On the use of passive UHF RFID tags in the pharmaceutical supply chain: a novel enhanced tag versus hi-performance commercial tags

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Abstract: Item-level RFID-based tracing systems are of growing interest both from industrial and scientific standpoints. In such a context, the choice of the most adequate RFID tag, in terms of shape, frequency, size and reading range, is crucial. The potential presence of items containing materials hostile to the electromagnetic propagation exacerbates the problem. In addition, the peculiarities of the different RFID-based checkpoints make the requirements for the tag even more stringent. In this work, the performance of several commercial UHF RFID tags in each step of the pharmaceutical supply chain has been evaluated, confirming the foreseen criticality. On such basis, a guideline for the electromagnetic design of new high-performance tags capable of overcoming such criticalities has been defined. Finally, driven by such guidelines, a new enhanced tag has been designed, realised and tested, demonstrating that high performance item-level tracing systems can actually be implemented also in critical operating conditions.

Keywords: performance evaluation; radio frequency identification; supply chain; ultra-high frequency; item-level tracing.

Reference to this paper should be made as follows: Catarinucci, L., Colella, R. and Patrono, L. (2013) 'On the use of passive UHF RFID tags in the pharmaceutical supply chain: a novel enhanced tag versus high-performance commercial tags', *Int. J. Radio Frequency Identification Technology and Applications*, Vol. 4, No. 2, pp.122–137.

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1 Introduction

The need for a traceability system implemented at item level is becoming increasingly essential in many business processes and, among the different potential enabling technologies, passive Radio Frequency Identification (RFID) (Finkenzeller, 2003) is undeniably the most adequate candidate. Indeed, its simplicity of use as well as its very attractive cost-benefit ratio strongly appeals. Among the wide range of application sectors, the pharmaceutical supply chain, with millions of medicines moving around the world and needing to be traced at item level, represents a very interesting test case. Furthermore, the growing counterfeiting problem raises a significant threat within the supply chain system. Moreover, several international institutions (e.g. the Food and Drug Administration, the European Medicines Agency, the European Federation of Pharmaceutical Industries and Associations) are encouraging the use of innovative solutions in healthcare and in the pharmaceutical supply chain, to improve patient safety and enhance the efficiency of the pharmaceutical supply chain, with better worldwide drug traceability (FDA, 2004). In order to select the most adequate hardware solution, though, it is compulsory to take several aspects into account, including the working frequency, the Near Field (NF) or Far Field (FF) empowering methods, but also the differences among the various RFID-based checkpoints of a generic supply chain (Uysal et al., 2008; Catarinucci et al., 2011). In fact, depending on the considered step of the supply chain, at least three different RFID checkpoints are commonly used. They differ from one another in terms of interrogation distance, number of items to be read, reader antenna typology and scanning speed. It is worth pointing out that the tag marking an item must work properly in all checkpoints. More specifically, one of the possible checkpoints is given by the so-called items line, where the tagged product must be singularly scanned by using NF (Rao et al., 2005) reader antennas. Whatever tag is used for the item-level traceability, it should guarantee good performance even in NF conditions. A second kind of checkpoint is given by the so-called cases line, where a case containing a number of homogeneous items packed together, passes through a NF tunnel in order to read all the items in one shot. Consequently, the RFID tags used to assure reliable items level tracing systems should work correctly even at medium distance from the interrogator antennas. Moreover, the problem of the multiple readings of tags and of the tag overlapping should be considered. A third kind of checkpoint is given by the so-called border gate. When a pharmacy retailer is restocked it becomes necessary to simultaneously read all the different tagged items contained in a box or in a plastic bag. The border gate, equipped with FF reader antennas, is designed for such a purpose. Also in this case, some new requirements for the tag to be used are added up. The tag must work properly in FF conditions and also in this case, the potential tag overlapping and the multiple tag reading needs, should be considered. Besides the RFID checkpoints peculiarities, another important aspect is the effect on the tag performance of the platform where the tag is attached. Ultra-High Frequency (UHF) tags, more than High Frequency (HF) ones (Turner and Mickle, 2007; Catarinucci et al., 2010), are influenced by the presence of electromagnetically hostile materials (Uysal et al., 2008; Catarinucci et al., 2010; Catarinucci et al., 2011), such as liquids and metals; this aspect is crucial because in several scenarios, including pharmaceutical one considered here, metals and liquids are massively present.

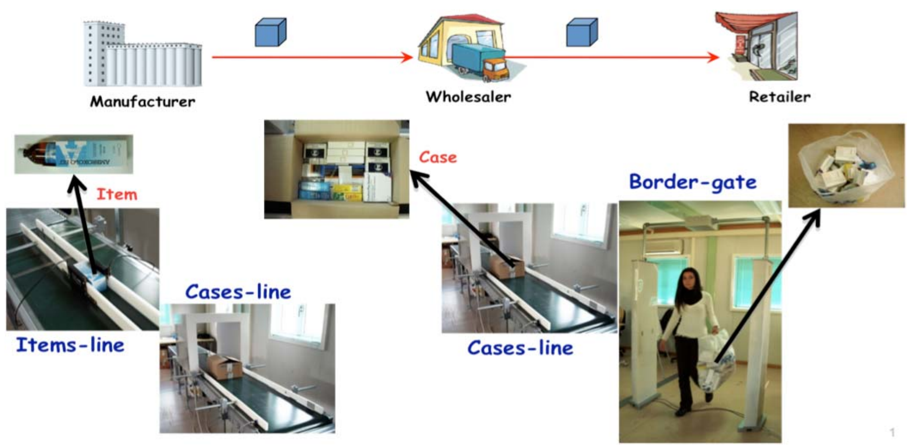
The sum of the requirements to be met by a single tag, functioning properly in every step of the supply chain, will be extended in the next sections. Nevertheless, it is already clear that the choice is polarised towards tags working in the UHF band. HF tags, in fact, guarantee a smaller reading distance than UHF ones, thus resulting in the inability to work in the cases line and in the border gate. Moreover, UHF tags are EPCglobal compliant (Barchetti et al., 2009). EPCglobal is a network architecture, whose main feature is represented by the use of the Electronic Product Code (EPC), a code able to uniquely identify each item. This architecture is composed of a set of standards for hardware devices (e.g. reader), software systems, network services and data interfaces that allow EPCglobal network to play a very important role in traceability systems. EPCglobal is an open architecture, based on a distributed database, able to guarantee effectiveness, flexibility and scalability. Consequently, in the first part of this work, a UHF test bed environment reproducing the three main RFID-based stages of the pharmaceutical supply chain has been installed and characterised. Afterwards, an extensive measurement campaign has been performed on six different FF UHF tags and on two NF UHF tags. More specifically, the successful read rate has been chosen as the reference metric and it has been evaluated by varying the type of tagged product and the steps of the supply chain. The analysis of the results highlights the strong performance decrease when a general purpose tag is used to trace some types of products containing a significant amount of metals and/or liquids. In the second part of this work, then, the main causes of performance degradation are individuated and a guideline for the design of a new kind of RFID tag, working properly in each step of the pharmaceutical supply chain and regardless of the kind of traced product, has been drawn. By following the guideline, a new enhanced tag has been realised and tested, and results discussed.

2 Test environment

The controlled test environment, shown in Figure 1, has been realised in order to simulate the main steps of the pharmaceutical supply chain. This test case has been selected because of its criticalities, both in terms of products to be traced and low admissibility of reading failures. The test environment, in fact, makes it possible to carry out effective experimental campaigns to evaluate the performance of UHF RFID-based tracing systems, even in particularly stressed operating conditions. Based on the three main components described above (items line, cases line and border gate), the deployed test environment enables an unbiased and repeatable comparison among the technologies. More specifically, the items line consists of a conveyor belt whose speed can be tuned in the range from 0 m/s to 0.66 m/s, in order to guarantee real requirements of pharmaceutical manufacturing processes. The conveyor belt has a double containment edge to keep products in the same position throughout the belt. In the middle of each containment edge, a NF reader antenna has been installed and connected to a high performance UHF RFID reader compatible with the EPC Class1 Gen2 standard. For the items line, the following devices have been used: two Impinj Mini-Guardrail reader antennas and one Impinj Speedway UHF reader. Similarly, the cases line consists of a conveyor belt, equipped by a line speed regulator in the range from 0 m/s to 0.66 m/s, a double containment edge to keep cases in the same position throughout the belt, one Impinj Speedway reader, and two roller conveyors. In the middle of the line, four small NF reader antennas (Impinj Brickyard) have been installed within a metallic tunnel. Each reader antenna is in the centre of each tunnel side. The width of the tunnel is equal to 0.6 m. Additional characteristics are: 50 Ω of impedance, 6 dBi as maximum FF gain and –15 dB as Return Loss.

Finally, the border gate uses a single UHF RFID reader (Impinj Speedway) and four FF UHF reader antennas.

Figure 1 Main steps of the pharmaceutical supply chain reproduced in the laboratory (see online version for colours)



3 Experimental campaigns settings

3.1 Drugs classification

The pharmaceutical market is characterised by a wide heterogeneity of drugs, which may differ in terms of both medicine state (i.e. solid, liquid, gas, etc.) and material (e.g. glass, metal, plastic, etc.) of the primary package. By taking into account such factors, a complete taxonomy of the most popular drugs may be drawn up. The first classification, which takes into account only the medicine state, splits all pharmaceutical items into four main categories:

- Solid: tablets capsules, granules, etc.
- Semi-liquid: creams, suppositories, etc.
- Liquid products: syrups, oral liquids, solutions, etc.
- Gas: pressurised gases.

Another useful classification can be done in terms of the material of the primary package. Plastic is the most widely diffused material because of the large use of bottles, blister packs and film layers. Nevertheless, even the use of metal is fairly common: aluminium blister packs and sachets are possible examples. Another common material for pharmaceutical products is glass which is very valuable especially for liquid products. The classical applications of glass packaging are bottles for liquids, ampoules and vials.

Based on the above information and discussions, Table 1 summarises a simple taxonomy of pharmaceutical products according to their physical properties. It is worth observing that this classification is very important to perform significative tests because different materials interact with Radio Frequency (RF) waves differently. In particular, liquids cause the RF waves attenuation by absorbing their energy, whereas metals do not let RF waves pass through by reflecting them. Moreover, in both cases, the impact on the radiating properties of the RFID tag antennas is relevant. The reported taxonomy, hence, becomes a compulsory instrument to select the most adequate drug for the specific laboratory test, so as to evaluate the impact of hostile materials on the performance of the RFID systems in the UHF band.

Table 1 Classification of pharmaceutical products

Product type		*Package material*		
		Metal	*Glass*	*Plastic*
Solid	Tablets in blister packs	X		
	Tablets in a bottle			X
	Granules in sachets	X		
	Powders in a bottle		X	
Semi-liquid	Cream	X		X
Liquid	Syrup		X	
	Single injectable solution in syringe		X	
	Multiple injectable solution in syringes		X	
	Oral solution			X
	Ophthalmic solution		X	
Gas	Bomb spray	X		

3.2 Description of the operating conditions

An effective evaluation of RFID reliability in a pharmaceutical supply chain cannot neglect the effects on the performance caused by hostile factors such as: the potential misalignment between tag antenna plane and reader antenna plane, the multiple reading of tags, the distance between tag antenna and reader antenna.

The misalignment problem is mostly relevant in the items line. To test such a misalignment impact, four different operating conditions should be tested. They are characterised by a mutual orientation between the plane where the tag antenna lies and the plane where the reader antennas lie: 0°, +90°, –90° and 180° are considered. In particular, this last represents the worst case and allows the performance evaluation under unfavourable conditions. Vice versa, the 0° case is the ideal condition. Finally, the –90° case is characterised by the contact between tag and conveyor belt. Instead, in the +90° case the tag is attached to the up-side of the item, so that the potential interference with the conveyor belt is avoided but the distance with the reader antennas depends on the size of the item.

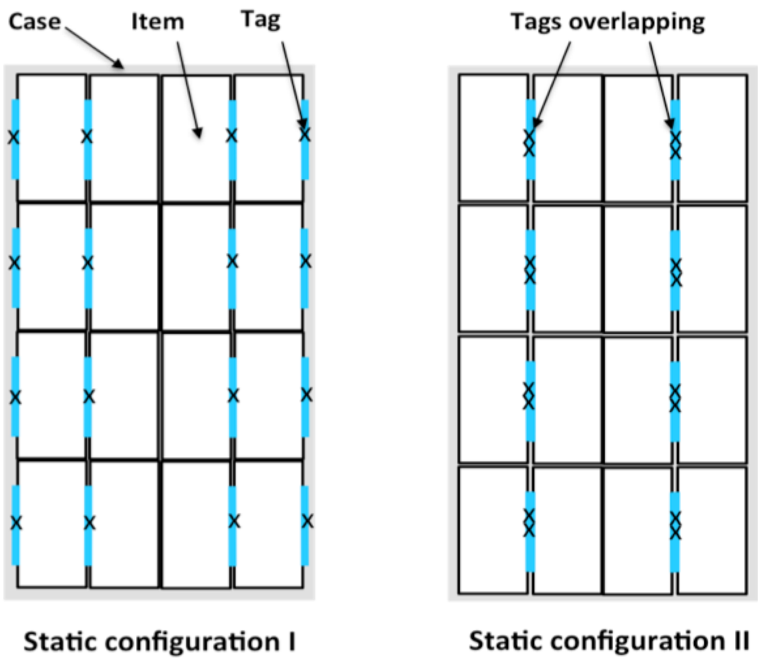
Another problem to be analysed deals with the collisions among tags, impacting both the cases line and the border gate. For the cases line both homogeneous cases (consisting of a single product type) and heterogeneous cases (containing of products of different types) should be tested. Moreover, the configuration of the cases also plays an important role. In order to simulate realistic conditions, three different configurations have been adopted for each case:

- Configuration I: the case was prepared placing the items with their tag antenna oriented toward the reader antennas and avoiding the overlapping of tag antennas.
- Configuration II: the case was prepared placing the items with their tag antenna oriented toward the centre of the tunnel (i.e. opposite to the reader antennas) and trying to obtain the overlapping of tag antennas.
- Configuration III: the case was prepared considering four different random dispositions of items. These dispositions were alternated in progress during the test bed.
- In order to better clarify the compositions of cases, in Figure 2, the configurations I and II are schematically reported. The overlapping of two different tags is represented by a double ‘x’.

Further tests related to cases line and border gate should also be carried out on sets of heterogeneous drugs. More specifically, cases filled with a mix of 50 items in the cases line and a mix of 200 items in the border gate will be considered in our measurements. Three different combinations of items into the case (cases line test) and into the plastic bag (border gate test) have been prepared considering the following percentages:

- MIX1: 40% solids, 40% liquids and 20% semi-liquids;
- MIX2: 50% solids, 30% liquids and 20% semi-liquids;
- MIX3: 60% solids, 20% liquids and 20% semi-liquids.

Figure 2 Some examples of case composition (see online version for colours)



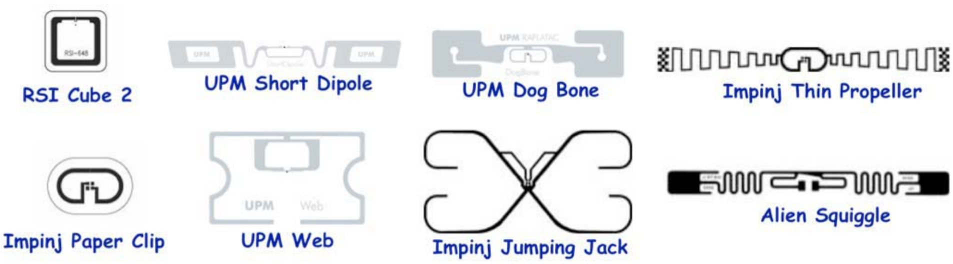
3.3 Description of the pre-selected commercial UHF RFID tags

In order to carry out an effective performance comparison among commercial RFID tags, so to evaluate the current limits in item-level tracing systems in the whole supply chain, a preliminary technological scouting has been carried out. Note that for item-level tagging applications, the choice of the tags is affected by different requirements such as small size of the tag itself, compatibility with the EPC global standard, high scanning speed, low cost and high stress of tag label during product life cycle. As already stated, particular attention is focused on passive UHF tags that can be split into two sub-sets: NF and FF tags. In this work, eight different types of passive UHF tags, six FF and two NF have been tested. All pre-selected tags are characterised by the same memory (96 bit), operating frequency (860–960 MHz) and compliance with the standard EPC Class1 Gen2. On the contrary, the main differences are on antenna geometry and on the size of tag. The layout antenna of the eight pre-selected RFID tags is reported in Figure 3. The following types have been considered in more detail:

- RSI Cube 2: is a small NF tag, whose size is 25.4 × 25.4 mm, with an NXP Ucode G2XL chip, designed for pharmaceutical and applications where small form factor is required.
- Impinj Paper Clip: is a small NF tag with an Impinj Monza3 chip, whose size is 19.0 × 12.7 mm, designed for pharmaceutical and applications where small form factor is required.

- Impinj Thin Propeller: is a FF tag with an Impinj Monza3 chip and with an antenna, whose size is 8.0 × 95.0 mm, that is a high-performance dipole configuration. It guarantees large working bandwidth and is designed for warehouse, logistics, case, carton and garment applications.
- Impinj Jumping Jack: is equipped with an Impinj Monza3 chip, a high-performance FF antenna and a NF antenna. Its size is 44.5 × 88.9 mm and it is designed for long-range, multi-orientation warehouse, logistics, carton, baggage and garment applications.
- UPM Dog Bone: is a high performance tag for a wide range of RFID Supply Chain Management RFID Apparel and RFID Transportation applications. It is equipped with an Impinj's Monza3 chip. Its size is 27 × 97 mm.
- UPM Web: is a high performance tag for RFID item-level use, whose size is 34 × 54 mm. Reliable reads/writes when tags are in close proximity to each other. It is equipped with an NXP U-Code G2XL chip.
- UPM Short Dipole: is equipped with an NXP U-Code G2XL/G2XM chip. It is designed for a wide range of RFID Supply Chain Management. Its size is 15 × 97 mm.
- Alien Squiggle: is equipped with an Alien Higgs-3 chip. It is designed for a wide range of RFID Supply Chain Management. Its size is 12.3 × 98.2 mm.

Figure 3 Layout of the eight pre-selected commercial passive UHF RFID tags (see online version for colours)



4 Experimental results of commercial RFID tags

In order to analyse the strengths and weaknesses of commercial passive NF and FF UHF tags in the pharmaceutical supply chain, several experimental campaigns have been performed. In all tests, the speed of the conveyor belt has been set to 0.66 m/s and 0.33 m/s, respectively, for the items line and cases line. The transmission power of the reader RFID has been set to 1 W. Furthermore, the RFID tag is applied on the secondary package (made of cardboard) of the medicine product.

The first part of the experimental campaign is performed on a large number of heterogeneous drugs (12 types) able to cover the overall taxonomy reported above in normal and favourable operating conditions. These tests have been carried out on the three steps of the supply chain. A first performance comparison of only three passive commercial tags has been performed in terms of successful read rate. In particular, the following tags have been considered: RSI Cube2, Impinj Thin Propeller and UPM Dog Bone.

On the contrary, the second part of the tests is focused on just two types of drugs (bomb spray and ophthalmic solution), which are the most hostile to electromagnetic propagation. In such a test, the RFID system performance has been evaluated under very stressing operating conditions. In this work, experimental campaigns have been mainly focused on the items line and the cases line, and the above-described eight commercial passive UHF tags have been analysed.

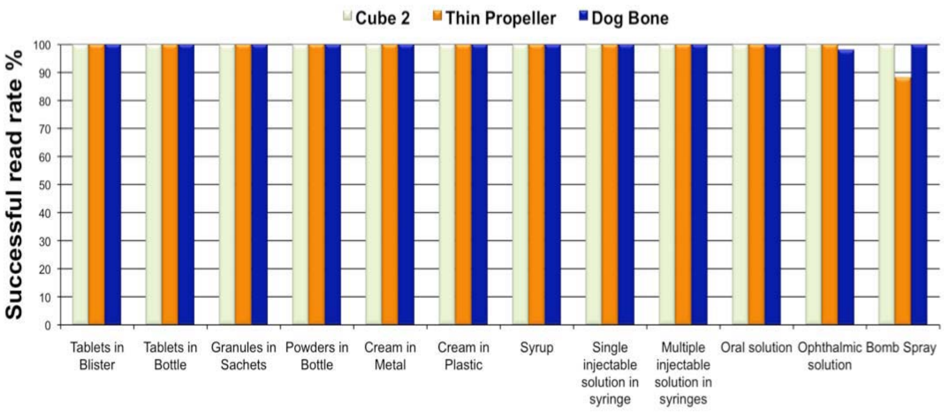
All results, reported in this paper, are characterised by a confidence level equal to 95% with maximum relative error of 5%.

4.1 Test results in ideal operating conditions

The first part of the experimental campaigns is focused on a performance comparison between NF and FF commercial UHF tags applied on different drug types in each step of the supply chain. The following RFID tags have been used: RSI Cube 2 as NF tag, Impinj Thin Propeller and UPM Dog Bone as FF tags.

In the first test, the most favourable working conditions in the items line are reproduced. Indeed, the mutual orientation between the plane where the tag antenna lies and the plane where the reader antennas lie is 0°. Results reported in Figure 4 show that the NF tag Cube 2 ensures optimal performance for every drug type, even in the presence of critical materials such as liquid and metal. Likewise, the two FF tags have also given good results, even though a slight effect due to the presence of metal and liquid, above all in the bomb spray and ophthalmic solution cases, is observed.

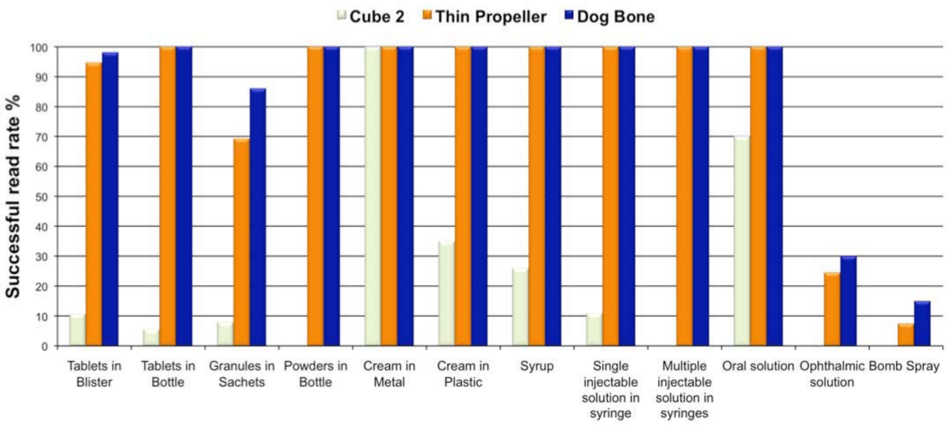
Figure 4 A performance comparison on the items line by varying the drug type and the tag type considering normal operating conditions (mutual orientation 0°) (see online version for colours)



In a second test, the worst conditions are reproduced: a mutual orientation between the tag plane and reader antenna plane of +180° has been considered. This has been done by switching off one of the two reader antennas and by applying the RFID tag on the package face opposed to the active reader antenna. The experimental results, reported in

Figure 5, clearly shows that FF UHF tags perform better than NF ones. The results where even the Dog Bone tag is not characterised by a successful read rate of 100%, have been obtained mainly in the presence of granules in aluminium sachets, ophthalmic solution in aluminium sachets, syrup and bomb spray. For these cases, though, the Cube 2 tag has shown very poor performance, reaching values of successful read rates near to 0%.

Figure 5 A performance comparison on the items line by varying the drug type and the tag type and considering extreme operating conditions (mutual orientation +180°) (see online version for colours)



In order to evaluate the reliability in the presence of multiple reading of tags at the same time, trying to analyse collision and misalignment problems that may occur when a case containing a number of homogeneous or heterogeneous items is traced in other steps of the supply chain (such as the cases line), several experimental campaigns have been carried out. More specifically, eight different types of product, chosen among the four categories previously defined, have been used to perform tests on homogeneous (single type of product) and heterogeneous (mix of products) cases (see Section 3.2). Homogeneous cases have been analysed by considering a random disposition of items within the case. In particular, the type of case composition is the Configuration III previously described. Figure 6 shows the experimental results obtained by testing again the NF Cube 2 tag and the two FF, Thin Propeller and Dog Bone, tags. The histogram clearly demonstrates that the performance of FF UHF tags is better than the NF Cube 2 tag. Furthermore, this test shows that all the analysed tags are not able to guarantee good performance in the presence of materials that are hostile to electromagnetic propagation. In particular, the experimental results show a very unsuccessful read rate when the homogeneous case is composed of items such as bomb spray or ophthalmic solution.

Further tests allowed the evaluation of the performance, in this case also in the presence of multiple reading of tags, but considering the heterogeneity of drugs. In particular, Figure 7 shows a performance comparison in the cases line by varying the configuration of the case in terms of drug types. The three different and previously described realistic compositions have been considered (MIX1, MIX2 and MIX3). The experimental results clearly show that optimal performance (100% of successful read rate) can be obtained using the two types of commercial UHF tag.

Figure 6 A performance comparison on the cases line by varying the drug type and the tag type considering homogeneous cases and a random disposition of the items within the case (Configuration III) (see online version for colours)

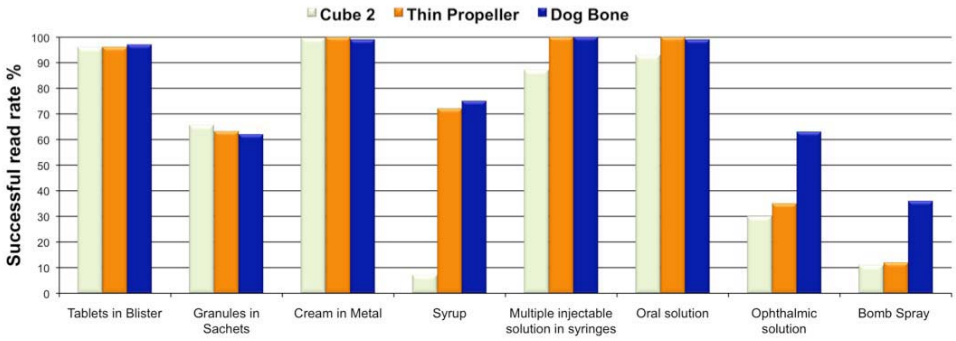
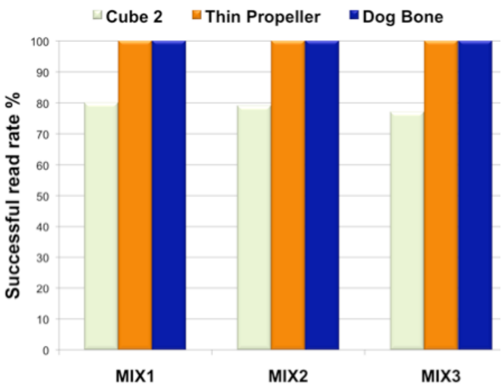


Figure 7 A performance comparison on the cases line by varying the tag type and the composition of the case containing heterogeneous drugs (see online version for colours)



Finally, the last test of the first part of the experimental campaigns is aimed to evaluate the reliability of commercial UHF tags in the border gate. An adequate number of 200 heterogeneous items contained in a big plastic bag has been considered. For this test, the same three previous different compositions, in terms of drugs type, have been considered.

The experimental results of Figure 8 show that a NF UHF solution is definitely not suitable for item-level tracing systems in this step of the supply chain.

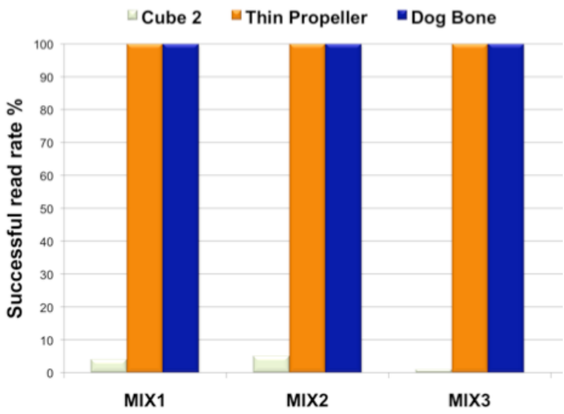
The first part of the experimental campaigns has demonstrated that the use of commercial

UHF RFID tags represents a suitable solution for the traceability at item level at least in the presence of non-critical operating conditions.

4.2 Test results on critical operating conditions

As stated above, when the operating conditions do not present particular criticalities, the selected FF tags work properly. Nevertheless, the performance degradation observed when the tags have been tested on products containing relevant quantities of liquid or metal is evident. For such a reason, this section focuses on the tag performance evaluation under more severe operating conditions. The products which resulted as being the most critical in the previously conducted tests, the bomb spray and the ophthalmic solution, have been considered. As previously stated, in fact, when the item to be traced is composed of metal and/or liquid, the tag performance could decrease considerably.

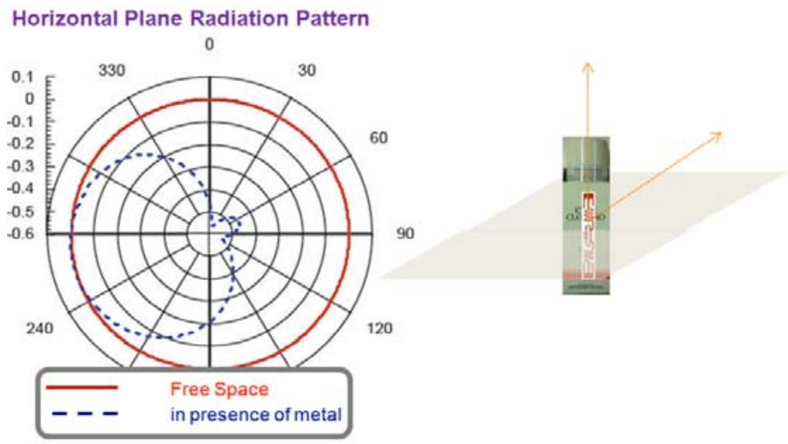
Figure 8 A performance comparison on the border gate by varying the tag type and the composition of the plastic bag containing heterogeneous drugs (see online version for colours)



This is substantially due to the fact that the horizontal-plane radiation pattern of the tag antenna, that is almost omnidirectional in free space conditions, varies significantly because of the presence of such materials.

In Figure 9, for instance, the horizontal plane radiation patterns of the Alien Squiggle RFID tag both in free-space conditions and in the presence of metal are reported. It can be observed that, for many directions, the potential link between tag and reader is not possible anymore when the tag is attached on the bomb spray case. This effect becomes relevant when there is 90° of misalignment between the planes individuated by the reader antenna and the tag, respectively.

Figure 9 Horizontal radiation pattern in free space condition (red line) and in presence of metal (blue line) of the Alien Squiggle Tag (see online version for colours)



The results reported in Figures 10 and 11, for instance, refer to the successful read rate measured in the items line, respectively, for the ophthalmic solution case and the bomb spray case. In order to stress the misalignment problem, tests have been carried out by considering the three different operating conditions previously described and characterised by a mutual orientation between tag antenna and reader antenna equal to 0°, +90° and –90°, respectively.

Figure 10 A performance comparison on the items line by varying tag type and the tag-reader antenna misalignment in the presence of liquids and metals (ophthalmic solution) (see online version for colours)

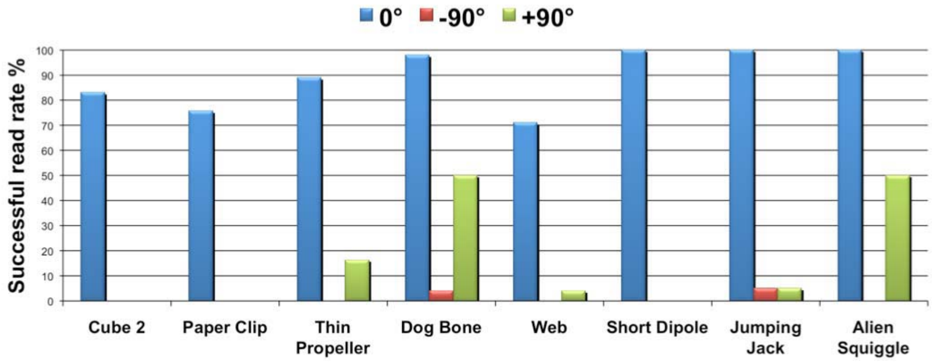
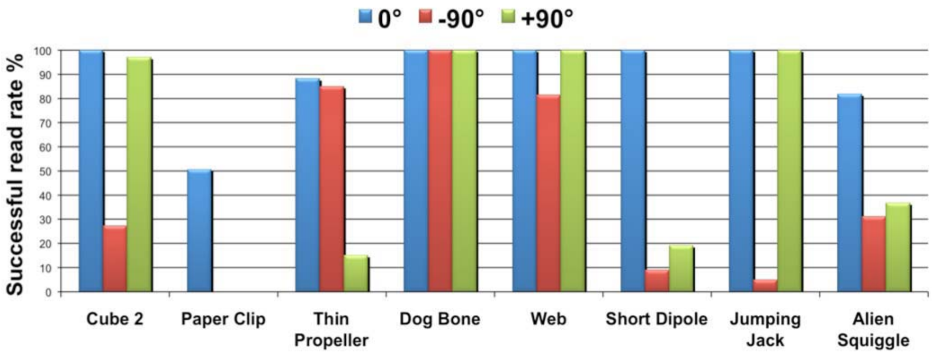


Figure 11 A performance comparison on the items line by varying tag type and the tag-reader antenna misalignment in presence of metals (bomb spray) (see online version for colours)



Results are quite relevant: despite the very good values obtained in the case of alignment, in general it emerges that none of the tags guarantees satisfactory performance levels in both cases and for each orientation.

Even more interesting are the results obtained by testing the tags in the cases line. As an example, Figures 12 and 13 report the successful read rate evaluated by packing together 36 secondary packages of ophthalmic solution and 14 packages of bomb spray, in the three configurations previously described and named, respectively, Configuration I, Configuration II and Configuration III. It can be observed that the considerable presence of metal and liquid inhibits the communication between reader and NF tags.

Moreover, when FF tags are also considered, very low performance is obtained in each configuration, demonstrating once more that general purpose commercial tags are not appropriate for the implementation of complex item-level tracing systems. This is substantially due to the fact that when such tags are designed, the peculiarities of the scenario where they must be utilised are not taken into account.

Figure 12 A performance comparison on the cases line by varying tag type and the homogeneous case composition in presence of liquids and metals (ophthalmic solution) (see online version for colours)

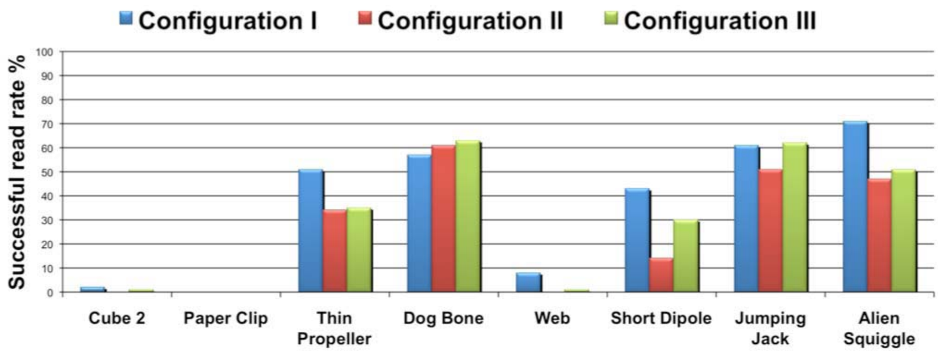
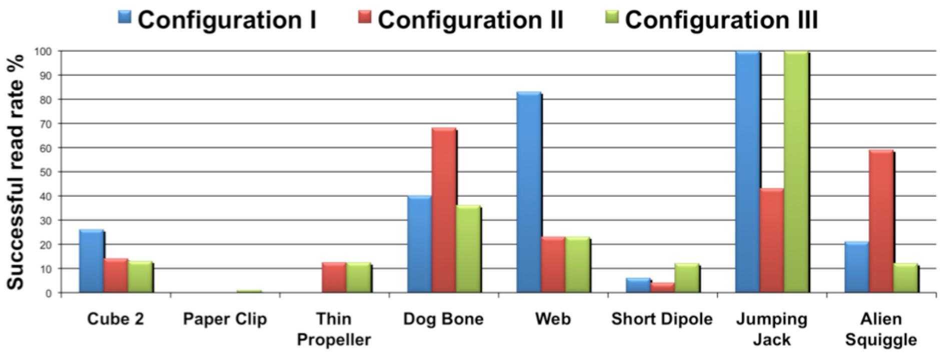


Figure 13 A performance comparison on the cases line by varying tag type and the homogeneous case composition in presence of metals (bomb spray) (see online version for colours)



In the next section, a requirement analysis for a tag appositely designed to work in a complex supply chain, such as the pharmaceutical one, are individuated and described and are used to drive the development of a new high performance UHF RFID tag.

5 An enhanced passive FF UHF RFID tag

On the basis of the results shown in the previous sections, the realisation of a tag designed ad hoc for the specific supply chain scenario is a must. Consequently, this section focuses on the analysis of the pharmaceutical supply chain peculiarities and on the individuation of the properties that a tag should own in order to guarantee high performance in all supply chain steps, even when used to track items containing electromagnetically critical materials, such as liquids and metals. It is worth observing, though, that the pharmaceutical sector is only one of the many scenarios where a similar study could be of interest.

As seen, one of the sources of performance degradation in the items line is given by the potential misalignment between the NF reader antenna and the tag attached to the secondary package of an item. In fact, by means of a conveyor belt, the tagged item passes through two NF RFID antennas. Nevertheless, it is possible that the item surface on which the tag lies and the plane on which the reader antennas lie are mutually orthogonal. Now, as depicted in Figure 9, despite the almost omnidirectional tag radiation pattern in free space condition, the presence of metal or liquid inside the item strongly modifies the radiating properties, even inhibiting, in some cases, the communication with the reader.

A first fundamental requirement can be deduced: a correctly performing tag should guarantee at least two main lobes of the radiation pattern, ideally orthogonal each other mutually, in every working condition.

Another reason of reading-failure in the items line is due to the use of a FF tag antenna with a NF reader antenna. Although NF reader antennas are used in the items line, NF UHF tags cannot be used because they would not work properly in the subsequent supply chain steps, where FF reader antennas are adopted.

Therefore, the second requirement is: a correctly performing tag should exhibit good performance both in the NF and the FF.

On the items line step, the products are read one-by-one and no multiple-reading related problems arise; on the contrary, they will occur in the cases line and in the border gate. In such situations, shielding effects due to the presence of plenty of items as well as the potential overlapping of tags, could lead to a strong performance collapse. Furthermore, in these cases, problems due to a potential misalignment of tag and reader antennas can also arise.

Consequently, some new requirements can be individuated: a well performing tag should be designed in order to avoid the complete tag overlapping and, moreover, it should guarantee (also in this case) multiple radiation pattern lobes.

By following the guideline above individuated, a new enhanced tag has been realised. The new tag (patent pending number TO2010A000493) is substantially based on a dual-lobe conformal antenna, adaptable to the different shapes of the various item packages and easily integrated into them. The shape of the antenna has been modelled in order to make the complete tag overlapping highly improbable. Moreover, the common design solution, based on the use of an inner loop around the microchip, has been adopted in order to guarantee good performance also in NF conditions. The antenna has been realised in copper tape. Cost and size are comparable with canonical label-type general purpose tags. Unfortunately, because of the patent-pending status, no details can be given on the shape and on the electromagnetic solutions adopted in order to reach the prefixed goal. Nevertheless, this is not even the primary purpose of this work. On the contrary, what is fundamental to highlight is the obtained result: in each operating condition and whatever pharmaceutical product is used, the enhanced tag boosts up the successful read rate to 100%. This impressive result is not surprising at all: if a tag is specifically designed for this specific problem, then the effective item-level traceability can be reached.

6 Conclusions

In this paper, the problem of the effective RFID-based traceability performed at item level has been addressed. The pharmaceutical supply chain has been considered and its criticalities, in terms of kinds of goods to trace and peculiarities of the RFID checkpoints, have been individuated and discussed. The inadequateness of the use of commercial general purpose tags has been proved through an exhaustive performance evaluation campaign, aimed at evaluating the successful read rate in each step of the supply chain for numerous tagged products. Six different commercial FF UHF tags and two NF UHF tags have been tested; these last are the less reliable, but the FF ones also exhibit strong limits when used to trace products containing metals or liquids. Consequently, by taking into account the traceability scenario, the requirements that a tag should own in order to overcome such limits have been individuated and, on such basis, a new enhanced tag has been realised. Its performance has been rigorously evaluated and the impressive results have been discussed. If the tag is designed considering the peculiarities of the specific tracing system, a successful read rate of 100% can be obtained, regardless of the supply chain step, the composition of the traced product and the operating conditions.

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