DOI: 10.2195/LJ_Ref_Wehking_e_042006

RFID Transponders : Link between information and material flows. How reliable are identification procedures?

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Introduction

Along with the growing complexity of logistic chains the demand for transparency of informations has increased. The use of intelligent RFID-Technology offers the possibility to optimize and control all capacities in use, since it enables the identification and tracking of goods alongside the entire supply chain. Every single product can be located at any given time and a multitude of current and historical data can be transferred.

The interaction of the flow of material and the flow of information between the various process steps can be optimized by using RFID-Technology since it guarantees that all required data is available at the right time and at the right place. The local accessibility and convertibility of data allows a flexible, decentralised control of logistic systems. As additional advantages of RFID-Components can be considered that they are individually writable and that their identification can be achieved over considerable distances even if there is no intervisibility between tag and reader. The use of RFID-Transponder opens up new potentials regarding process security, reduction of logistic costs or availability of products.

These advantages depend on reliability of the identification processes. The undisputed potentials that are made accessible by the use of RFID-Elements can only be beneficial when the informations that are decentralised and attached to goods and loading equipment can be reliably retrieved at the required points. The communication between tag and reader can be influenced by different materials such as metal, that can disturbed or complicate the radio contact. The communications reliability is subject of various tests and experiments that analyse the effects of different filling materials as well as different alignments of tags on the loading equipment.

1. RFID technology - basics

RFID stands for **r**adio **f**requency **id**entification. The term describes the way in which a transponder and the corresponding read/write unit communicate with each other.

The use of RFID technology for identification purposes is superior to the currently used bar-code method due to the following aspects [Overmeyer05]:

- Additional information such as expiration date, origin, etc. can be set directly on the transponder
- Depending on the design of the system transponders can be programmed within the logistics system
- Unambiguous identification of items by means of a unique transponder ID number
- No visual connection is required between the transponder and reader
- Identification without additional handling of the item
- Transponders can be placed in a position where they are protected against mechanical (damage, loss,...) as well as chemical (acids, dirt, …) influences
- Enables recognition of several transponders during a single read operation (bulk recognition)

Transponder is an artificial word made up of “transmitter” and “responder”. Sometimes “tag” is used as a synonym. RFID systems always consist of two components: a read/write device with its associated evaluation unit [Finkenzeller02] [Bapat04] for data management and one or more transponders.

A key factor of an RFID system is its operating frequency. This property has a substantial impact on its range and behaviour in different media. Generally speaking, a frequency increase lowers the required operating power and boosts the theoretical range as well as the data transmission rate. Along with this, however, the reflection and absorption characteristics of the field upon its impact on materials like metal or water are also altered.

From a legal point of view RFID systems are radio devices which are subject to the relevant legal provisions. Considering other existing radio operators and users, this leaves only very few frequency bands available, of which the following bands are mainly used for RFID purposes:

- Low frequency (LF): 135 KHz
- High frequency (HF): 13.56 MHz
- Ultra high frequency (UHF): 868 MHz (Europe), 915 MHz (USA)

- Microwave (MW): 2.45 GHz

Transponders can also be categorised according to type of power supply:
- Passive transponders receive their operating energy by tapping the antenna field. They do not have an energy source of their own.
- Active transponders are powered by an active source of energy (battery), i. e. they do not require energy from the antenna field to transmit their data. They are more expensive than passive transponders, but have much greater transmitter power.
- Semiactive transponders also have an active source of energy. This source, however, is used to operate an additional function implemented with different measuring sensors (e. g. for temperature control). The transponder itself receives its energy from the antenna field, just like passive transponders.

2. Standardisation

In order for RFID to function smoothly across enterprises along the entire supply chain [tenHompel04] [Friess00] with various partners, it is essential that both hardware and software/data structures are standardised. It will still be some time before this standardisation process [Roos02], which is necessary for the global use of RFID, is completed.

Several independent organisations are working towards standardisation. The interests of trade organisations, producers of consumer goods, technology suppliers, and consulting firms are represented by EPC Global, which consists of GS-1 Germany (formerly "Centrale für Coorganisation" - CCG) [GS1o.J] and the Uniform Code Council (UCC). On the part of the automobile industry, the VDA (German Association of the Automotive Industry) channels the efforts toward standardisation and unification.

The various efforts towards standardisation and regulatory documents [Jansen05] can be categorised according to their respective focus as follows:

Technology standards:

Technology standards describe and define the basic technical properties of RFID systems, e. g. the frequency bands to be used and the design of contact-free chip cards. Several other standards, such as ISO 18000, which deals with the aerial antenna-transponder interface, are also worth mentioning.

Application standards:

Application standards recommend technical solutions tailored to specific applications. To date, there are rather few application standards, except for the fields of animal identification at low frequencies (ISO 11784, 11785, and 14223) and container identification with active UHF and MW systems (ISO 10374 and 23389). Work is currently underway on standards ISO 17363 and 17367 which deal with all the consolidation hierarchies in any one logistic system.

Data standards:

Data standards standardise data formats and data organisation to ensure that the required data can be smoothly exchanged within the supply chain. Examples include the identification number defined in ISO 15963 or the data protocol of read/write units described in ISO 15962.

Licensing regulations:

As mentioned before, RFID systems are considered radio devices and are therefore subject to the corresponding regulations. For LF and HF applications, EN 300330 must be complied with, for the MW range EN 300440 is applicable. UHF applications must observe EN 300220, which currently still limits transmitter power to 0.5 watts, compared with 4 watts in the US. Due to EN 302208, recently adopted by the European Telecommunications Standards Institute (ETSI), the power of 868 MHz RFID readers in Europe can be raised to 2 watts.

3. The challenge: reliability of the read/write access

A transponder is a major component in ensuring the flow of information in logistics systems. However, the efficiency of RFID depends greatly on the reliability and availability of the identification processes. The potential which RFID systems offer can only be fully exploited if the information which is directly assigned to the items or load units in a distributed manner can be reliably accessed at the necessary positions.

If information transfer is unrealiable at the interfaces between logistic processes, e. g. when commissioning several single items for a shipment, the flow of information is interrupted. In this case, the RFID potential cannot be exploited, and back up solutions (e. g. conventional delivery notes, double-checking with database) have to be used instead.

Communication reliability between transponder and read/write unit depends on several factors which have to be taken into account when implementing RFID:

DOI: 10.2195/LJ_Ref_Wehking_e_042006

- System frequency
- Amount of data
- Type and number of transponders in the reader field
- Alignment and relative position of the transponders
- Alignment and position in the antenna field
- Type, amount, and distribution of critical materials, such as metal or water, at the labelled object

4. Test installation for bulk detection with KLTs

IFT is currently carrying out experiments on the bulk detection of passive 13.56 MHz transponders. The aim of these tests carried out in a nearly realistic environment of industrial applications is to determine the degree of recognition reliability of transponders and the load units on which they are attached. The influence of transponder position and different types of load on the recognition rate are also taken into account.

The tests are carried out along a conveyor including roller and chain conveyors with a load capacity of 250 kg (see Fig. 1). The palette moves back and forth along the roller conveyor at a speed of appr. 0.5 m/s. The RFID device, a two-sided gate antenna made by Texas Instruments for the 13.56 MHz range, is installed in the centre of the conveyor.

Fig. 1: Test installation at IFT

4.1. Test setup

The tests are carried out with two types of test setup which a varying transponder alignment, setup A and setup B. Both setups use a euro palette as their basic load carrier, with 12 C-KLT 6428 containers (L*W*H: 600*400*280 mm) piled up on them in three layers. KLTs (small load carriers) have become the standard container in the automobile industry with more than 35 million units overall. Each KLT contains four passive transponders (48 per palette), so called “smart labels”, i. e. one on each side. The only difference is the way the transponders are positioned on the sides.

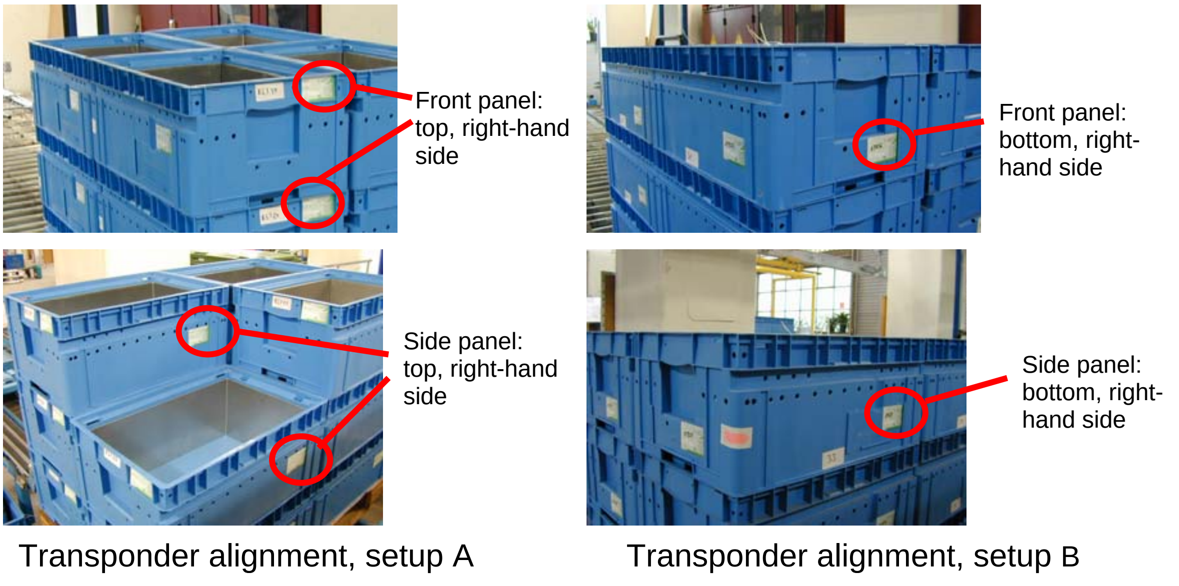


Fig. 2: Transponder position in setup A and B in comparison

Fig. 2 shows both setups. In setup A, the front-panel transponders are placed in the upper right-hand corner, and the side-panel transponders are placed below the vent openings. In setup B, the transponders are placed in a lower position (see

Fig. **3**)

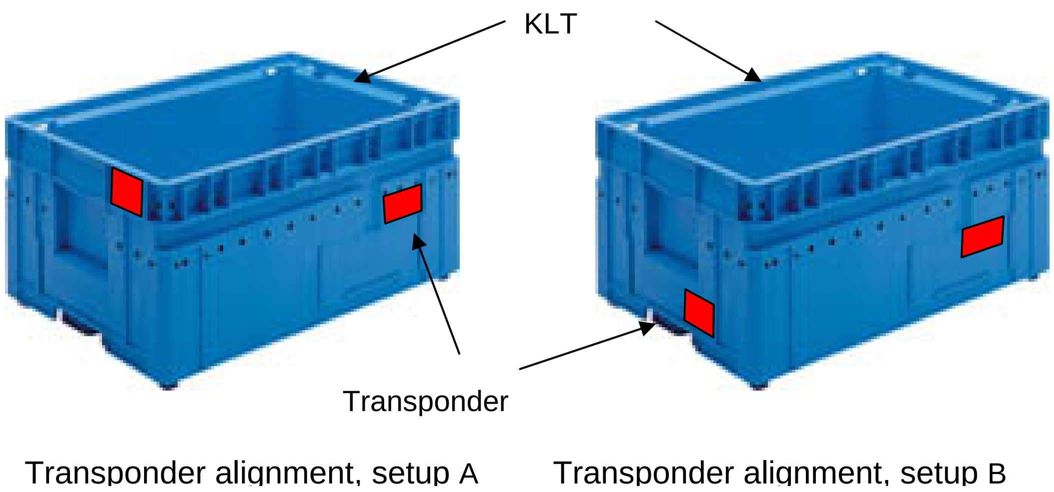


Fig. 3: transponder alignment setup A versus B

When stacking the KLTs, the total height of the containers cannot be used completely because the KLTs are slightly moved into each other (a lowered bottom, which sits on the inner border of the container underneath). This creates openings between the stack layers which are not directly covered by the test load. The potential influence of these unavoidable openings on the readability of transponders is tested by placing the front-panel transponders in setup A as close to the top as possible, so that they are located within the open area. In setup B, the transponders are completely covered by the load.

4.2. Starting the test installation

The gate antenna used in the test consists of a basic and a supplementary antenna mounted on each side of the roller conveyor section used for the test (see Fig. 1). Each part is attached in a vertical position at an equal distance from and parallel to the conveyor. In order to avoid metal objects around the antenna, it was mounted onto a wooden frame.

After installing and aligning the antenna, the basic antenna must be adapted to environmental influences. To do this, all manual settings are reset to their standard values, and the automatic adaptation mode is activated. The same procedure is applied to the supplementary antenna.

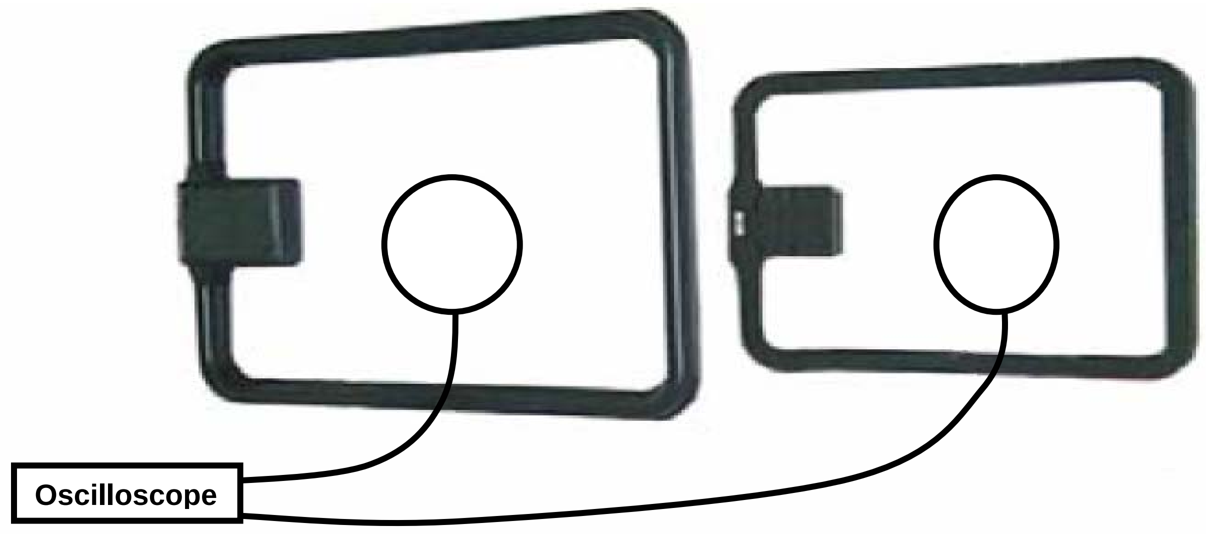


Fig. 4: Basic and supplementary antenna with principal measurement scheme for signal adaptation

The signals of the antennae are now brought in line by placing two measuring antennae into the antenna rings (see Fig. 4). An oscilloscope is used to visualise the measuring signals.

Fig. **5** shows an example of the signal flow of the basic and the supplementary antenna, respectively. For the installation to run smoothly, the amplitude difference must be limited to a maximum of 30%. The phase shift, i. e. the difference of the signals in time, should amount to 90° +/- 10° (according to the manufacturer). Figure 5 shows the comparison of the installation's antennas. The amplitude difference is minimal and the phase angle lies at 90°. Preliminary Tests have shown that it is important to comply with these values as accurately as possible.

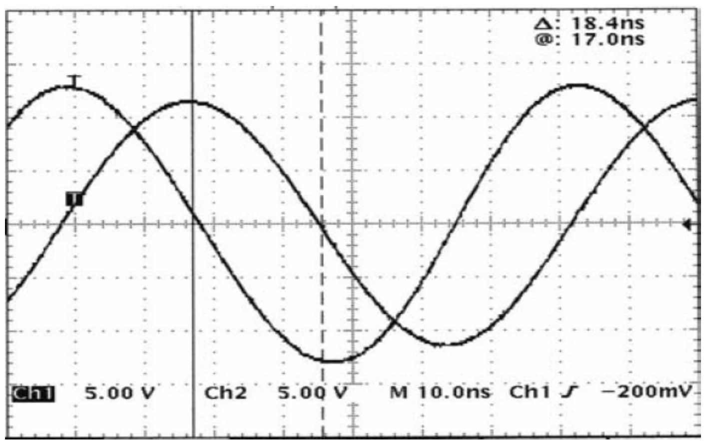


Fig. 5: Measured signal of the antenna installation

4.3. Preliminary tests

The test setup described above was the result of preliminary tests. First of all, the calculated capacity of the installation was checked and its software parameters optimised with respect to the maximum number of transponders that can be read.

The software parameters, for example time slot settings, can be optimised depending on the number of transponders to be recognised or the amount of data. This was achieved by setting up the test installation with all the transponders on one level (see

Fig. **6**).

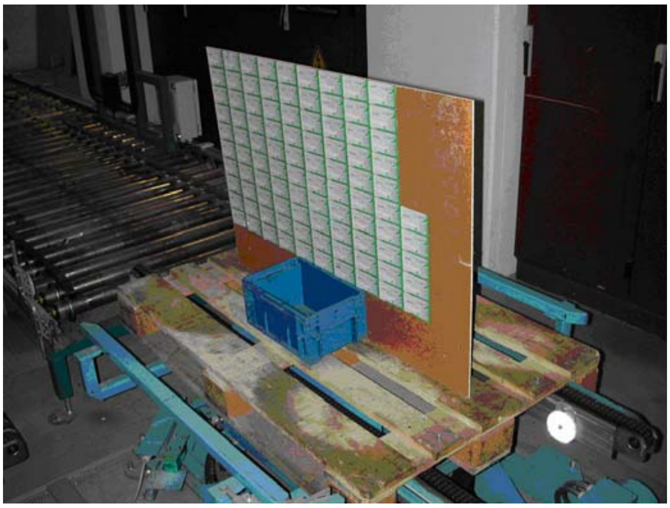


Fig. 6: Two-dimensional preliminary test setup with 95 transponders

In order to optimise the test installation, the following two parameters were subsequently altered (Additional description concerning the optimisation of the installation: see appendix):

- Number of time slots in anti-collision handling

A transponder collision is defined as the situation when more than one transponder at a time reacts to a request by the reader. In the case of a collision the attempts for contact may be triggered, i. e. contact is established in several subsequent time slots until there is no more collision. The number of these time slots can be increased.

- Number of re-read attempts during a read cycle

This parameter defines how often an attempt for contact is repeated when the signal contact is interrupted. If the connection between reader and transponder breaks off during communication, the number of attempts to re-establish contact can be modified.

The optimisation of the parameters showed that modified time slot settings resulted in an improved transponder recognition rate. Increasing the number of read repetitions, on the other hand, did not bring about any significant changes. By optimising the software parameters a recognition rate of 99.53% was achieved when using the two-dimensional installation with 95 transponders (see

Fig. **6**).

After completion of the preliminary test with transponders positioned in two dimensions, tests were initiated using the planned KLT installation with 96 transponders, as shown in

Fig. **7**. For these tests, twelve KLTs were stacked in three layers. Eight transponders, i. e. two on each side, were attached to each KLT. As many transponder as possible were used as to operate the installation at its before calculated capacity. Despite another check of the software parameter for this installation, however, only 86.98% of the read cycles returned the complete recognition of all the 96 transponders. During the other read cycles at least one transponder was not recognised. This raises the question why the recognition rates of the KLT installation were significantly lower than that of the two-dimensional test setup. (Additional description: see appendix)

DOI: 10.2195/LJ_Ref_Wehking_e_042006

Fig. 7: KLT setup with 96 transponders (eight for each KLT)

Tests with modifications of the test setup, e. g. replacing layers of the stack with KLTs without transponders or interchanging layers from top to bottom and vice versa, showed that neither the KLTs themselves affected the recognition rate nor that the transponders were damaged.

Consequently, the deterioration of the transponder recognition rates when moving from a two-dimensional setting to a KLT test installation must be caused by the fact that this is a three-dimensional setting. All of the transponders of the test installation shown in

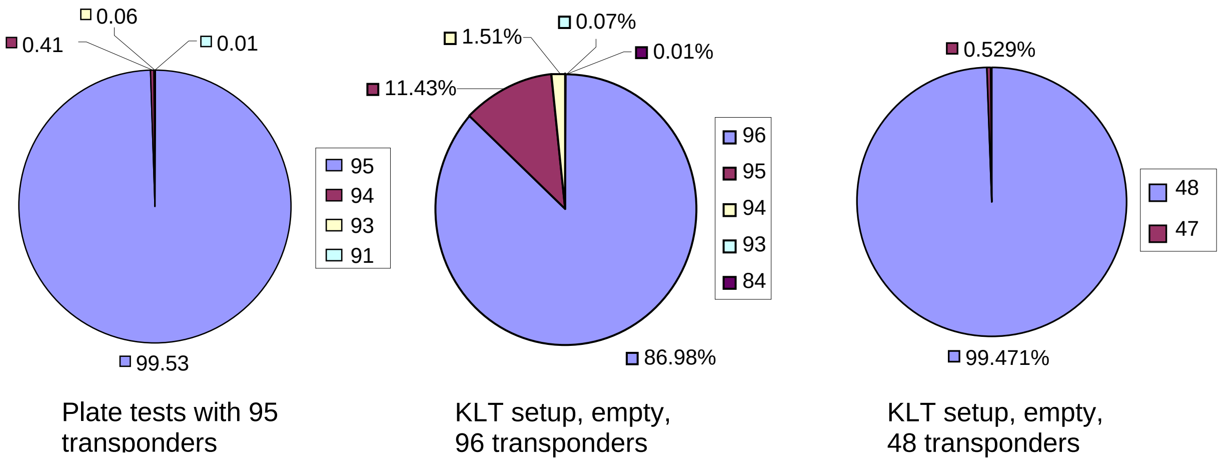
Fig. **6** are placed on one level at a constant distance from the antenna and have the same spatial alignment. The KLT installation, on the other hand, (see

Fig. **7**) has varying spatial alignments. The transponders are mounted on the front and side panels of the KLT. This distribution over all three dimensions results in different distances of the respective transponders from the antenna.

As a consequence, the number of transponders per KLT had to be reduced to a reasonable amount which could be safely handled. For reasons of installation symmetry and a realistic setup of the load units, the number of transponders was reduced from eight to four per KLT. Only one instead of two transponders is now attached to each side of the KLT, an overall of 48 per palette.

The following figure shows the respective recognition rate of the two-dimensional setup, the KLT setup with 96 transponders and the eventually used KLT test setup with 48 transponders. The diagrams show the distribution of the number of transponders recognised in each read operation in percent. It can be seen that during the plate tests with a two-dimensional transponder alignment 99.53% of the read operations recognised all the 95 transponders, and the remaining 0.47% recognised between 94 and 91 transponders. When using a KLT setup with 96 transponders, the number of read operations in which all of the transponders are recognised slumps to 86.98%, a mere 11.43 % of the remaining read operations return a result of 95 transponders.

The actually used KLT setup with 48 transponders leads to an increased 99.47% of all read operations with a complete transponder recognition, along with a minimum number of 47 recognised transponders.



Explanation, e. g. left diagram: For 99.53% of read cycles all 95 transponders were recognised.

Fig. 8: Recognition rate achievable in the respective test setups with parameter optimisation

4.4. Objectives of the test series

The setups identified in the preliminary stage allow statements on the recognition rate of the various transponders depending on their position in the test installation.
The tests are aimed at the following:

- Determining the influence of different types of loads on transponder recognition
- Determining the recognition rates on the basis of KLTs with different loads. This includes examining how a 100% readability of a KLT (representing a load unit) can be achieved.
- Determining the optimised transponder position on the KLTs
- Deriving general rules which have to be complied with when implementing RFID technology

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4.5. Carrying out the test series

During each of the test cycles the unique ID of each transponder is read. It is assigned to the respective transponder only once and saved irreversibly on the transponder. The position of each transponder is documented, thus enabling the recognition rate to be correlated to each transponder position.
The influence of the following loads on transponder identification is investigated in subsequent cycles:

- sheet steel
- sheet aluminium
- PET-Water Bottles
- pressboard
- medium-density fibreboard
- solid wood
- plywood
- others

The results for the metal material have already been established and are presented in the following section.

4.6. Test results

Empty KLTs:
Tests with empty KLTs show very good transponder recognition rates for both setups. For setup A, 46 out of 48 transponders are recognised in every cycle, and only two of the transponders are omitted in one read operation each – in a total of 9026 test cycles. Setup B brought about similar results: Only three transponders were not recognised during the test (3977 cycles overall).
Use of metal loading:
The use of these materials with RFID presents a challenge because they tend to block the signals. The tests conducted at IFT confirmed this assumption in part. On the other hand, however, they showed that containers with metal loads are readable if certain additional conditions met. First and foremost, this includes the position and alignment of the transponders on the container.
When using sheet steel and aluminium, the recognition rate shows a strong variation depending on the position of the respective transponders in the various setups.

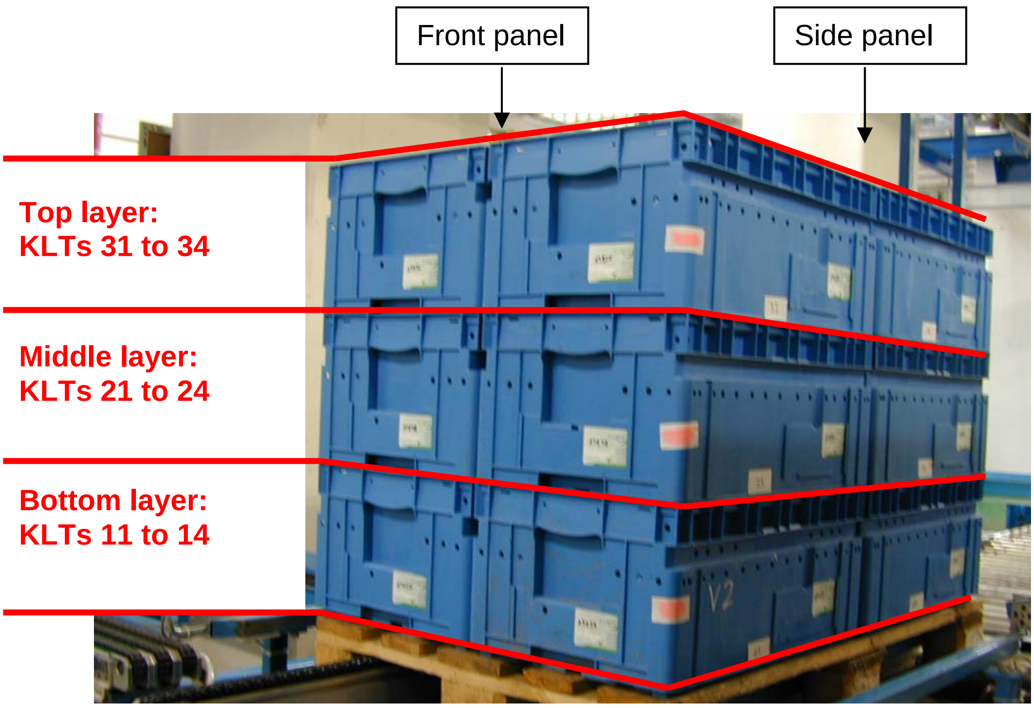

Fig. 9: Stacked KLT layers on palette and numbering of containers

However, significant differences can be identified depending of the position of the transponders in the various layers of the stack. Fig. 10 gives an example of the distribution of the recognition rates for the respective stack layers in setup A and B, respectively (corresponding to

Fig. 3), when loaded with sheet steel. Setup A is shown on the left-hand side, setup B on the right-hand side. The various layers of the stack (bottom, middle, and top layer) of each setup with the respective KLTs are illustrated in a bird view diagram. Each of the coloured marks represents a transponder at its respective position in the setup.

Fig. 10: Recognition rates of the respective transponders

It is evident that there are no systematic deviations of the recognition rates along the vertical alignment, i. e. from the bottom to the top layer. On the other hand, the transponders mounted on the inner side panels of the KLTs are not recognised in either test setup, as was to be expected.

A significant difference between the two setups, however, can be detected when the transponders are placed on the inner front panels of the KLTs. Setup A provides relatively effective transponder recognition on the inner front panels; setup B does not.

As shown in Fig. 10, the recognition process is relatively reliable when the transponders are mounted on the outer side panels of the test installations. When the transponders are completely hidden behind or between the metal load, recognition is virtually impossible. The fact that in setup A the inner transponders are recognised despite the metal load, is due to their position. As described above, the front-side transponders are mounted near the upper edge of the KLTs and are therefore not covered completely. This is why these transponders can be recognised despite the metal load.

Thus, if containers with metal loads are to be recognised with RFID, the reliability of the process can be substantially increased if the transponders are not mounted inside the containers, i. e. not behind metal surfaces. If this type of positioning is not viable for technical reasons, there are two possible workarounds:

1. Labelling with two transponders mounted diagonally on opposite sides of the container. This ensures that there is always at least one transponder located at the exterior and oriented towards the antenna. The drawback of this solution, however, is that the unique transponder ID cannot be used for recognition since there are always two "twin transponders" mounted on a container which need to be associated to each other during the recognition process.

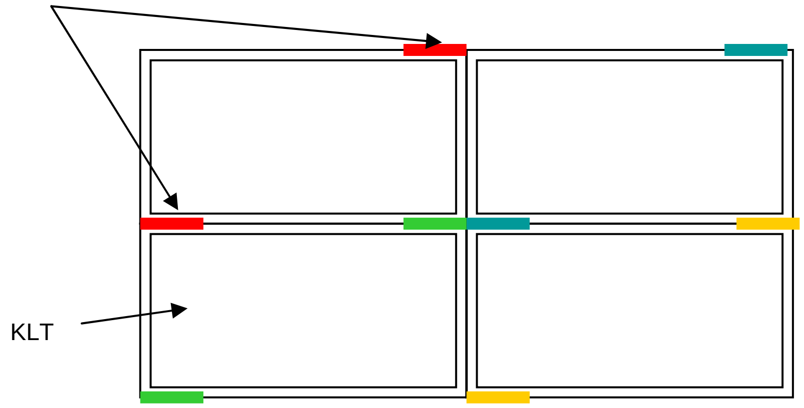

Fig. 11: KLTs with two transponders each (bird view)

2. If the containers cannot be filled to the upper edge (due to a cover, a clearance for upper container, etc.), the transponder should be placed in this area if possible. Here the transponders are not blocked directly by the metal and can generally be recognised. In this case, however, each setup would have to be checked to ensure that the field created in the "opening" is sufficient for recognition.

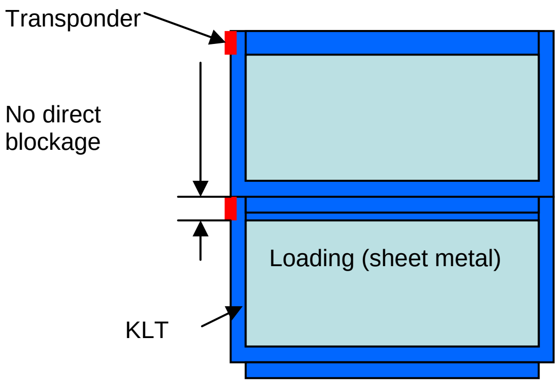

Fig. 12: Mounting the transponders outside of the usable loading level

5. Need for research

In recent years, theoretical findings on radiation properties, read fields, and the impact of different media on the RFID technology have been analysed under lab conditions, usually with clearly defined environmental parameters.

Currently, research and development projects are focusing on the use of RFID along the supply chain and its optimisation.

The technical interface between transponder and read/write station, however, has been given very little attention so far. According to IFT, no systematic research on how and under what conditions transponders can reliably be read in an industrial environment – individually as well as in bulk – has been carried out to date. Many RFID scenarios are based on the assumed functionality and reliability of RFID systems, despite the lack of test data on the technical reliability of operational systems.

Initial research at IFT showed that the theoretical and calculated functionality and reliability of the recognition process can substantially deviate from the actual results achieved under realistic conditions.

Therefore it is necessary to supplement any theoretical assumptions by adjusting the transponders, the load unit, the handling technology, and the read/write station. This adjustment and checking process must be carried out on an individual basis since for example even a modified mounting position on an otherwise identical load unit could result in a significant change of the recognition rate.

It is extremely important to continue research on the interface between the transponder and the read/write station under practical working conditions with components used in material handling and storage because the viability of the use of RFID depends largely – besides the need for standardisation – on the reliability of the recognition process.

Issues like the best labelling methods for load units and the appropriate environmental conditions for the use of RFID need to be addressed. The aim of these investigations should be to generate recommendations on the technical conditions required for an optimised recognition process. Consequently, the tests carried out at IFT on these issues will continue. In addition, tests are planned with 868 MHz transponders under otherwise identical conditions. Their outcome will then be compared with the results of the 13.56 MHz technology.

6. Literature

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7. Appendix

Preliminary tests without loads were conducted to determine a suitable test setup and to optimise the installation parameters. These tests showed that the recognition reliability of transponders depends on the following two factors:

7.1. Position and spatial alignment of the transponders

A two-dimensional setup on one level (see preliminary tests) results in a significantly higher number of reliably recognised transponders than in a three-dimensional setup with (empty) KLTs, if the parameter settings are identical. The following figure shows examples of the recognition rates in a plate setup versus a KLT setup with 96 transponders and identical parameter settings. In the two-dimensional setup 98.92% of the read cycles recognise all of the 100 transponders, whereas in the KLT setup only 62.95% of the read cycles recognise all 96 transponders.

DOI: 10.2195/LJ_Ref_Wehking_e_042006

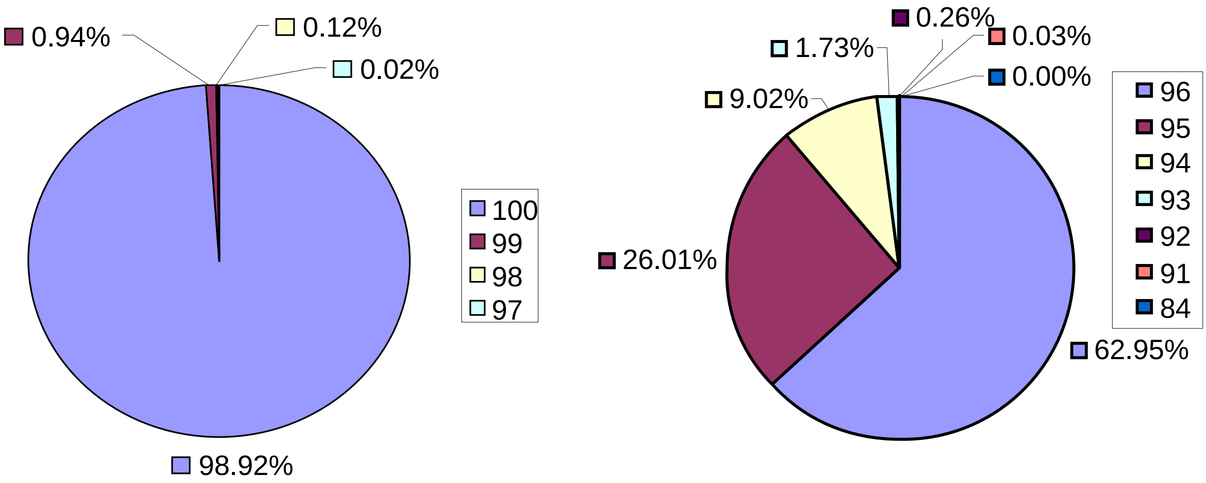
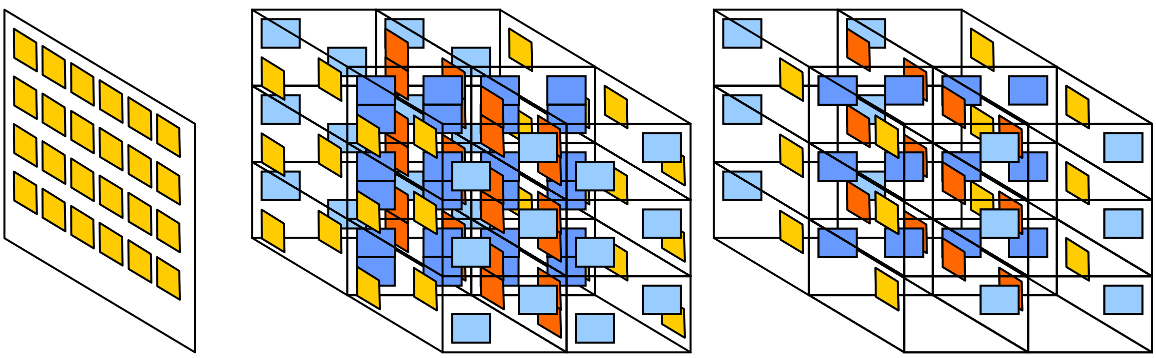


Fig. 13: Recognition rate in a two-dimensional plate setup (100 transponders, left) versus a three-dimensional KLT setup (96 transponders, right) with identical parameter settings (example)

Obviously, the possible number of recognised transponders largely depends upon their spatial alignment. In an almost "ideal" spatial alignment, such as for the plate tests (Fig. 14), the achievable value is higher than in three-dimensional setups with different types of spatial alignment.



Two-dimensional setup on one level, 95 transponders

Three-dimensional spatial setup with different transponder alginment, 96 transponders

Three-dimensional spatial setup with different transponder alginment, 48 transponders

Fig. 14: Spatial transponder alignment for the plate tests and the KLT setups with 96 and 48 transponders

Since the transponders are mounted on the test plate, they all have almost the same alignment and position relative to the antenna field when moved through this field. As a consequence, virtually identical reading conditions apply to all of the transponders, resulting in the recognition of all transponders at an almost identical quality.

In the KLT setups, on the other hand, the transponders are located on several levels. Moreover, they have a different alignment with respect to the antenna field, i. e. the entry angle and the distance from the antenna field are different. This is the reason why the transponders are read with different reliability when entering and crossing the antenna field in different zones.

Fig. **15** schematically illustrates the ideal alignment of a transponder with a coil antenna relative to the antenna field, i. e. to its field lines. Also, the field lines are aligned in parallel over the entire area of the gate antenna, creating zones with good or bad readability depending on the alignment of the transponders.

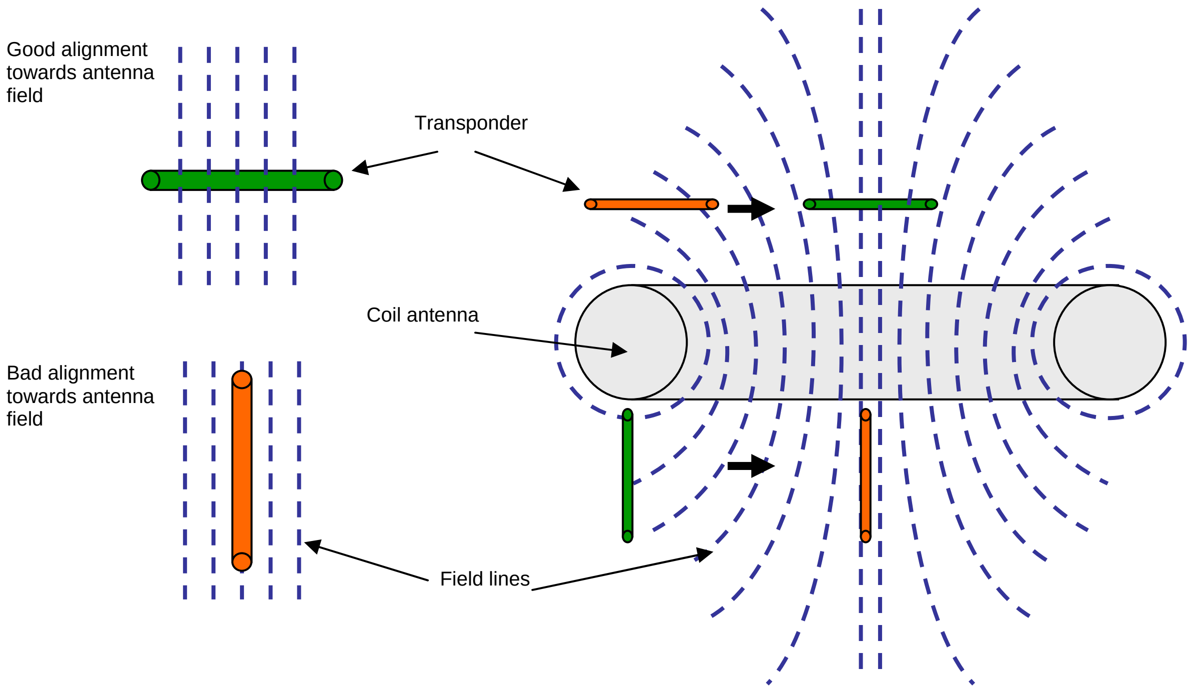


Fig. 15: Transponder alignment with respect to the field lines and within the antenna field

7.2. Optimisation of the installation parameters

A perfect adjustment of the installation configuration with respect to the container has a major impact on the readability of the transponder. The following two diagrams show the recognition rates of the KLT test setup with 96 transponders at different time slot settings:

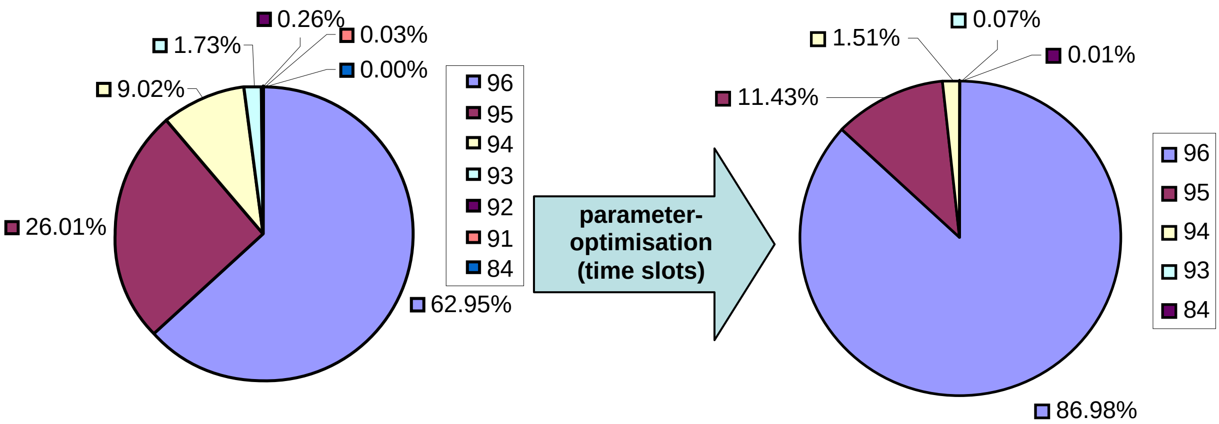


Fig. 16: Increase of recognition rate due to parameter optimisation in preliminary test setup with KLTs and 96 transponders (example)

In order for an installation to function smoothly, it is important to optimise its number of transponders per read operation by means of preliminary tests.