Chapter 12
Dual Frequency Tag Performances in the Fashion Industry

Andrea Volpi, Antonio Rizzi and Rinaldo Rinaldi

Abstract The paper strives at benchmarking performances of dual frequency inlays, operating in UHF and HF bands, when deployed in the apparel logistics and end-user retail processes. The developed testing protocol makes it possible to evaluate performances of RFID devices in simulated supply chain and end-user-oriented processes. It has been designed according to the needs for identification both of the supply chain and of the end-users, who can take advantage of the adoption of NFC technology. We applied the testing procedure to RFID inlays equipped with an innovative IC and two antennas, capable of managing both EPC communication in UHF band and NFC communication in HF band with smart devices. The performances of the inlays have been compared to standard tags commonly used in EPC and NFC fields. We measured and compared read rate, accuracy, and read time when testing EPC capabilities, and read/write throughput, time and distance when measuring NFC functionalities. By simulating a real-world environment, test results give a direct insight of performances to be expected from different dual frequency RFID inlays. Therefore, IT and logistics managers can find answers to how these innovative tags perform and which would be the best choice for new RFID applications.

Keywords RFID · Apparel · Performance benchmarking · NFC · Dual frequency

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12.1 Introduction

The implementation of the Radio Frequency Identification (RFID) in the apparel industry had a steady increase over the past several years and this trend is projected to continue for the immediate foreseeable future. As suggested by several studies, fashion and apparel retail is a leading sector for RFID technology, because RFID implementation in this sector can count a wide diversity of use cases, and it has the potential to solve unique problems (Bottani et al. 2016; Rizzi et al. 2016). Harrop and Das (2013) forecast the annual demand for RFID tags from the apparel industry to reach 20 billion within the next decade; this is due to the fact that about 100 apparel and related firms are currently at the RFID tag trial and rollout stage, and that the combined annual demand from just two of these firms is about 500 million tags. Moreover, during the next decade, they expect the systems and tag business in the apparel industry to grow at double the rate of the overall RFID market. Given these premises, the apparel industry appears to be a significant player in RFID adoption and use scenarios, thus there is a need to give a direct insight of performances to be expected from different dual frequency RFID inlays.

The benefits of item-level RFID tags in the apparel industry span a wide spectrum, depending on the application context. For example, a report from Motorola (2010) identifies several benefits of item-level RFID tags in a retail store setting that include improved inventory accuracy, fewer inventory check personnel, lower out-of-stock situations, just-in-time inventory replenishments, improved stock flow between stockroom and sales floor, reduced inventory carrying cost, improved customer service, faster checkout, improved information-rich customer shopping experience, efficient returns management and enhanced loss prevention. Several benefits of item-level RFID tags are also found in distribution and logistics that include better inventory visibility, lean inventory management, electronic proof of delivery, shorter invoice and payment cycle times and improved shipment accuracy.

From the above discussion, it is clear that there should no longer be any doubt with respect to the decision to adopt RFID in the apparel retail industry. The auto-identification needs at different points in the apparel retail supply chain (e.g., warehouse, during transit, supplier, retailer, end-user) are not necessarily the same. The auto-identification needs could be different even between two retail settings. For example, a retailer of relatively inexpensive fast moving consumer goods, whose requirements are mainly related to stock management as in Bertolini et al. (2013), may require simple passive RFID tags with minimal memory and processing power compared to that which is required by an exclusive high-end retailer whose needs may be aligned more with counterfeit prevention. To add to the complexity, the availability in a wide variety of specifications of each RFID system component (e.g., tags, readers) necessitates a careful analysis of the application needs and the assembly of the most appropriate RFID system that comprises selected individual components. Given this, the natural next step is to develop guidelines on the RFID adoption process. The RFID technologies commonly adopted in current scenarios are based on Electronic Product Code (EPC) standards, for logistics and supply chain processes, and on Near Field Communication (NFC) standards, for use cases involving item's identification by an end-user. A couple of tag, one for each standard, is required in order to merge the benefits of the two technologies, but a synchronisation issue arises between the memories of the two ICs. Innovative chips available on the market can implement EPC and NFC standards, sharing the same data stored on the tag. Logistics, supply chain, anti-counterfeit, after sales processes can profitably relay on the same data stored in tag's memory and accessible via both interfaces.

12.2 Literature Review

The performance of the supply chain can be easily improved adopting Information and Communication Technologies (ICT), as repeatedly reported in literature. There is an extensive set of published literature that considers the use of RFID, an ICT example, in the apparel industry; for this reason, RFID systems have been gaining popularity in supply chain applications due to their beneficial properties.

Bertolini et al. (2012a) consider the supply and demand side of RFID systems. Specifically, they evaluate available RFID solutions in the fashion industry in terms of their performance and attempt to match these with end-users of such technology. Performances of RFID and production systems can be monitored by means of business intelligence modules described in Bertolini et al. (2009).

Bertolini et al. (2012b) quantify the business benefit of RFID in apparel and fashion supply chains related to logistics and store processes at both operational and strategic levels. With results obtained from about 20,000 tags on garments tracked from a distribution centre to a retail store of a major Italian fashion brand, they observe that sales and customer satisfaction increase with the use of data generated through RFID tags.

GS1 has recently defined the Tagged Item Performance Protocol (TIPP) guidelines (2015), aimed to provide standard procedures to express performance requirements of UHF tags in retail, and a standard test protocol to verify the performance of a tagged item. GS1 workgroup defined performance levels for tagged items (rather than tags, inlays, labels), that can be verified independently by retailers, suppliers or any 3rd party by means of a standardized test procedure. TIPP introduces the concept of grade for UHF tags, defined as a group of performance specifications for a tagged item; it is easily measurable for tags in an anechoic chamber using dedicated hardware and software. A tag matches a specific grade if it satisfies all the performance requirements of the considered grade; different tags with same performances (sensitivity and backscattered power) has the same grade. For RFID end-users, it is more difficult to establish the required grade for their processes, since in-field tests are needed because it is not possible to get this information from a laboratory test. In this paper the GS1 TIPP is not applied for two reasons: (1) the two fashion companies interested in the dual frequency tags needed results in a short time, not allowing us to equip the lab with an anechoic chamber; (2) they were interested in measuring the performance of the tags in their logistics processes, whose grade is still undetermined.

Dahl et al. (2015) pointed out that currently, there is not sufficient published data about the performance and energy efficiency of NFC as experienced by NFC applications and there does not exist proper tools for NFC application developers to efficiently benchmark and test tags. Thus, the authors developed an open source Android based toolset for NFC tag testing and performance evaluation. Moreover, as a confirmation that the application fulfils its purpose, extensive testing has been performed to compare five tags based on NFC standard.

These are just some samples of literature related to RFID and its use in the apparel industry. In order to validate the capability of RFID devices to reach and support the above-mentioned expected benefits, it is necessary to test new equipment (tags, readers) in the considered use cases, i.e. processes involving logistics and end-users. In the remaining part of the present work a test methodology is presented in order to assess and compare the performances of tags operating according to EPC, NFC or both standards.

12.3 Materials and Methods

The presented testing procedure is aimed at assessing the performance of innovative RFID dual frequencies inlays, operating according to EPC and NFC standards. To this extent, specific testing procedures have been designed in order to compare the performances of the inlays with standard, commonly used RFID tags operating in the first or the second scenario. The dual frequency inlays are composed of a chip capable of connecting and managing two antennas, one dipole antenna operating in the UHF band according to EPC standards, and a loop antenna tuned in the HF band according to NFC standards. The chip shares the same memory blocks across the two standards, thus the information contained in the IC's memory can be read or written by means of UHF readers (commonly adopted in logistics processes) or HF readers (typically smartphones). These functionalities are very important in the fashion retail sector, where the tag can be profitably adopted in both logistics/supply chain processes and in customer-oriented processes.

12.3.1 EPC Tests

Six families of different tags have been tested, according to Table 12.1. Tag 1, 2 and 3 are three tags commonly used in retail, thanks to their good performances and the suitable form-factor, while Tag 4, 5, and 6 are equipped with the innovative dual frequency IC.

A logistic process involving reads of multiple tags has been replicated to test the performances of the tags. In particular, a handheld RFID reader (*manual test*) and

Table 12.1 Tags tested in EPC scenario

Tag	Frequency	Standard	IC
1	UHF	EPC	NXP G2iL
2	UHF	EPC	NXP UCODE 7
3	UHF	EPC	NXP G2iL
4	UHF/HF	EPC/NFC	EM4423
5	UHF/HF	EPC/NFC	EM4423
6	UHF/HF	EPC/NFC	EM4423

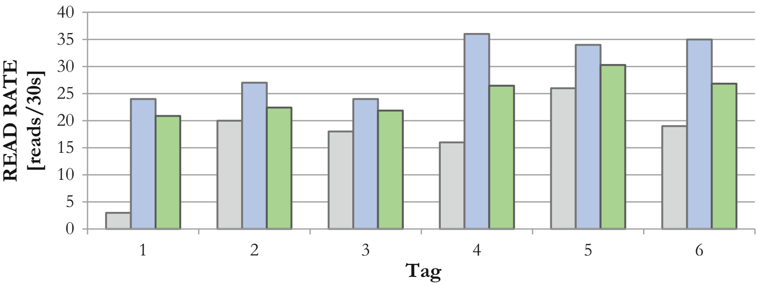

Fig. 12.1 Minimum (grey), maximum (blue), average (green) read rate (reads/30 s), mobile reader

a fixed RFID reader (*automated test*) have been used to inventory tags in a bulk shipping/receiving test.

Manual shipping/receiving test is aimed at reading the maximum number of tagged garments placed inside a cardboard box and read with a Zebra RFD8500 handheld device at maximum power (32 dBm ERP). The device is waved for 30 s around the box containing 90 tagged garments, 15 for each family of tags. The number of tagged items contained in the box has been chosen in order to be representative of the real logistics processes taken in retail; the reading time is set to 30 s because of two reasons: it is compatible with the operation considered (manual shipping or receiving process) and, according to the experimental results, the highest accuracy for each read is achieved within the first 10 s, and just sporadic reads occur during the remaining time. Test procedure is repeated 10 times.

Measured KPIs include: Accuracy, percentage of tags correctly read out of the overall number of tested tags (90); Read rate, number of time a tag has been read in 30 s timeout. Average accuracy is 100% for all considered tags, while Fig. 12.1 shows the achieved read rate. The better the performance, the higher the achieved read rate; closer values of minimum, maximum, average read rate mean higher control of tag production process (and thus constant tag performances) and/or favourable orientation of the tag towards the reader's transmitting antenna.

During the execution of the automated shipping/receiving dock door test, the box is moved and rotated through an RFID gate composed of a Impinj Threshold antenna connected to a Impinj Speedway R420 reader, without any added shielding

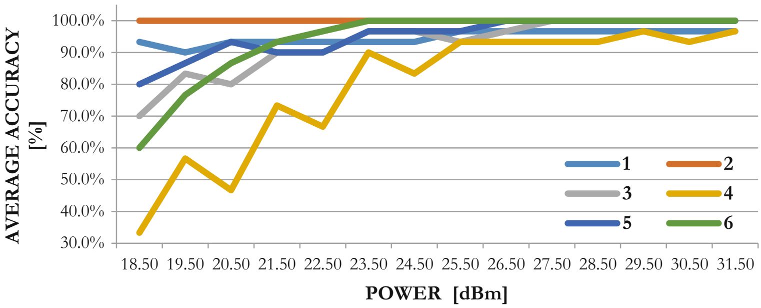

Fig. 12.2 Average accuracy (%), fixed reader

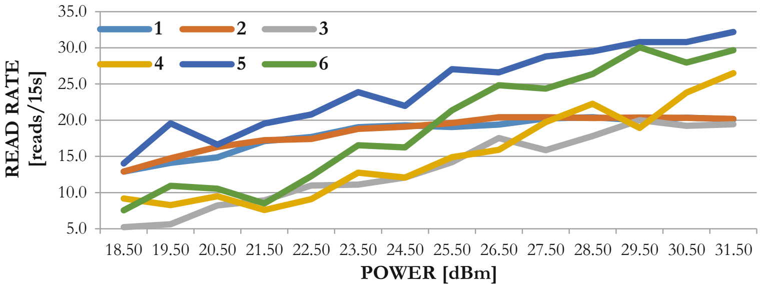

Fig. 12.3 Average read rate (reads/15 s), fixed reader

structure. During each test run, the reader is activated using the software provided by the manufacturer (Multireader), the power is swept from 18.5 to 31.5 dBm, and for each power level a 15 s read is performed. The reading time is set to 15 s because of two reasons: is compatible with the operation considered (automated shipping or receiving process) and, according to the experimental results, the highest accuracy for each read is achieved in the first 4–5 s, and no significant reads occur during the remaining time. Test is repeated 10 times.

Measured KPIs include: Accuracy, percentage of tags correctly read out of the overall number of tags tested (90); Read rate, number of time a tag has been read in 15 s timeout; TTFR (Time to First Read): time required to read all the readable tags belonging to the same family. Figures 12.2, 12.3 and 12.4 plot the measured performances.

12.3.2 NFC Tests

Seven different families of tags have been tested, as reported in Table 12.2.

Tag 1, 2, 3 and 7 are four commonly used tags in NFC applications for their performances and the form-factor; while Tag 4, 5, and 6 are equipped with the

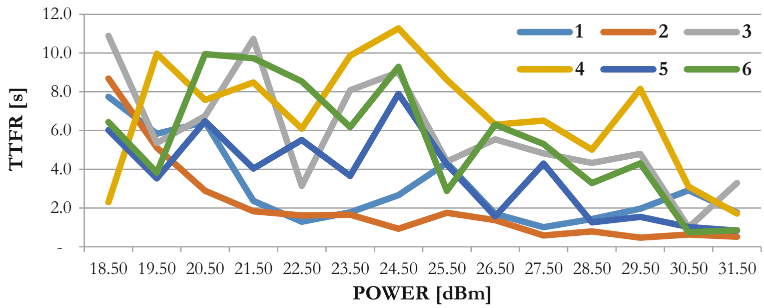

Fig. 12.4 Average TTFR (s), fixed reader

Table 12.2 Tags tested in NFC scenario

Tag	Frequency	Standard	IC
1	HF	NFC type 2	NXP MIFARE ULTRALIGHT
2	HF	NFC type 2	NXP NTAG203
3	HF	NFC classic	NXP MIFARE CLASSIC
4	UHF/HF	EPC/NFC	EM4423
5	UHF/HF	EPC/NFC	EM4423
6	UHF/HF	EPC/NFC	EM4423
7	HF	NFC type 5	NXP ICODE SLIX

innovative dual frequency IC. Tags have been tested according to a typical use case of NFC tag: short range read by means of a mobile phone, following two different test procedures.

Procedure #1: simulation of a typical use case involving a single tag read by the end-user.
The tag under test is placed on a wooden table, then a stack of 8 cardboard spacers, 6 mm thickness each, is placed over the tag. A mobile phone equipped with a NFC reader is set in continuous reading mode and placed over the stack, aligning the transmitting antenna of the phone with the tag, and kept in this position for 10 s or until the complete read of the tag's memory is over. If no read is possible, after 10 s the phone is removed anyway. Tag Info application, developed by NXP, is used on the mobile phone to activate and control the NFC reader; the whole tag memory (UID and user memory) is scanned and read, measuring the required time. One cardboard spacer is removed from the stack and the test is repeated as described above. The whole test procedure is repeated 10 times; while three different mobile phones have been used.

Measured KPIs include: Average read time required to read the tags of the specific family using three different mobile phones; Maximum distance required to obtain 90% accuracy. Figure 12.5 shows the achieved performances.

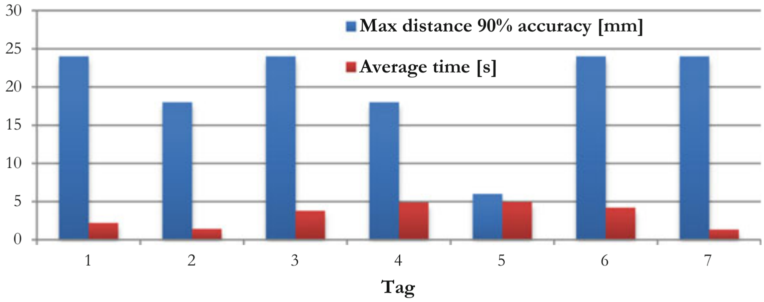

Fig. 12.5 Maximum distance (mm) and Average reading time (s)

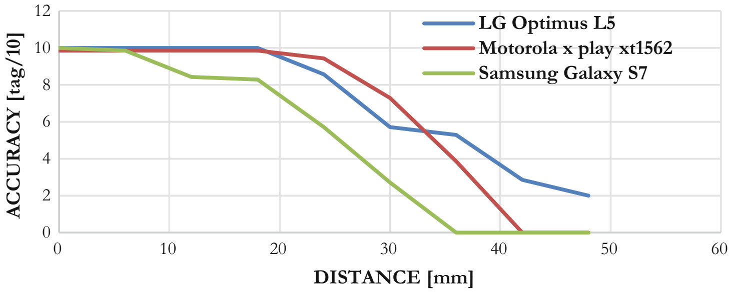

Fig. 12.6 Average accuracy (read tags/10)

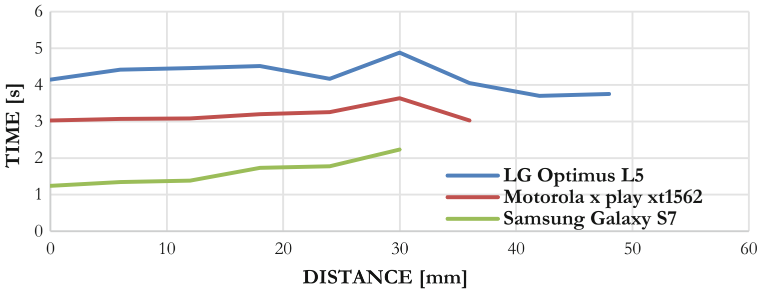

Fig. 12.7 Average read time (s)

As far as it concerns the mobile phones under test, measured KPIs include: Accuracy, number successful tag reads out of the overall number of read attempts for each family (10); Average read time required to read the tags of all the families. Figures 12.6 and 12.7 chart the achieved performances.

Procedure #2: replication of the tests described by Dahl et al.
The authors simulated typical use cases involving a single tag read by the end-user, in particular the tag under test is placed on a plastic card connected to a sliding rail,

Table 12.3 Tags tested in NFC scenario by Dahl et al.

Tag	Frequency	Standard	IC
1	HF	NFC type 1	Topaz 512
2	HF	NFC type 2	NXP NTAG203
3	HF	NFC type 3	FeliCa Lite-S
4	HF	NFC type 5	Mifare Desfire
5	HF	NFC classic	MF1S50

which is used to control and set the tag/reader distance. A mobile phone, equipped with a NFC reader and running an ad hoc developed application, is fixed to the rail by means of a clamp and kept in this position until the complete read of the tag's memory is done by the software. If no read is possible, after 10 s the read is stopped anyway. NFC Benchmarker application, developed by the authors of the paper, is used on the mobile phone to activate and control the NFC reader; tag memory (UID and user memory) is read and scanned, and the required time is measured for different sizes of memory blocks. After the test is done, the clamp with the tag is placed closer to the phone and the test is repeated as described above. Five different tags have been tested, as shown in Table 12.3.

It must be noticed that above listed Tag 2 has the same IC of Tag 2 tested in the present work (NFC type2, NTAG 203), thus it can be taken as a benchmark for performance comparison. Due to some technical issues arisen during the execution of the test, some restrictions had to be applied; in particular:

- a compatibility issue between the App and the mobile phone used (a Samsung Galaxy S2) and/or its Android release made impossible the exact replication of all the tests described by Dahl et al., more precisely only *Read/write throughput* test could be performed;
- tags listed in Table 12.2 could not be all tested, in fact Tag 3 and Tag 7 were not compatible with the App and/or NFC stack.

Measured KPIs include: Average speed and Std Dev for reading/writing tag's memory with packets size ranging from one byte up to maximum memory size. Tables 12.4 and 12.5 show the achieved performances.

12.4 Conclusions

The tests show that the performances of the dual frequency inlays are appropriate in the considered processes, and comparable to the performance of specific tags designed and optimized for only one standard.

In EPC scenario, the accuracy of all the tested tags is 100% when read by a mobile reader, showing a read rate which guarantees a good capability of detection for almost

Table 12.4 Average speed and Std Dev (BPS) for tag's memory reading operations, and comparison with Tag 2 tested by Dahl et al. (2*) with 64 bytes packets

Tag	Speed 0 mm	Std Dev 0 mm	Speed 5 mm	Std Dev 5 mm	Speed 10 mm	Std Dev 10 mm	Speed 20 mm	Std Dev 20 mm	Speed 30 mm	Std Dev 30 mm
1	60	198	59	192	71	230	63	204	65	213
2	911	470	974	480	970	496	946	549	–	–
4	1.160	350	1.127	331	1.064	376	1.151	311	–	–
5	1.252	325	1.112	339	1.076	397	–	–	–	–
6	1.114	342	1.120	343	1.132	328	1.185	335	–	–
2*	1.520	106	1.430	151	1.450	144	–	–	–	–

Table 12.5 Average speed and Std Dev (BPS) for tag's memory writing operations, and comparison with Tag 2 tested by Dahl et al. (2*) with 64 bytes packets

Tag	Speed 0 mm	Std Dev 0 mm	Speed 5 mm	Std Dev 5 mm	Speed 10 mm	Std Dev 10 mm	Speed 20 mm	Std Dev 20 mm	Speed 30 mm	Std Dev 30 mm
1	24	78	24	78	23	76	19	70	23	75
2	290	146	311	142	294	147	310	144	–	–
4	384	63	376	68	376	60	379	69	–	–
5	385	74	377	67	383	60	–	–	–	–
6	385	65	377	66	374	56	380	55	–	–
2*	303	22	287	34	301	21	–	–	–	–

all families. In fact, for Tag 2, 3, 4, 5, 6 every tag has been read at least 15 times in 30 s, so the shipping/receiving process appears reliable.

When a fixed reader is used and transmitting power is set higher than 27.5 dBm, 100% accuracy and good read rate are obtained for all the tags except for Tags 1 and 4. TTFR shows high oscillations, being in any case lower than 12 s; this result appears absolutely compatible with the manual logistic process considered which takes usually longer.

In NFC scenario, Tag 4 and 5 show worse performances than other specific NFC tags, while Tag 6 has better reading distance and faster reading time, being comparable to standard dedicated NFC tags.

The performances of NFC reading devices show that older phones have better accuracy compared to new models, but they are slower in reading tag's memory. The longer reading time can be explained considering that old phones have low performing CPUs (affecting time to scan and process data) but probably better radio interface (affecting reading distance). Their HF transmitter uses chips that are designed for HF readers commonly adopted in industry and not specifically optimized for smartphones, the latter having lower energy consumption and lower reading distance.

The use of a specific benchmark software enabled the measurements of reading and writing speed in different conditions for most of the tags under test; the obtained results are comparable with the results reported by other authors. Slight deviations can be explained considering the differences in smartphones used and tag's antenna design.

In conclusion, dual frequency tags, although quite innovative and still not available for mass production, have good performances comparable to standard RFID tags operating only in a specific band (HF or UHF). It must be considered that logistics processes are more critical in terms of performance requirements than NFC reads; in fact, a missed tag in a receiving process may lead to inventory inaccuracy while missing a NFC read can be quickly fixed repeating the read attempt by the end-user. As a consequence, Tags 5 and Tag 6 are the most suitable for companies operating in fashion and retail; Tag 6 has top performances in both EPC and NFC scenarios, Tag 5 works well in logistics and has acceptable performances in NFC applications.

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