromagnetic simulation and that the only approach to detect a RF signature in the presence of metal was to reduce as much as possible the carrier frequency of the RF field.

The smallest carrier frequency available for RFID is 125 kHz; this frequency allows the electromagnetic field to penetrate a few millimeters of the most common metals used in the luxury good industry. The field penetration through the metallic part is enough to supply the RFID tag and allow the tag to respond with its signature to the reader.

Two sorts of tags have been evaluated for the watch integration:

The ferrite tag is composed of a ferrite core and a copper coil wound around the core. The chip is positioned on the side of the core. A ferrite core gives a good performance in metal integration due to the field concentration in the core.

Figure 2 : LF Ferrite tag

The circular tag is only made by a copper coil connected to the chip.

Figure 3 : LF Circular tag

After analyzing the mechanical drawings of the watches, it was not possible to find a ferrite tag sensitive enough when in the watch. The sensitivity of a ferrite tag is dependent on the length of the core, the diameter of the core and the number of turns on the antenna. Any of theses combinations determine a tag's geometry and its ability to be integrated in the watch.

4.1.2.1.1 Small watch

Then, the focus was on the circular coil and the analysis started with the small watch, as this watch was the most difficult due to it's fully metallic case and very small size. The RFID tag size had to be calculated in order to fit into the watch and to give enough RF signal.
A tri dimensional drawing was made to evaluate the RFID tag dimensions and verify if the tag could be correctly fixed in the case without any impact on the watch design and mechanism.

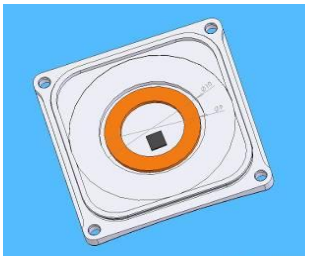


Figure 4 : 3D drawing of tag integration

The tag parameters are defined as follows:

Characteristics	Min	Typ	Max
Copper Wire Diameter cladding thermo adherent	*See manufacturer*	24,5µm / 33µm 50AWG CU B155,Grade1B	*See manufacturer*
Internal coil diameter	/	9 mm	9,1mm
External coil diameter	3,9mm	4 mm	/
Coil antenna thickness	/	330 µm	320 µm
Turn number	692 turns	702 turns	710 turns
Number of copper turn per layer	/	10	/
Number of layer	/	64	/
Inductance @119kHz	2,9 mH	3 mH	3,1 mH
Parasitic capacitance	1 pF		8 pF
Serial resistance DC	490 Ω	500 Ω	510 Ω

Table 1 : Tag parameters for the small watch

We also use a chip which is able to send a signal using a frequency lower than the carrier frequency. The SpaceCode chip is working in the low frequency band and is especially designed to work close to the metal. The antenna parameters are modified by the proximity of the metallic part and also the tuning of the chip.

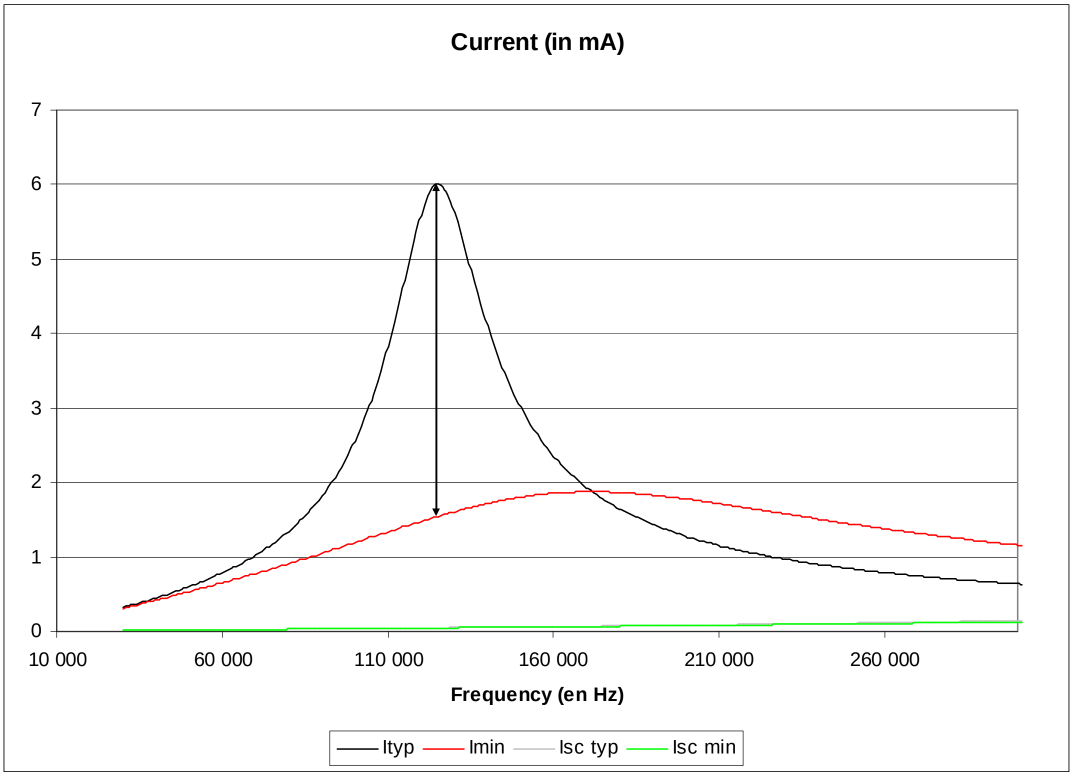


Figure 5 : Resonant frequency

The black curve shows the typical response in frequency of ISO 11785 tags. The antenna circuit is tuned at the resonant frequency (125kHz) and the current induced in the antenna is maximal.

The red curve shows the impact of two pieces of metal around the antenna - using the same frequency the current induced in the tag antenna is divided by 2,6 due to the antenna inductor modification (3mH to 1,6mH) and the parasitic resistor increase from 476Ω to 590Ω.

The grey curve shows the typical current induced in a tag tuned at a higher frequency than the working frequency - the impact of the metal at 125kHz is negligible by comparison with the green curve corresponding to the metal impact on the antenna.

This phenomenon allows the tag to answer at a specific frequency detected by the reader. The tag was built according to the specifications in Table 1 and attached on the inside of the back cover of the watch

Figure 6 : Small watch tag integration

4.1.2.1.2 Big watch

The big watch was analyzed using a 2D drawing of the watch assembly. In this example, the watch casing is made of glass in the middle and a thick metallic ring all around.

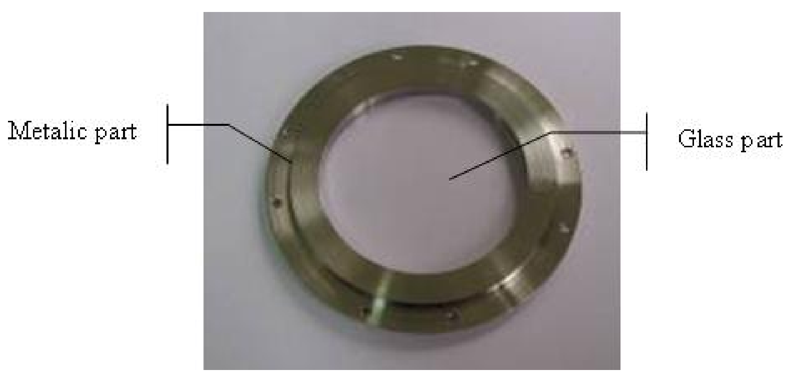


Figure 7 : Back case of the big watch

The analysis of the watch showed that it would be possible to integrate an RFID tag into the metallic part of the case but only after creating a special groove to accommodate it. In order to still comply with the mechanical constraints of the watch

assembly, the watch maker had to define the exact size of the groove to be created in the metallic casing.
The size gives three options for the tag integration:

Characteristics	Min	Typ	Max
Copper Wire Diameter cladding thermo adherent	*See manufacturer*	20µm / 26µm 52AWG CU B155,Grade1B	*See manufacturer*
Internal coil diameter	/	28 mm	28,1 mm
External coil diameter	29,2mm	31 mm	/
Coil antenna thickness	/	200 µm	220 µm
Turn number	522 turns	524 turns	526 turns
Number of copper turn per layer	/	11	/
Number of layer	/	46	/
Inductance @119kHz	19 mH	20 mH	21 mH
Parasitic capacitance	1 pF		8 pF
Serial resistance DC	2600 Ω	2700Ω	2800 Ω

Table 2 : Tag parameters for the big watch

The Figure 8 shows the impact on a tuned tag; the black curve shows the antenna parameter without the impact of the metal and the red curve show the antenna parameter modification with the metal around. The grey and green curves show the antenna parameter of the non tuned tag, and there is no signal deviation at the working frequency.

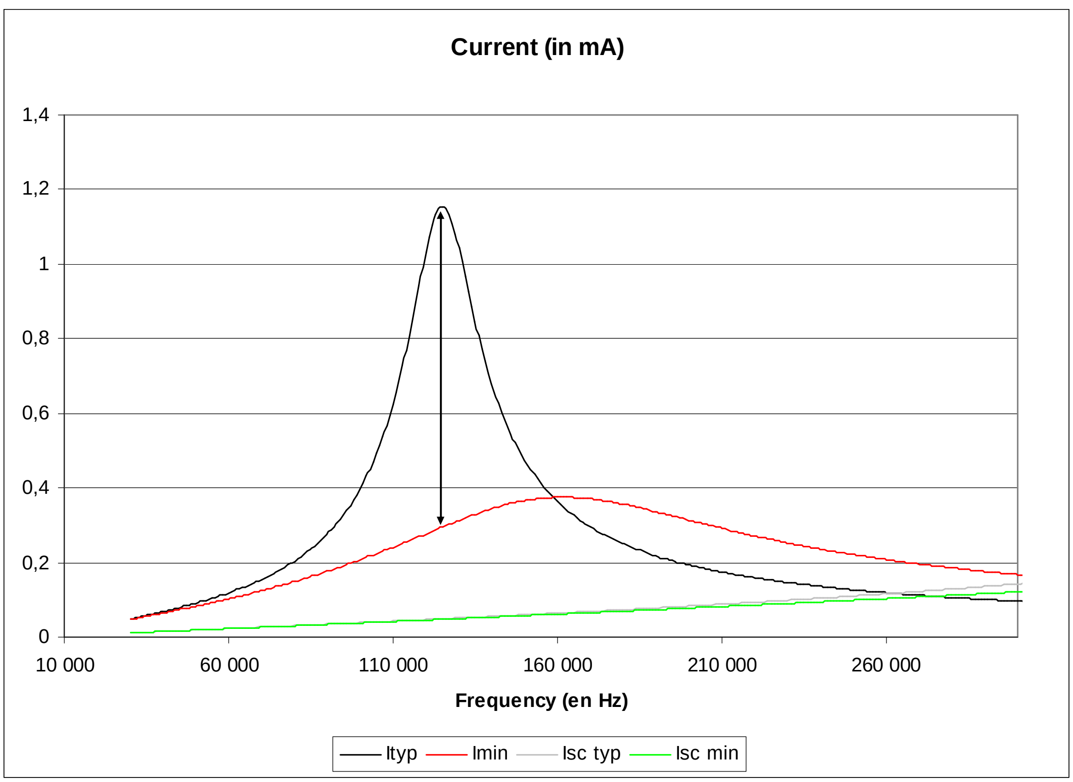


Figure 8 : Resonant frequency

In the first option, the chip is positioned on top of the antenna. This position allow to use an antenna having an external diameter of 31mm but a hole must be created to place the chip, the hole will make 0,3mm depth and a diameter of 2,5mm.

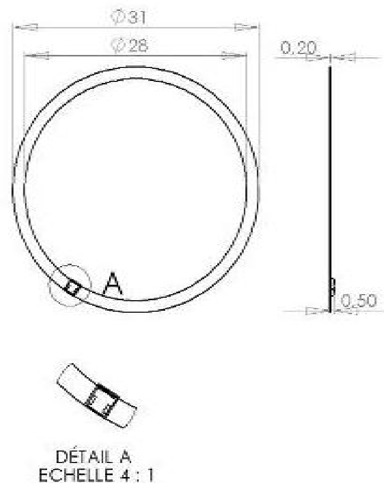


Figure 9 : Drawing for tag integration (option 1)

In the second option, the chip is positioned tangentially outside of the antenna. This position makes it possible to use an antenna having an external diameter of 31mm but an area must be created in order to insert the chip.

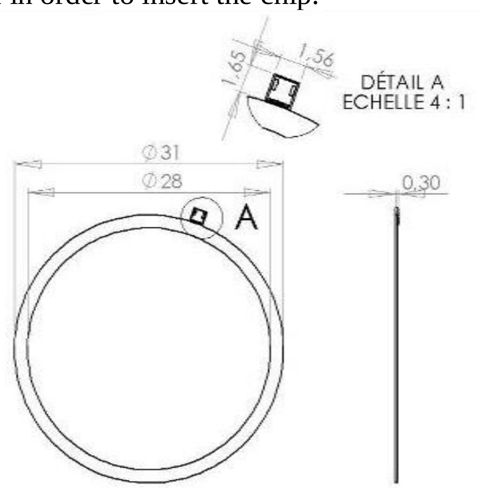


Figure 10 : Drawing for tag integration (option 2)

In the third option, the chip is positioned tangentially inside of the antenna. This position makes it possible to use an antenna having an external diameter of 31mm but an area must be created in order to insert the chip.

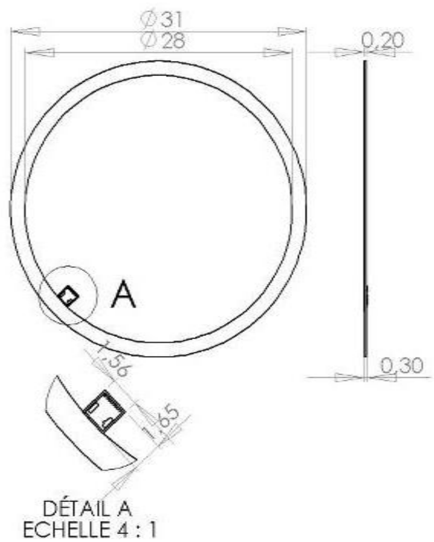


Figure 11 : Drawing for tag integration (option 3)

The second and third options were not used due to the mechanical constraint of the area created outside or inside the groove.

The first option is the best and allows the most protection for the chip connection and thus makes the tag more robust.

Finally the tag is assembled in the watch case and protected by an epoxy resin to avoid tag failure and removal.

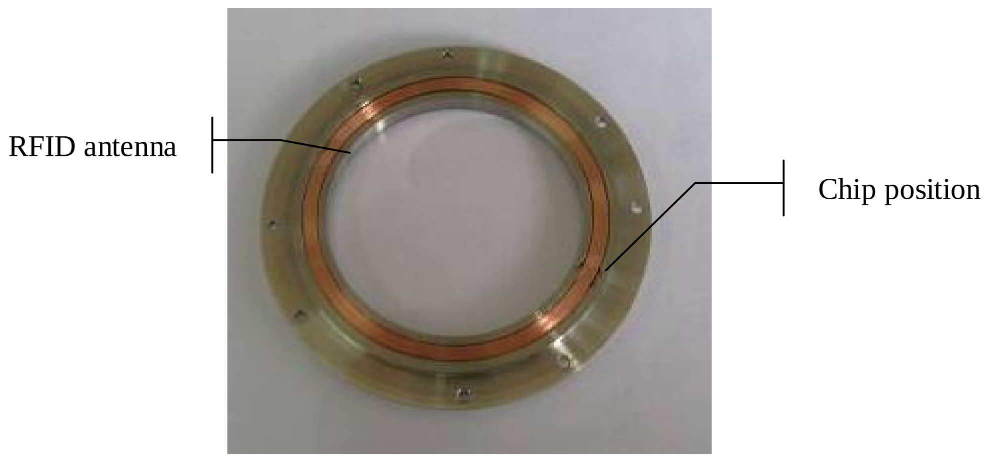
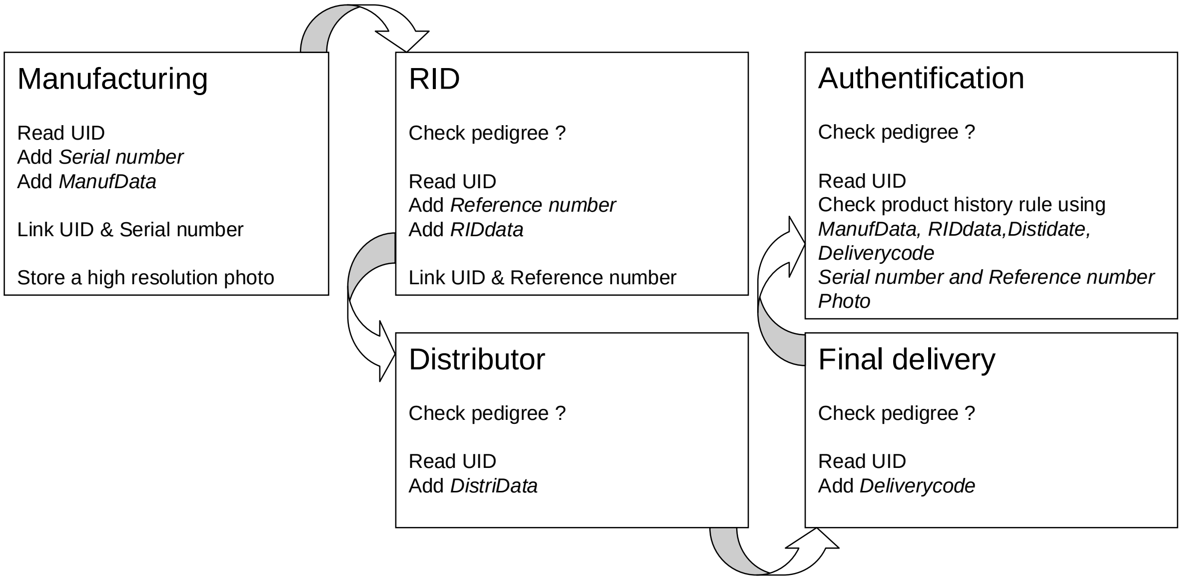


Figure 12 : Realisation example

4.1.2.1.3 RF signature key feature:

A non tuned tag gives the possibility to work in close proximity of a wide range of materials, without having to modify the antenna parameters.
The tag is composed of a SpaceCode Tau R6 chip with a memory of 72 bits engraved by laser. The unique code is permanently locked, can not be modified and can only be read by a proprietary reader - this makes counterfeiting and cloning of this item

almost impossible. This unique code combined with the serial number of the watch, engraved on the back of the watch, and a high resolution picture allows the RF signature to give an instantaneous validation of product authenticity.



The tag will be attached on the inside of the back case of the watch using a specific resin, thus avoiding the tag to be damaged, destroyed or removed.

4.1.2.2 Leather good case

In this study, the focus was made on leather products (bags, wallets) and also on small metal pieces (earrings, bracelets) of the brand.

In the case of the bag the RF signature was integrated in a small pocket where the brand card is already integrated. This RFID tag position can be easily modified to the lining of the leather product for other tests.

Figure 13 : Leather good with RFID tag

The authenticity of the leather goods is determined by the track and trace parameters of the products during their movement through the supply chain. In deliverable 4.2, we decided to use the EPC UHF gen2 chip platform in order to achieve bulk identification. Actually, the shipment box contains around 50 products. Depending of the product size, the primary package is adapted to fit.

Three sorts of tag were integrated in the leather good and branded jewelry.

4.1.2.2.1 The Satellite inlay

This tag use the Impinj Monaco/64 chip, it is a flexible inlay with a size of 32mm*18mm.
The antenna design utilizes a loop/dipole hybrid configuration. The antenna designs illustrated above exploit magnetic and electromagnetic field coupling, enabling both near and far field reads in a single tag.

Figure 14 : Satellite inlay

The Monaco/64 chip chips provide 64 bits of user-rewritable memory, extending Gen2 RFID tag data storage capabilities beyond the standard 96-bit electronic product code (EPC) to include additional item-level information. Monaco/64 chip memory can be read and written, enabling the maintenance of dynamic data, which can also be locked to prevent subsequent alteration.
The reading distance of this inlay is a maximum of 1,8m in the air and reduces to 1,4m when the tag is integrated into the leather good.

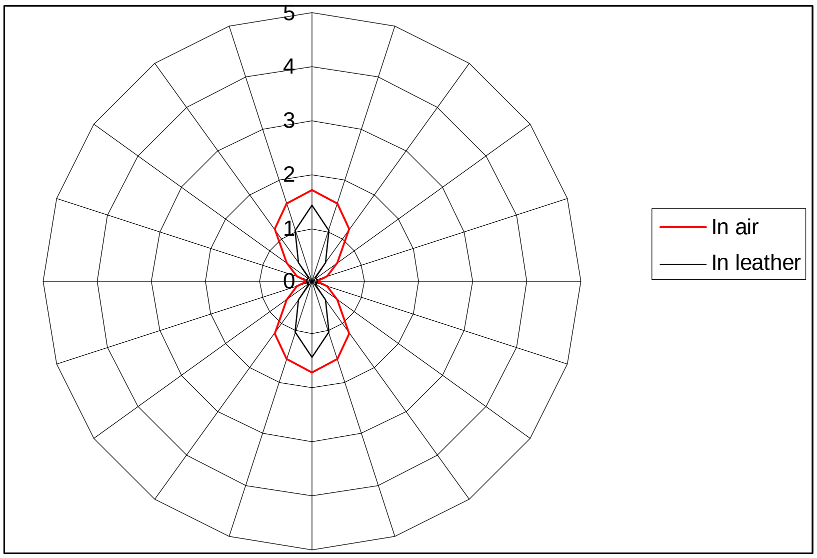


Figure 15 : Satellite inlay reading distance

4.1.2.2.2 The Web Inlay

The Web inlay uses the NXP G2XM chip. The inlay size is 30mm*50mm and is especially design to be used for item-level applications. The UCODE G2XM IS

EPCglobal compliant and provide scalable EPC numbers up to 240 bit, 64bits tag identifier, including 32 bits of unique serial number. In addition, the UCODE G2XM provides 512-bit user memory and a 32 bits access password ideal to protect the memory access and 32 bits for kill password.

Figure 16 : Web inlay

The reading distance of this inlay is about 4 meters in the air and reduces to 3,5 meters when the inlay is put in the leather bag.

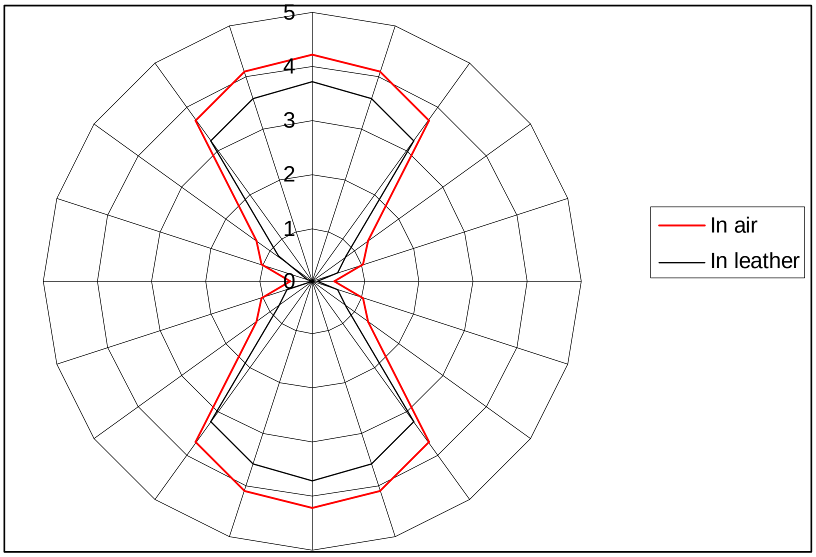


Figure 17 : Web inlay reading distance

4.1.2.2.3 The Propeller inlay

This inlay is a high performance dipole tag design with a size of 94mm*7,8mm and provides a good placement versatility and tag readability. Due to its design this inlay is ideal for warehouse and logistic applications. This inlay is using the MO

Figure 18 : Propeller inlay

The Monza/ID chip is EPCglobal Gen 2-compliant featuring factory-programmed and secure (permanently locked) serialized product identification numbers (in addition to the standard 96-bit electronic product code), making it the solution of choice for anti-counterfeiting and anti-cloning RFID applications.

The reading distance of this inlay is about 4,5 meters in the air and reduces to 3,5 meters when the inlay is put in the leather bag.

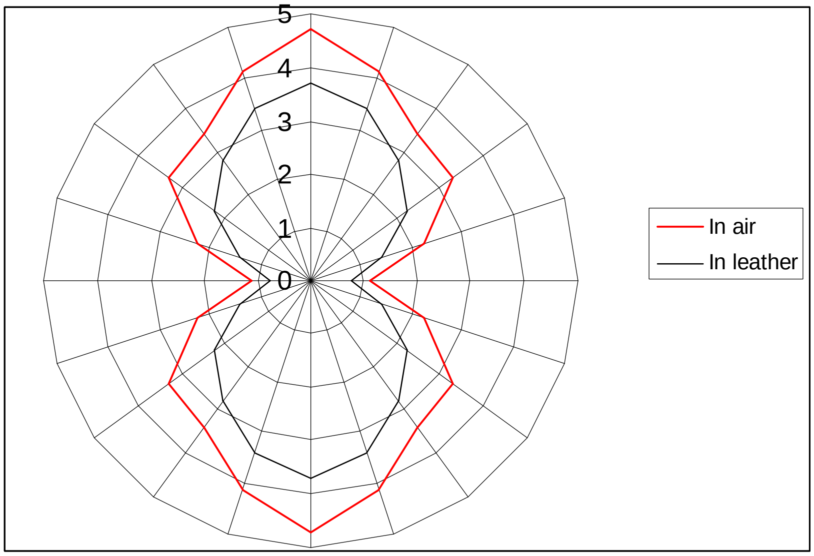
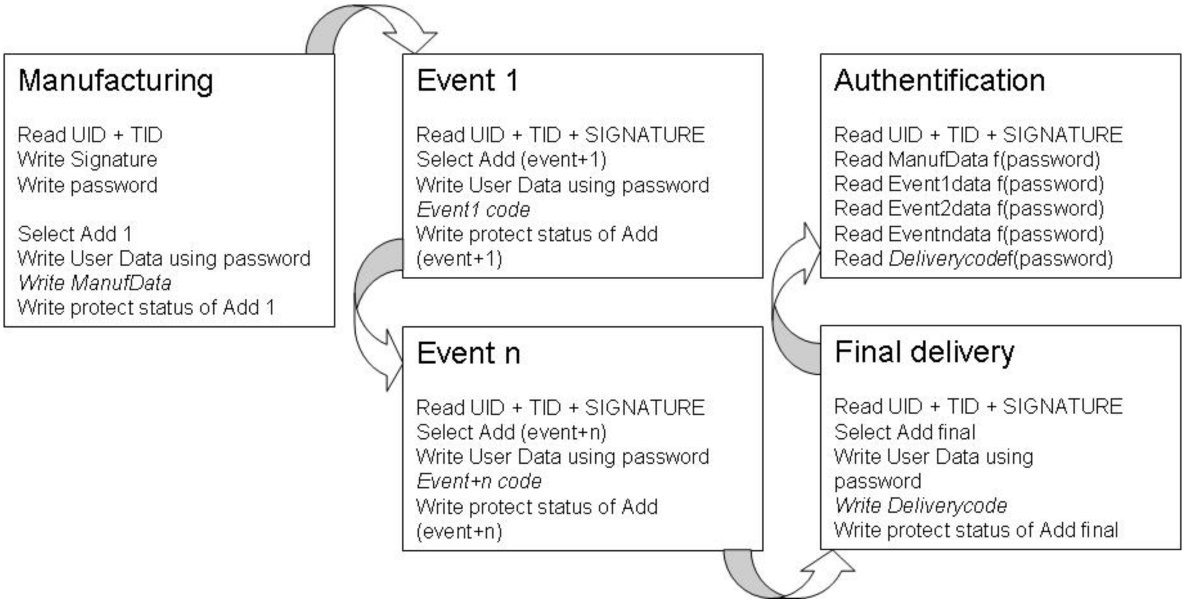


Figure 19 : Propeller inlay reading distance

4.1.2.2.4 RF signature key feature:

To achieve the bulk identification, the tags use for the integration and trials are the Propeller for its ability to be read in long range and the Web inlay for the read/write capability.

The track and trace process can be perform using both of inlay, with the Propeller, the EPC code, the UID or link into the data base, with the Web inlay data can be updated all along the supply chain process.



4.1.3 Aviation parts

The aviation industry is an industrial sector with high safety requirements, especially with respect to airplane construction. For each part that is built into an airplane the aircraft manufacturer issues a specification and test procedures that have to be strictly followed by part manufacturers. Environmental conditions and test procedures for airborne equipment are for example issued by the non-profit organization RTCA in the form of the DO-160 document, which contains "standard procedures and environmental test criteria for testing airborne equipment for the entire spectrum of aircraft."[1]

The commitment to specifications and test procedures by a part manufacturer becomes manifest in the *Declaration of Design and Performance* (DDP). According to the ISO (International Organization for Standardization), "a DDP is the commitment of a manufacturer to deliver a product complying with the defined dimensions and performances, based on qualification tests carried out by the NSO (National Surveillance Organization), a major user or by the manufacturer himself."[2]

With respect to the aviation trial this means only certified RFID tags can be used to equip aviation parts. Currently, the only tag on the market that is compliant to DO-160 (test certificate: IO83A-TB-09/01) and thus airworthy is the Master Tag by Kortenburg International[3]. Because of this Master Tags will also be used in the aviation trial. The next two sections will discuss requirements of the aviation industry that were considered during the development of the Master Tag as well as its specification.

4.1.3.1 RFID Requirements for the Aviation Industry

The aviation industry had certain RFID requirements that had to be considered during the development of the Master Tag:

- RFID tags have to be very robust in terms of being able to **withstand all kinds of operating conditions** within an airplane, both in pressure ventilated and not pressure ventilated areas and thus be durable for many years. In addition, they have to be **lightning resistant**. All in all RFID tags have to be **airworthy**.
- In the aviation industry, UHF tags are needed to fulfill certain requirements in the areas of logistics. However, for anti-counterfeiting purposes **HF tags** (13.56 MHz) are needed as most tags offering cryptographic features are of this type. In the future the vision is also to use active tags in certain scenarios.
- RFID tags must have high storage capacity (at least **64 kbit**) as a significant amount of maintenance event records have to be stored on them.
- **Read rate** of RFID tags should be **100%**.
- Weight of RFID tags is negligible.

[1] http://www.rtca.org/downloads/ListofAvailableDocs_JULY_2008_WEB.htm#_Toc204498448
[2] http://webstore.ansi.org/RecordDetail.aspx?sku=ISO%2fTR+224%3a1998
[3] http://www.logica.com/r/400003996/400011812

4.1.3.2 Specification of the Master Tag

There are different variants of the Master Tag that are composed of different sizes of housings, based on the same chip principle and same casting material. Antenna composition and memory size varies depending on size. All tag variants operate on 13.56 MHz (HF) and are compliant to ISO 15693.

4.1.3.2.1 Master Tag D5 Special Avionic

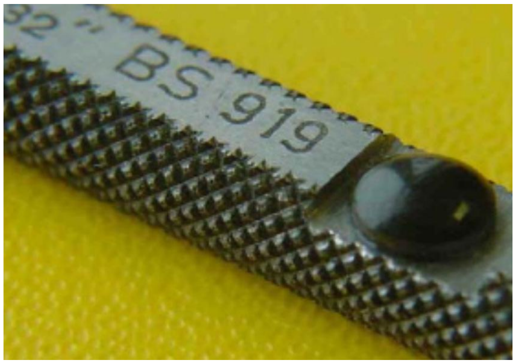


Figure 20: Master Tag D5 Special Avionic

Technology	closed coupling, 13.56 MHz, based on ISO 15693	
Communication Distance	0 mm – 4 mm (dependent on reader antenna and metal environment)	
Type	11.550	53.550
Standard	-	ISO 15693-2
Chip Type	iID-N	iID-G
Communication Rate	26.4 kbps	26.4 kbps
Memory Capacity	64 bit (read only, laser programmed ROM)	16,000 bit (EEPROM, endurance > 100,000 cycles, data retention > 10 years)
Storage Temperature	-45 °C – 180 °C	-45 °C – 150 °C
Operating Distance	1.5 mm	2.0 mm
Dimensions	diameter: 5 mm (half lens form), thickness: 1.7 mm	
Casing Material	epoxy, inlet mixed ferrite epoxy	
Operating Temperature	-25 °C – 65 °C	

4.1.3.2.2 Master Tag Mini Special Avionic + Master Tag Mini Special 8.5 Avionic

This section covers the *Master Tag Mini Special 8.5 Avionic* that is an extended temperature version of the *Master Tag Mini Special Avionic*. A 64.000 bit version of the *Master Tag Mini Special Avionic* is in pre-production stage.

Figure 21: Master Tag Mini Special 8.5 Avionic

Technology	closed coupling, 13.56 MHz, based on ISO 15693	
Communication Distance	0 mm – 5 mm (dependent on chip type, reader antenna and metal environment)	
Type	15.32.502	15.53.502 / 15.54.502
Standard	ISO 15693	ISO 15693-2
Chip Type	iID-M	iID-G
Communication Rate	26.4 kbps	26.4 kbps
Memory Capacity	2,000 bit (EEPROM, endurance > 100,000 cycles, data retention > 10 years)	16,000 bit / 32,000 bit (EEPROM, endurance > 100,000 cycles, data retention > 10 years)
Storage Temperature	-45 °C – 150 °C	-45 °C – 150 °C
Operating Distance	3.0 mm	2.5 mm
Dimensions	diameter: 8.5 mm +/ 0.1 mm, thickness: 2.0 mm	
Casing Material	PEEK, epoxy, inlet mixed ferrite epoxy	
Operating Temperature	-25 °C – 65 °C	

4.1.3.2.3 Master Tag D14 Special Avionic

This section covers the *Master Tag D14 Special Avionic*. A 64.000 bit version of this tag is in pre-production stage.

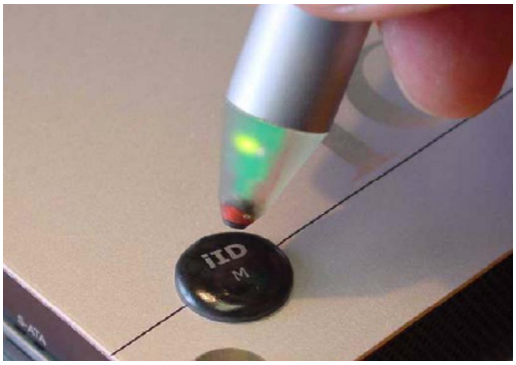


Figure 22: Master Tag D14 Special Avionic

Technology	closed coupling, 13.56 MHz, based on ISO 15693	
Communication Distance	0 mm – 15 mm (dependent on reader antenna and metal environment)	
Type	12.32.550	12.53.550
Standard	ISO 15693	ISO 15693-2
Chip Type	iID-M	iID-G
Communication Rate	26.4 kbps	26.4 kbps
Memory Capacity	2,000 bit (EEPROM, endurance > 100,000 cycles, data retention > 10 years)	16,000 bit (EEPROM, endurance > 100,000 cycles, data retention > 10 years)
Storage Temperature	-45 °C – 125 °C (180 °C for short time)	-45 °C – 125 °C (180 °C for short time)
Operating Distance	10.0 mm	10.0 mm
Dimensions	diameter: ~ 15 mm, thickness: 2.5 mm	
Casing Material	multi layer plastic package, front side black EP (laser printed), half lens form	
Operating Temperature	-25 °C – 85 °C	

4.1.3.3 Installation Surface Enhancers

Part of the Master Tag Series is an installation surface enhancer, the *Master Tag Coni* and a high temperature version, the *Master Tag Insert Coni HT*. According to the manufacturer, the material is a polyamide 6 grade of intermediate to high viscosity that is well suited for the production of cast and blown film and monofilaments.

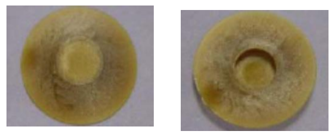


Figure 23: Master Tag Insert Coni

4.2 Phase II: Tag Testing

A comprehensive program of tests was carried out for each of the end user applications. The most important tag tests included density testing, speed and distance testing, and durability testing [KCSJ04]. These tests should be performed prior to product integration, as well as in situ following tag integration into the respective products.

- speed and distance testing: testing speed and distance is important to mimic real-world demands and indicates how sensitive the tag is and how efficiently it is functioning in the RF environment. To properly evaluate speed and distance, test each tag in different orientations at different distances from the RF source signal, and at different speeds e.g. stationary, on a conveyor belt etc. Each test should be performed solo (i.e. isolated), on different surfaces that the tag may be expected to be mounted mount on; and on/in the product itself
- environmental and RF interference testing: testing for environmental influence includes subjecting the tag performances to different sources of RF interference typical of the products into which the tags were to be integrated e.g. metal for watches; leather for leather goods, metal for conveyor belts etc. This was followed by direct validation in the product itself. In addition testing was also done on direct sunlight for a prolonged period of time, vibration for 72 hours in a vibration chamber, dropping tags from a height, immersion in water etc.
- integration constraints testing: this phase of testing advanced the testing protocol into the products themselves whereby the real world constraints could be definitively and directly tested including tag size variation (i.e. space available for tag integration in the product), tag density testing (providing a measurement of how well tags perform when they are placed in a volume with many RFID tags). Important measurements included identification of all tags, how many reads are acquired per second, and how long tag/s must remain in the read field to be read. The required result

should be that tag/s will respond in all locations rapidly e.g. under one second.

- process testing: parameters evaluated here mimicked all processes that a product might be subject to, and where RFID reading would occur. Examples included speed of a conveyor belt, watch manufacturing process, installation process for aircraft parts etc. Close attention was paid to the impacts of such processes on RFID tag performance and longevity/durability testing: these tests analyse a typical tag life.
  - read life involved the tag being run through a continuous read cycle for a specified period of hours to days, during which time the number of responses from the tag as well as the time to transmit i.e. the lag time, were recorded. Deterioration or problems with any of these over time could indicate problems with the tags internal electronics when subjected to continuous duty
  - write life: similar tests were performed on read write tags. Typical lifetimes of such tags are 100,000 writes. Tags were tested (either by consortium members or manufacturers) to ensure that they can meet the 100,000 writes specification.

In addition, a number of problem areas typical for tag deployment and integration were tested and evaluated including [KCSJ04]:

- tag and reader compatibility
- read range and speed of movement of the label through the read area
- tag to reader orientation
- EMI emissions in the environment
- interference from case contents
- damage during label application
- placement of label on packaging consistent with case analysis

The results of these tests for each of the SToP companies were as follows:

4.2.1 Pharmaceutical goods

We report in this section the results of the tag testing carried out on the production lines. UHF tags from three suppliers were tested, in addition to HF tags and 2D barcodes from one supplier each.

4.2.1.1 UHF tag testing

The testing results provided in this subsection were collected from ten experiments on UHF RFID tags from three different suppliers at 4 different line speeds. The pattern and statistical significance of the read and write errors encountered are summarized in Figure 24. The three most important conclusions to be drawn from the figure are:

- Overall the data are normally distributed
- The average number of defects from each experiment is 2.9
- The expected number of defects in an experiment can vary from 0.6 to 5.1

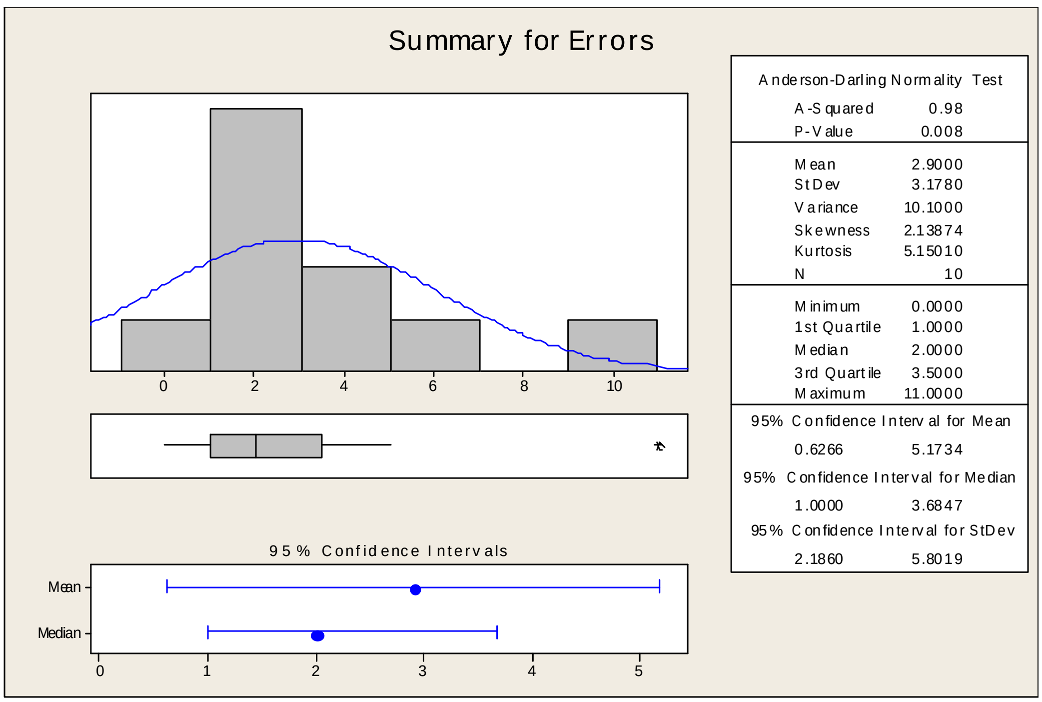


Figure 24: Summary of encoding errors for the UHF experiments

4.2.1.1.1 Correlation between line speed and errors

An important question that was investigated is whether the line speed was a factor in the defect rate. A regression analysis, shown in Figure 25, was conducted to check if the line speed was the main driver behind the number of errors encountered. Since the p-value pertaining to the line speed, .0155, was greater than 0.05, the line speed doesn't appear to be a significant factor. Since the overall variation is not explained by the line speed, other methods were investigated. The initial conclusion – that the line speed doesn't influence the number of errors – was confirmed by the analysis of residuals as shown in Figure 26. Finally, even the scatter plot of errors vs. line speed shown in Figure 27 shows the poor correlation between line speed and the number of errors.

Regression Analysis: Errors versus Line speed

```
The regression equation is

Errors = - 0.29 + 0.0225 Line speed

Predictor       Coef   SE Coef      T      P

Constant      -0.291     2.237  -0.13  0.900

Line speed  0.02247  0.01432   1.57  0.155

S = 2.94756   R-Sq = 23.5%   R-Sq(adj) = 14.0%
```

Figure 25: Regression analysis: UHF Errors vs. line speed

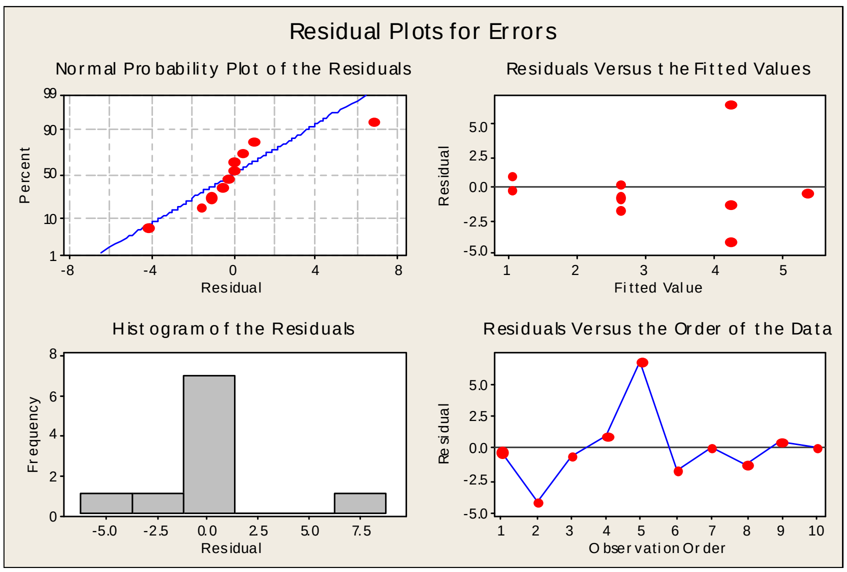


Figure 26: Residual plot of UHF errors

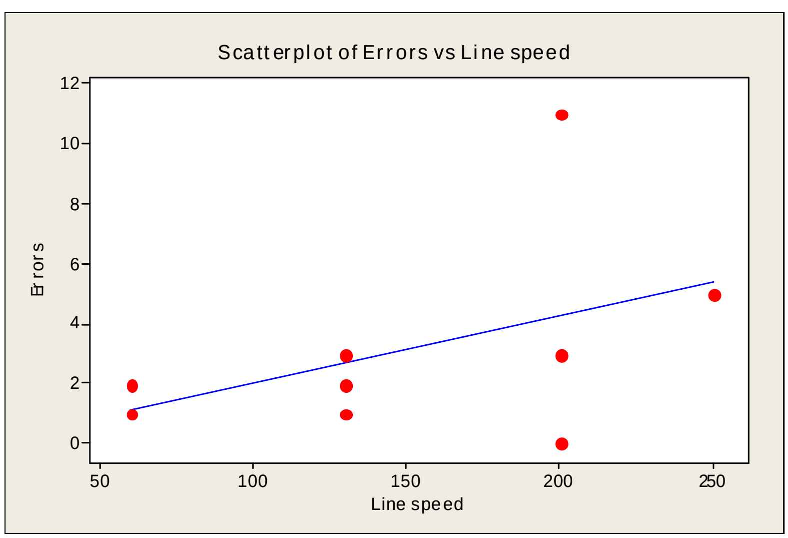


Figure 27: Scatter plot of errors vs. line speed

4.2.1.1.2 Difference between suppliers

Another important question that we investigated is whether there is any significant difference in the tag performance due to the suppliers. To answer that we conducted a Chi-Square test shown in Figure 28. Since the result yielded a p-value greater than 0.05, the test proves there is no difference among suppliers.

Chi-Square Test: Avery, Alien, Omron

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts
          Avery     Alien     Omron   Total
    1      4224      2862      3102   10188
        4220.99   2866.84   3100.18
          0.002     0.008     0.001
    2         9        13         7      29
          12.01      8.16      8.82
          0.757     2.870     0.377
Total      4233      2875      3109   10217
Chi-Sq = 4.015, DF = 2, P-Value = 0.134
```

Figure 28: Chi-Square test for suppliers

4.2.1.1.3 Average defects

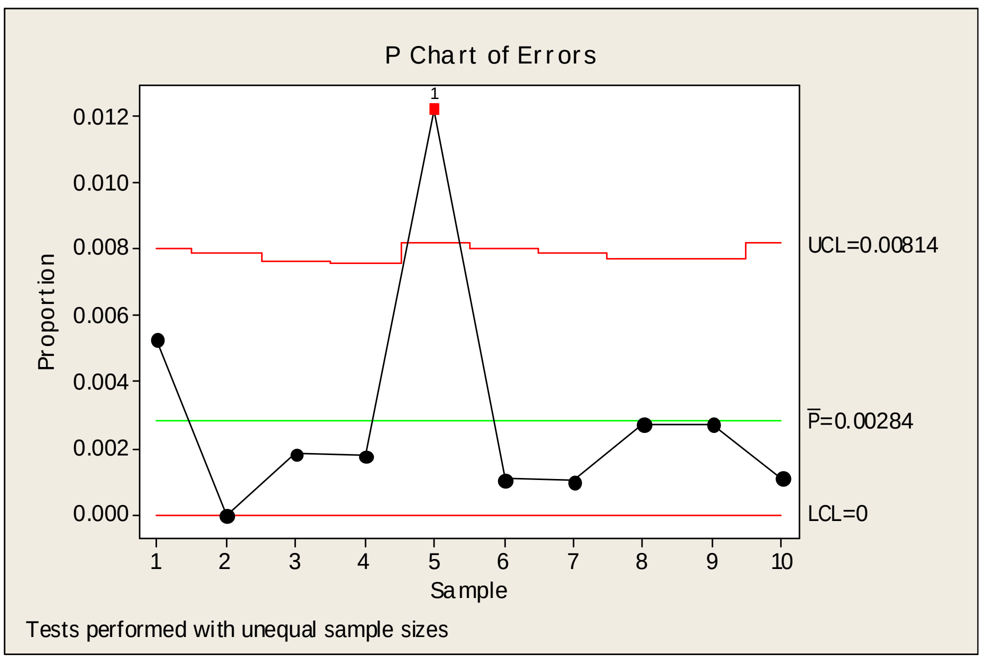


Figure 29: Percentage of errors in the sample

Figure 29 shows a plot of the percentage of errors with respect to the total sample size in each experiment. The overall percentage of defects is 0.28%. The figure also shows the lower and upper values of expected defect rates which were 0 and 0.8% respectively.

4.2.1.1.4 Conclusions and recommendations

In summary, the following statements could be made on the experiments performed:

- The expected number of rejected tags per hour for a line running at 250 units per minute is: 42 (based on rate of 0.28%)
- The typical size of a batch being 36,000 units: 100 tags would be rejected for encoding reasons only
- All conclusions are valid only in the range of 60 to 250 units/minute: no extrapolation feasible
- Recommendations for future experiments:
  - Need more tests at higher speeds
  - Include repetitions of experiments to assess process stability
  - Need to find other factor than line speed to control variation
  - This is excluding defects from labeling machine, readers, others…

4.2.1.2 HF tag testing

Five experiments were conducted to test for encoding defects encountered with HF tags from one supplier. Four different line speeds were used – 60, 130, 200, and 250 units per minute – and the experiment was repeated three times at medium speed. The statistical significance of the encoding errors is shown in Figure 30.

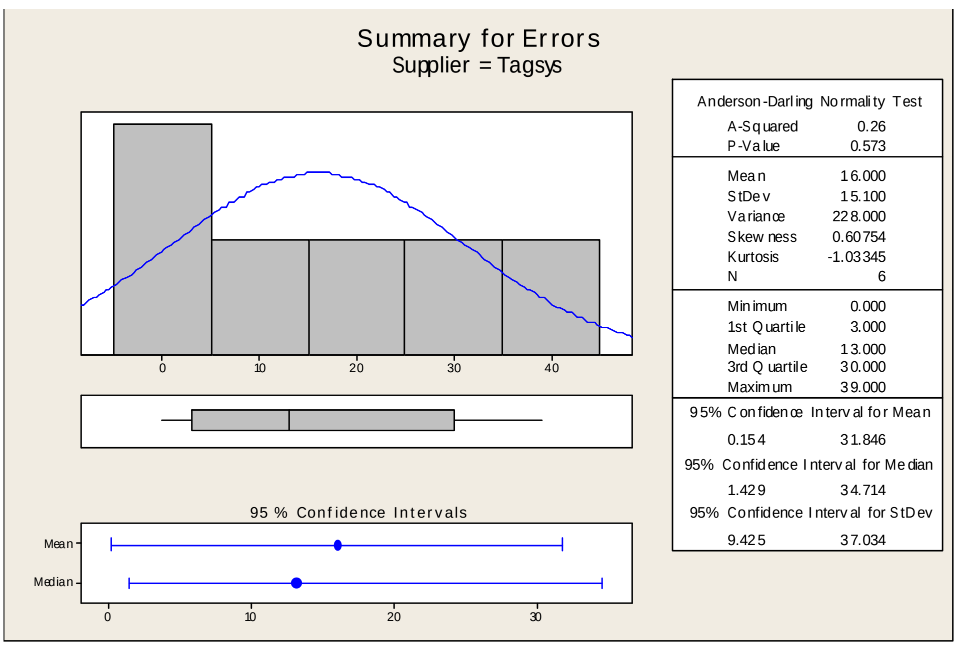


Figure 30: Summary of encoding errors for the HF experiments

Three important conclusions can be drawn from the figure:

- Overall the data are *not* normally distributed
- The median number of defects is 13
- The expected number of defects can vary from 1.4 up to 34.7

4.2.1.2.1 Correlation between line speed and errors

An important question that was investigated is whether the line speed was a factor in the defect rate. A regression analysis, shown in Figure 31, was conducted to check if the line speed was the main driver behind the number of errors encountered. Since the p-value pertaining to the line speed, 0.111, was greater than 0.05, the line speed doesn't appear to be a significant factor. Since the overall variation is not explained by the line speed, other methods were investigated. The initial conclusion – that the line speed doesn't influence the number of errors – was confirmed by the analysis of residuals as shown in Figure 32. Finally, even the scatter plot of errors vs. line speed shown in Figure 33 shows the poor correlation between line speed and the number of errors.

Regression Analysis: Errors versus Line speed

```
The regression equation is
Errors = - 8.5 + 0.163 Line speed
Predictor      Coef  SE Coef      T      P
Constant      -8.50    12.94  -0.66  0.547
Line speed  0.16330  0.08004   2.04  0.111
S = 11.8178   R-Sq = 51.0%   R-Sq(adj) = 38.7%
```

Figure 31: Regression analysis - errors vs. line speed

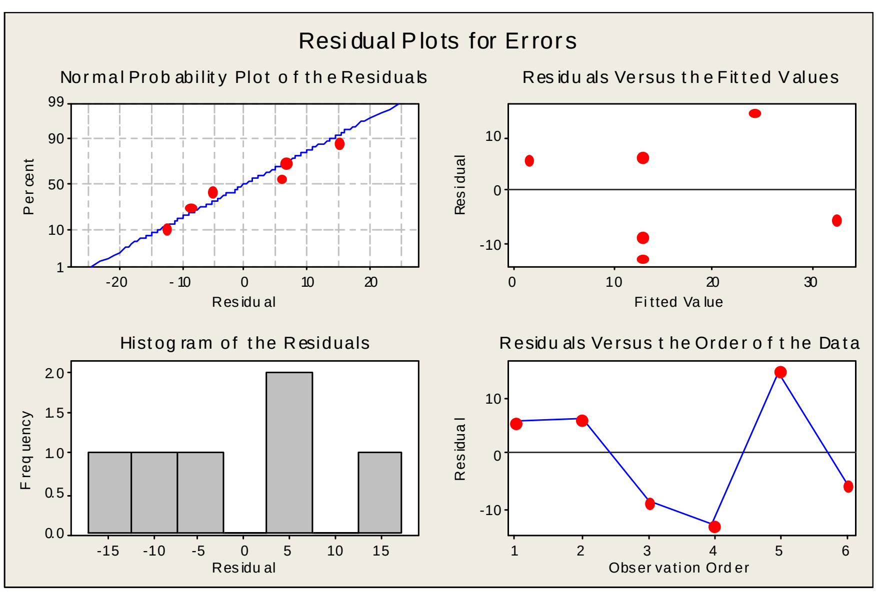


Figure 32: Residual plots for HF errors

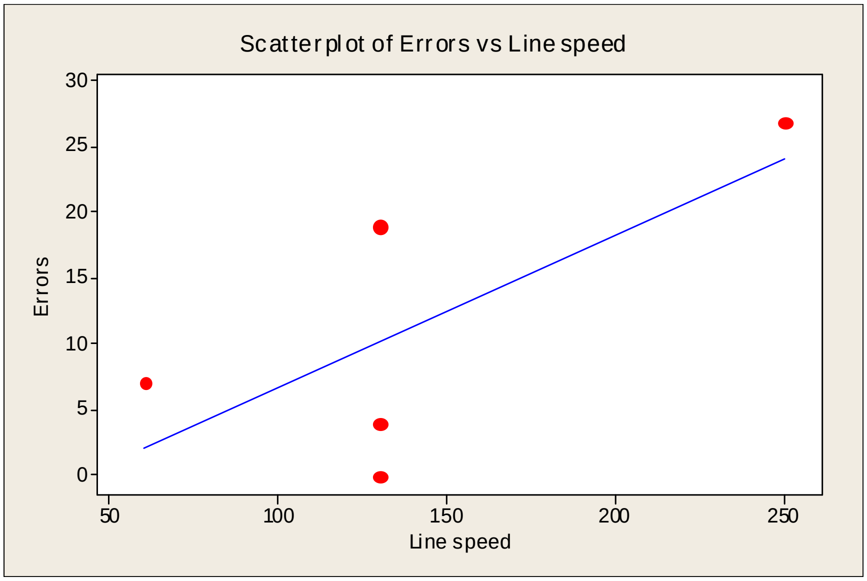


Figure 33: Scatter plot of HF errors vs line speed

4.2.1.2.2 Average defects

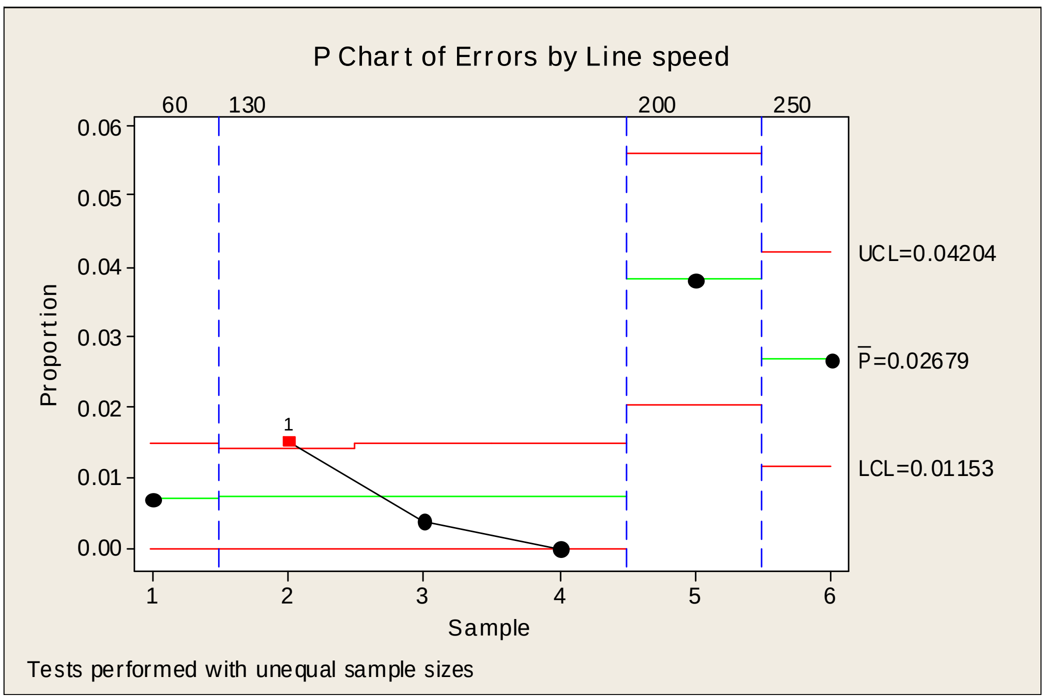


Figure 34: Percentage of HF errors

Figure 34 shows a plot of the percentage of errors with respect to the total sample size in each experiment. The proportion of defects at high speed is: 2.6%. The figure also shows the lower and upper values of expected defect rates which were 1.1 and 4.2% respectively.

4.2.1.2.3 Conclusions and recommendations

In summary, the following statements could be made on the experiments performed:

- The expected number of rejected tags per hour for a line running at 250 units per minute is: 405 (based on rate of 2.7%)
- The typical size of a batch being 36,000 units: 972 tags would be rejected for encoding reasons only
- All conclusions are valid only in the range of 60 to 250 units/minute: no extrapolation feasible
- Recommendations for future experiments:
  - Need more tests at higher speeds
  - Include repetitions of experiments at higher speeds than 130 units per minute to assess process stability
  - Need to find other factor than line speed to control variation
  - This is excluding defects from labeling machine, readers, others.

4.2.1.3 Data Matrix testing

Five experiments were conducted to test for defects encountered with Data Matrix codes from one supplier. As in the case of HF testing, four different line speeds were used and the experiment was repeated three times at medium speed. The statistical summary of errors is shown in Figure 35.

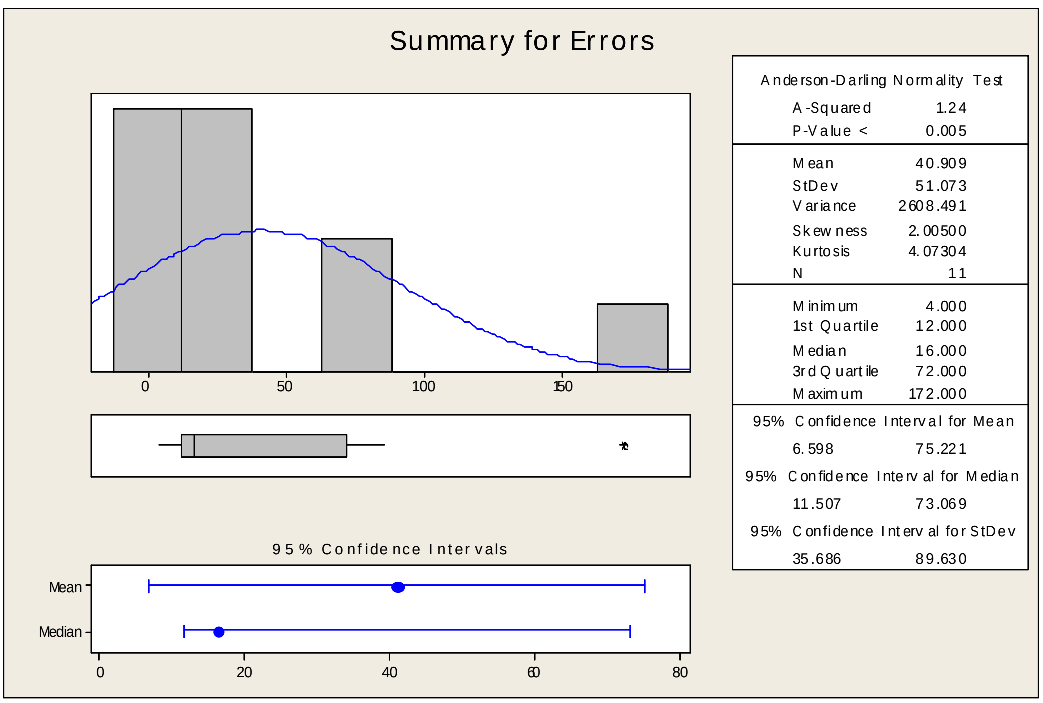


Figure 35: Summary of encoding errors for the Data Matrix experiments

Three important conclusions can be drawn from the figure:

- ✓ Overall the data are normally distributed
- ✓ The median number of defects is 40
- ✓ The expected number of defects can vary from 6.5 up to 75.2

4.2.1.3.1 Correlation between line speed and errors

An important question that was investigated is whether the line speed was a factor in the defect rate. A polynomial regression analysis, shown in Figure 36, was conducted to check if the line speed was the main driver behind the number of errors encountered. Since the p-value = 0 < 0.05, the overall variation is strongly controlled by the line speed. This is by far the main driver for errors in the case of Data Matrix and there is no need for further investigation. The relation between line speed and errors is linear and quadratic. Also, the R-Sq value shows that 97% of the variation is controlled by the line speed. The analysis of the residuals shown in Figure 37 confirms the linear and quadratic aspect of the error model. The strong correlation between line speed and errors is also evident in the line plot of Figure 36.

Polynomial Regression Analysis: Errors versus Line speed

```
The regression equation is
Errors = 42.85 - 0.9540 Line speed + 0.005804 Line speed**2
S = 8.59337   R-Sq = 97.7%   R-Sq(adj) = 97.2%
Analysis of Variance
Source      DF       SS       MS       F      P
Regression   2  25494.1  12747.1  172.62  0.000
Error        8    590.8     73.8
Total       10  26084.9
```

Figure 36: Regression analysis – Data Matrix errors vs. line speed

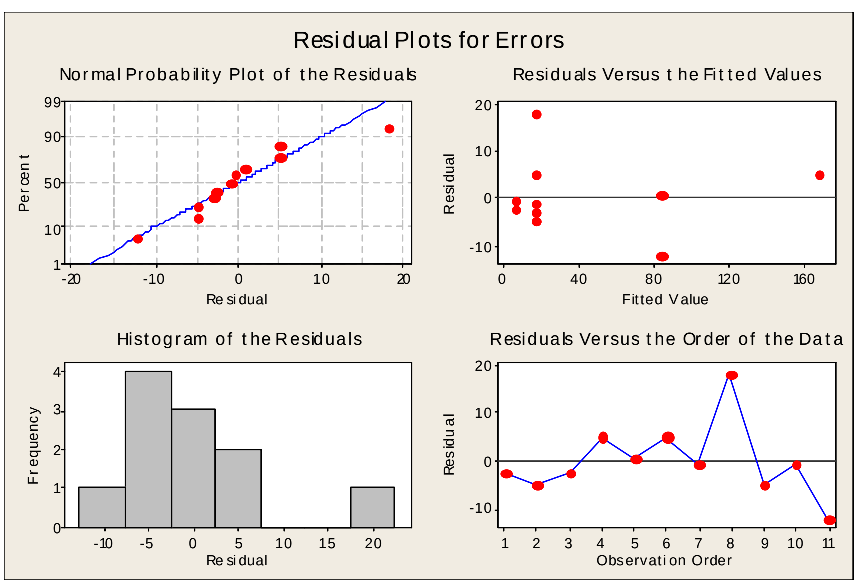


Figure 37: Residual plots for Data Matrix errors

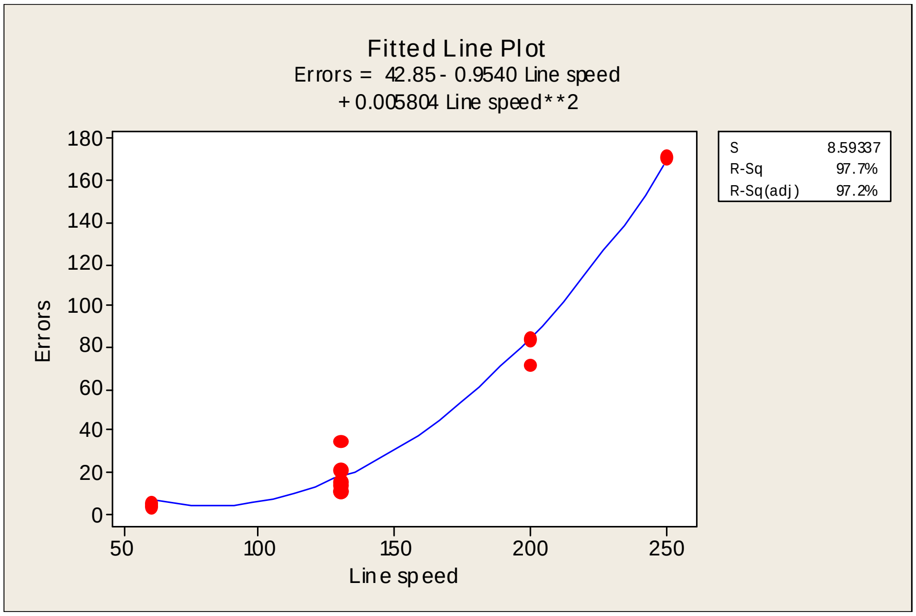


Figure 38: Scatter plot of Data Matrix errors vs line speed

4.2.1.3.2 Average defects

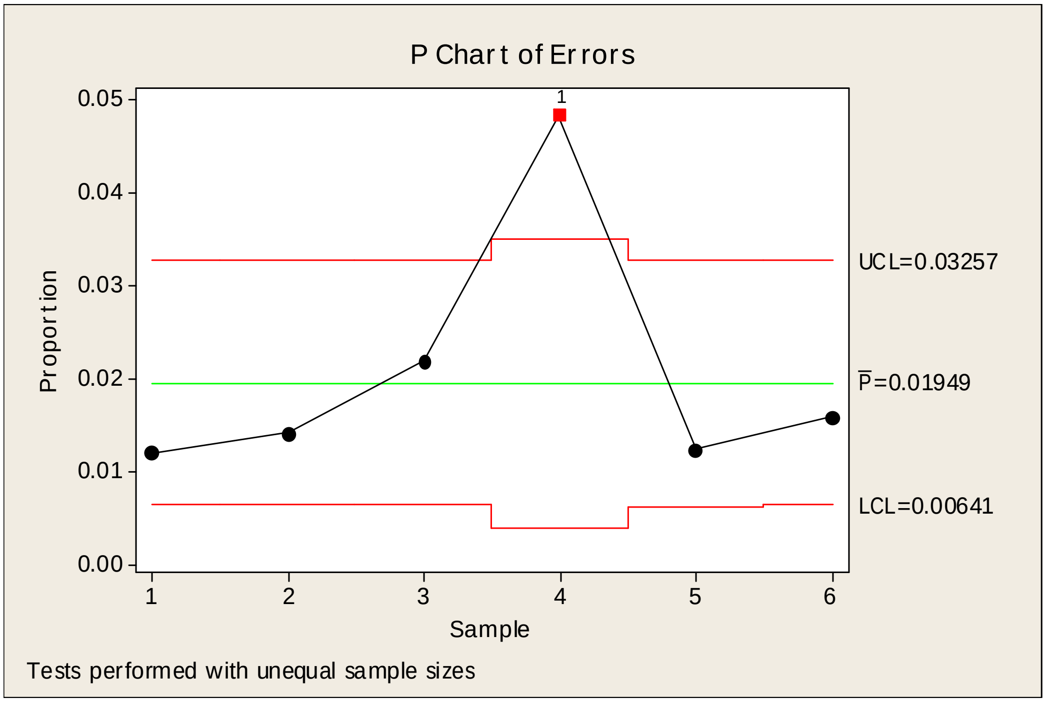


Figure 39: Percentage of Data Matrix errors

Figure 39 shows a plot of the percentage of errors with respect to the total sample size in each experiment. The proportion of defects at high speed is: 1.9%. The figure also shows the lower and upper values of expected defect rates which were 0.6 and 3.2% respectively.

4.2.1.3.3 Difference between data sets

Test and CI for Two Proportions

```
Sample    X     N  Sample p
1       137  5102  0.026852
2       141  4430  0.031828
Difference = p (1) - p (2)
Estimate for difference:  -0.00497623
95% CI for difference:  (-0.0117877, 0.00183527)
Test for difference = 0 (vs not = 0):  Z = -1.43  P-Value = 0.152
```

Figure 40: Correlation tests between two data sets

The last test we conducted for the Data Matrix codes aimed to check is different encoded data had an effect on the error rates. The experiments involved either EPC-only data or a full data load that was more information intensive. The test results shown in Figure 40 reveal no correlation between the data set and the error rates since the p-value > 0.05.

4.2.1.3.4 Conclusions and recommendations

In summary, the following statements could be made on the experiments performed:

- The system doesn't operate appropriately at high speed to assess the realistic level of defects expected on a production line
- Line speed strongly drives the defect rate on printing and it appears to be the main factor
- All conclusions are valid only in the range of 60 to 250 units/minute: no extrapolation feasible
- Recommendations: Need to change technology to allow high speed printing.

4.2.2 Luxury goods

4.2.2.1 Watch use case

For this use case, a specific reader antenna was developed to generate enough power to supply the inlay embedded in the metal case of the watch.

A standard reader coil antenna tuned at system frequency, using a serial capacitor is affected when a metallic part is placed in front of it. The detuning effect as well as the losses added by the presence of metal depends on the metal surface compared to the reader antenna surface and distance between the reader antennas and object to be identified.
In order to detect the tag inserted inside the big watch it will be necessary to create a magnetic field of few militesla.

The goal was to develop a specific reader able to place the antenna under a special support carrying the watches. This reader will be able to identify the watch perpendicular to the antenna plane.

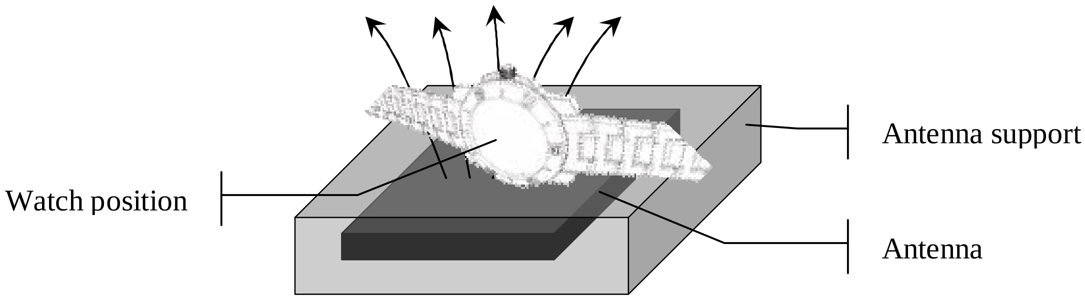


Figure 41 : Watch reading station

A Brook antenna (flat coil) can be used but the area detection is very small and localized immediately on the wires of the coil.
Basic rectangular Brook antenna was realized after simulation. Antenna size is limited to 6cm per 100mm.

The final reading station will look like Figure 42 below and the details of the station design will be give in Deliverable 5.3.

Figure 42 : Final reading station

4.2.2.2 Leather good use case

Two methods are identified for the trial:

- The picking station to prepare the order, and to validate the order. At this station the products are read one by one up to four by four
- The conveyor station is used to verify the box contain, the checking is perform in bulk with up to 50 products on the conveyor.

The secondary package is a create box with a size of 670mm*600mm*800mm.

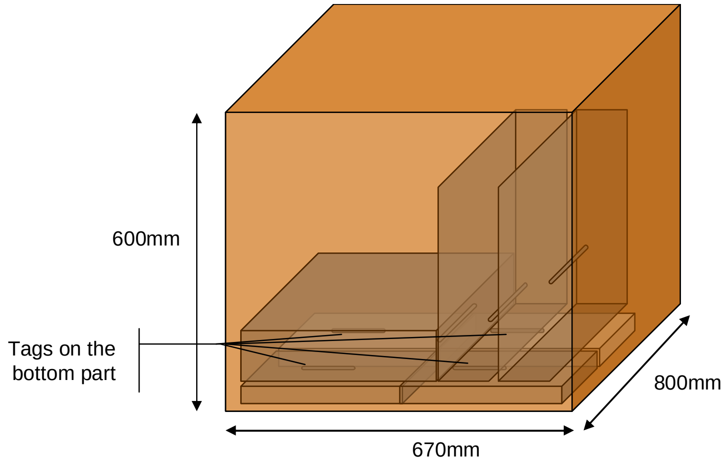
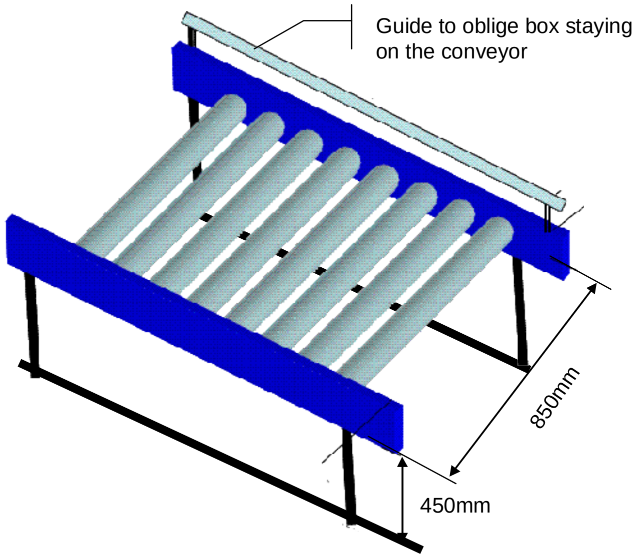


Figure 43 : Parcel organisation for leather good

When the order is finalized, the box is pushed by the user on a conveyor, the conveyor rolls are made of metal and will have a bad effect on the field propagation. Moreover, the product at the bottom of the box (containing thin wallets) will be positioned near the metallic rolls of the conveyor.



At the picking station, a near field antenna was used in order to focus the field on the picking area and to avoid the field perturbation.

The tests showed some erroneous reads due to the tag sensitivity. Depending on the position of the tagged products in the warehouse, some field reflections allowed tags to be read on products that were not included in the order or not even ready to be packed. To avoid this problem the field strength had to be adjusted during the trial session, as a function of the position of the product, or a reading zone will be defined showing the area where a tag can be identified.

4.2.3 Aviation parts

For the certification of the Kortenburg Master Tag several tests compliant to the DO-160D and DO-160E specifications were successfully performed (test certificate: IO83A-TB-09/01) on about 120 test samples. Based on these results Master Tags are approved to be attached to new aviation parts that are used in the construction of airplanes. Table 3 shows the title, the underlying specification, remarks, and the result of all tests performed.

Title	Specification / Section	Remarks	Result
Mechanical / Physical Tests			
Temperature Tests Combined Temperature and Temperature Variation Test	RTCA DO-160D / 4.5 & 5	*)	✓
Vibration Test	RTCA DO-160D / 8	Test performed at Center of Applied Space Technology and Microgravity, Bremen	✓
Shock Tests Operational Shock and Crash Safety	RTCA DO-160D / 7.2.1	Test performed at Center of Applied Space Technology and Microgravity, Bremen	✓
Humidity Test	RTCA DO-160D / 6		✓
Chemical Tests – Liquid Tolerance			
Fluids Susceptibility	RTCA DO-160D / 11 EN 3909	Solvents, De-Icers, Kerosene, Hydraulic Fluids, Cola, Coffee, Juice	✓
Electromagnetic Compatibility (EMC) Tests			
Radiated Frequency Susceptibility	RTCA DO-160D / 20		✓
Lightning Induced Transient Susceptibility	RTCA DO-160D / 22		✓
Electrostatic Discharge (ESD)	RTCA DO-160D / 25		✓

Table 3: DO-160 Test Summary

*) For the temperature tests the test samples were mounted to the adapter for the vibration, shock and electromagnetic compatibility tests. These assemblies have been used for all performed tests. The tests have been performed with a temperature variation according to the specification but a ground survival high temperature of 100°C instead of 85°C.

4.3 System Integration

One of the important aspects about the integration of RFID tags is system integration, defined as the integration of existing RFID technology and new business processes and systems. At first it can be divided in two parts which are hardware integration and software integration. By hardware integration we mean integration of RFID tags, readers and writers in existing (or new) business processes and with software integration we mean how the existing processes need to be changed (in the best case they can stay the same) so that the RFID technology can be used with all its features.

4.3.1 Hardware integration

Nowadays we use different equipment in normal business processes and most of that equipment comes in use with more or less resistance for the users who will use them. In some cases users are keen to use new technology, because they see the positive effects on their work, but in many cases users are still afraid of new things and are usually scared that they might lose their job because the technology or equipment is so advanced, that they feel that they might be replaced by those machines. We need to integrate all new technology with the minimal of negative effects because only by such integration, can we get the best results.

One of our trials was to integrate RFID tags and test its usability in a warehouse management system. We wanted to find out how the existing barcode that is used in most warehouses nowadays can be effectively replaced by the use of RFID tags. First we needed to choose the tags and because we wanted to see if RFID is usable in warehouse management systems we did not complicate matters and so used HF tags to integrate, in other words, replace existing barcodes. Warehouse manipulation was not the only objective of this trial but also an upgrade to use PVI inside warehouse business processes. So we replaced the barcodes by RFID tags and found many encouraging and positive results. The most positive aspect is a wider range of use of RFID tags in different weather conditions. As barcodes are usually printed on a paper (in some cases engraved in different materials, but those are more expensive and have less usability) they are practically not usable in wet weather conditions such as rain or snow, because the barcodes printed on paper get wet and they become unreadable. The downside of RFID tags is the area scan of the items, which can give negative effects such as the scan of items that we did not want to scan and the range of scan. For the trial of the warehouse management system we used handheld scanners produced by Datalogic - Kyman 701-932. We found this equipment very suitable for our trial because it is a handheld device with a wireless connection and as such is not different from equipment that we use in warehouse systems equipped with barcodes. This handheld device also has the laser scanner so it can be also used with barcode systems – both normal barcodes and 2D barcodes. We also tried to use a fixed RFID scanner from SpaceCode, but this was not continued as it was hard to integrate into current warehouse process due to the size of the equipment. The only way to use the fixed scanner was to build some kind of gateway to transfer all the items through that point, which in our opinion would introduce a new bottle neck in the warehouse. The handheld scanner that we used in the trial also has the telnet client which we have already used to communicate with other handheld devices that are equipped only with laser scanners, so it was practically very easy to integrate those scanners into existing warehouse management systems.

4.3.2 Software integration

Software integration is meant as the integration of new technology such as RFID to existing systems and existing business processes and also new systems such as PVI. Since the PVI can be treated as a new system, we need to somehow integrate that system to other existing systems or we can use it as a stand alone system. Mostly we will need to integrate the PVI system to other system such as ERP systems and other enterprise systems. In our case we tried to integrate PVI system to Warehouse Management System. This is one view of software integration and the other view is the use of RFID technology in existing systems and business processes. In our trial we tried to integrate RFID technology inside an existing warehouse management system and its associated business processes.

4.3.2.1 PVI Integration

PVI is an information system that stores its own data and has its own business logic integrated in it. But it can also use data from other systems, especially track and trace data can be accessed from other systems which need to be integrated in some "standard" way of communication between systems. PVI also needs some set up data – data that is born when the item is produced. In the first steps of integration between PVI and other external systems we have defined some different aspects of integration.

4.3.2.2 Set up data

Every information system needs a certain range of initial data to operate. The PVI system certainly needs such set up data. By set up data we mean data related to each single item, which has its own unique identifier and other information that are needed to process PVI functionality. The range of data can vary from different industries that are potential users of the PVI, but data that will be used in all industries are item identifier, item name, producer, status of single item which can come from external system or can be defined by the business rules defined inside the PVI, and some other data.

Set up data can come to the PVI from different locations and different sources such as the ERP system and that is why we need to define some standard protocols to be used. For that purpose we have defined a web service integration, where external systems that wants to be integrated with the PVI system can simply call a web service with a predefined XML structure and send its data to the PVI. The structure can be seen in the simple example below and can be extended with sections of required data in cases when PVI will need more data for its operation.

```
<?xml version="1.0" encoding="ISO-8859-1" standalone="yes"?>
        <pvi>
```

```xml
  <companies>
   <company>
    <company_id>000000</company_id>
    <company_name>Test Company</company_name>
   </company>
  </companies>
  <products>
   <product>
    <product_id>87-6-75-00</product_id>
    <company_id>000000</company_id>
    <product_name>Test item name</product_name>
   </product>
  </products>
  <items>
   <item>
    <product_id>401</product_id>
    <batch_id>0708533085710</batch_id>
    <serial></serial>
    <status>1</status>
   </item>
  </items>
</pvi>
```


Figure 1: Example of Set up data XML

4.3.2.3 Verification call

When external systems such as ERP or WMS want to integrate to the PVI system, the main reasons is that they can request item verification from the PVI. PVI's role is to store set up data and also other needed data for individual items, so it can successfully operate and process verification requests. PVI has its own functionality and the results of that functionality can be linked to other integrated system.

We have also defined a simple web service call to perform a verification check, which is triggered by other information systems and then the verification demand is transferred to the PVI. PVI returns the results of the verification back to the verification demand source as the response to the web service call.

```xml
<?xml version="1.0" encoding="ISO-8859-1" standalone="yes"?>
<pvi>
   <verification>
    <product_id>401</product_id>
     <batch_id>0708533085710</batch_id>
          <serial></serial>
   </verification>
</pvi>
```

Figure 44 : Example of Set up data XML

4.3.3 Business process integration

Probably the most important part of integration is integration of product verification into the existing business process. Each and every change to existing business processes risks causing resistance from users, because they tend to want to work as they are used to and in majority will have negative opinions on all changes to existing business process. By that we have tried to integrate needed changes into the process while minimising the changes for existing users.

In the case of warehouse management processes the end users, that are workers in warehouses, practically do not need to know if items that they move around are genuine or fake. We have to take supplies from company suppliers into the warehouse no matter what state the received goods are in. That is important especially in cases when we have some delay in the integration between warehouse management systems and the PVI system. In such cases the warehouse management system needs to put those kinds of items into the state of quarantine – no shipment or usage in production allowed until there is a positive authentication from the PVI. Integration to PVI is built as a back process and is not visible to the end users in the warehouse, except those, who have rights to check the process of verification. Usually those are not simple users, but users that have management responsibilities inside the warehouse.

So the existing system should be reengineered so that PVI integration and manipulation of goods in different states interferes with the end users as little as possible. In the case of a warehouse management system the end users are confronted with PVI integration only when they try to ship items with different PVI states or try to use them in the production of another item. Expert users mainly responsible for the quality control will use the most advanced functions of the PVI system and manage the item status.

In trials we have integrated all PVI communication inside existing processes so that they interfere as little as possible with processes for end users. The only block that can be seen by end users is when they try to ship items outside the company (or use – ship them in production line). When moving those items on shipment they get an error warning that items can not be shipped because they have an unresolved state from the PVI verification. Users responsible for resolving those states need to check those items and take the appropriate action depending on business rules inside each company.

5 Conclusion

This document explains how a smart RF signature can be integrated in a product and the different approaches and methods to achieve the correct RF tag integration.

Several technologies have been used to ensure that PVI performance and end user requirement will match. Performance of the PVI depends on the network infrastructure, the security features embedded in the RF tag, the product authentication method and the product itself.

This deliverable focuses on the product and gives different approaches to tag integration. Severe requirements have been imposed by virtue of the final application and the industry constraints concerning the tag location in the luxury industry, the environmental parameters for the aviation industry and the infrastructure constraint of the pharmaceutical industry.

Furthermore, the deliverable explains the impact of the product composition on the RF detection performance especially for the leather goods where the product material impact was not negligible and also for the metallic watch which behaves as an electromagnetic shield.

Theses constraints have been overcome by selecting the most appropriate technology and making the adequate integration of the authentication feature.

References

[DMS07] Diekmann, Thomas ; Melski, Adam ; Schumann, Matthias: Data-on-Network vs. Data-on-Tag: Managing Data in Complex RFID Environments. In: *Proceedings of the 40th Hawaii International Conference on System Sciences*. Washington, DC : IEEE Computer Society, 2007, 224a.

[FER04] Ferguson, R.B., Taking on RFID Challenge, Eweek, 2004

[JUE05] Juels, A., RFID Security and Privacy: A Research Survey, IEEE Journal Selected Areas in Communications, 2005

[KCSJ04] Kleist R., Chapman T., Sakai D., Jarvis B., RFID Labeling: Smart Labeling Concepts & Applications for the Consumer Packaged Goods Supply Chain, 2004

[WEI04] Weil, M., RFID confusion and possibility, APICS – the Performance Advantage, 2004

[WIDE04] Wilding, R., Delgado, T. RFID demystified: supply-chain applications, Logistics and Transport Focus, 2004