Preliminary Measurements with an Intelligent Shopping Cart

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Abstract.

In this article, we would like to summarize the problems, that may arise in a so called "Intelligent Shopping Cart", a special shopping cart, which is able to recognize the wares equipped by RFID tags. The shopping cart is able to register the wares- collected in the cart - with EPC standard GEN2 UHF RFID passive tags. Using a wireless communication technology, the central database is accessible, we can retrieve product information and send information about the wares currently in the cart. There are several ways to ensure this functionality, and several problems may arise.

Introduction

There are several approaches to speed up the shopping process, meanwhile reduce the human resources needed to serve customers. These are so-called "smart shopping". There are benefits for both parties, these are:

- Immediate identifying of the ware
- Immediate price, feature information of the wares
- Shopping list about the wares in the cart containing price pro piece, subtotal, and total information
- Leaving the shop at the gate the system can send information to the central computer about the total price. This computer can be equipped by a bank card reader, which can be used for paying.
- The whole shopping process can flow without human service from the shop

The structure of this document

The first part of this document starts with the four possible operating modes of the intelligent shopping cart and the typical cart sizes. Chapter 2 deals with degradation caused by special goods and the metallic environment. After we present several preliminary radio measurements done with the a metal shopping cart and also functional test with RFID devices. Our article ends with the summary of the Intelligent Shopping Cart.

1 The Operating Modes and Dimensions of the Intelligent Shopping Cart

The aim of the intelligent shopping cart project is to develop a special shopping cart, which is able to recognize the wares equipped by RFID tags. The shopping cart is able

- to register the wares- collected in the cart - with EPC standard GEN2 UHF RFID passive tags
- to recognize several number of wares simultaneously
- to differentiate the wares inside the shopping cart, and the wares outside the shopping cart

The complete system may contain an RFID gate to read and check the wares with RFID tags to create the final invoice. This gate optionally may disable the RFID tags as the final process of the shopping.

1.1 Sharp beam at the gate of the shopping cart

This operating mode works with a sharply beam formed radio field, which creates a thin layer at the top of the shopping cart. All wares, which put into the cart, travel trough this thin radio field. While the ware is traveling, the RFID recognition process can be done, and the wares in the cart can be registered. The detection of the direction of the traveling is not important, because counting the number of traveling through is enough to know, whether the ware is inside or outside of the cart.

1.2 Time division scanning the cart content by several antennas

In this solution several - probably 8 - antennas are used to scan the internal field of the cart with wares equipped with RFID tags. This scanning process is done in time division mode, but the whole scanning process can be finished in a second.

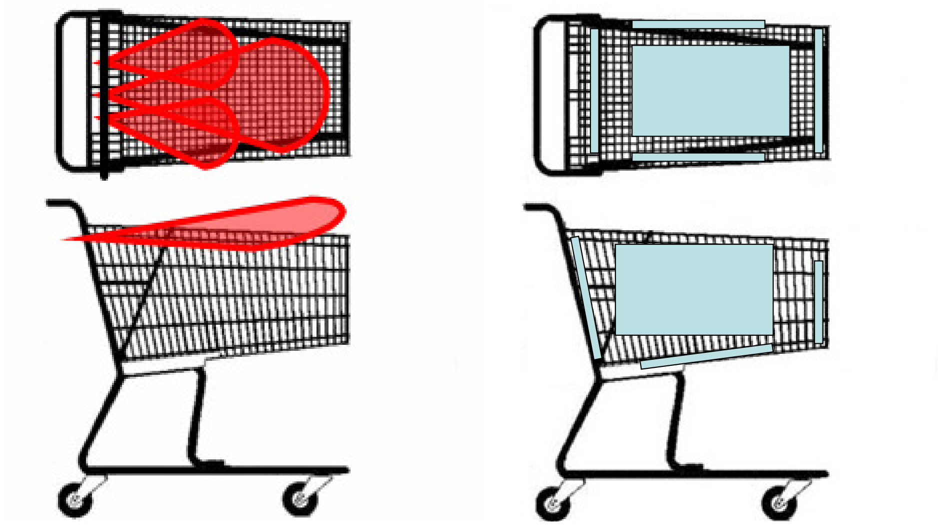

Fig. 1. a) Sharp beam at the gate of the shopping cart, b) Scanning the cart content by several antennas

1.3 RFID read by hand

This is the simplest mode of ware identification, when a low power RFID reader is used to read the RFID tag on the ware, which is put very close to the reader machine by the user similarly to the existing, barcode based solutions. This operation mode can also be used as a price check process before the real shopping. In this shopping phase the customer can get further information about the ware, using the connection with the central database, where additional data can be stored about the ware. Therefore the web site of the ware manufacturer can be reached and displayed on the embedded cart machine automatically. Applying this service the customer can be convinced easily to buy.

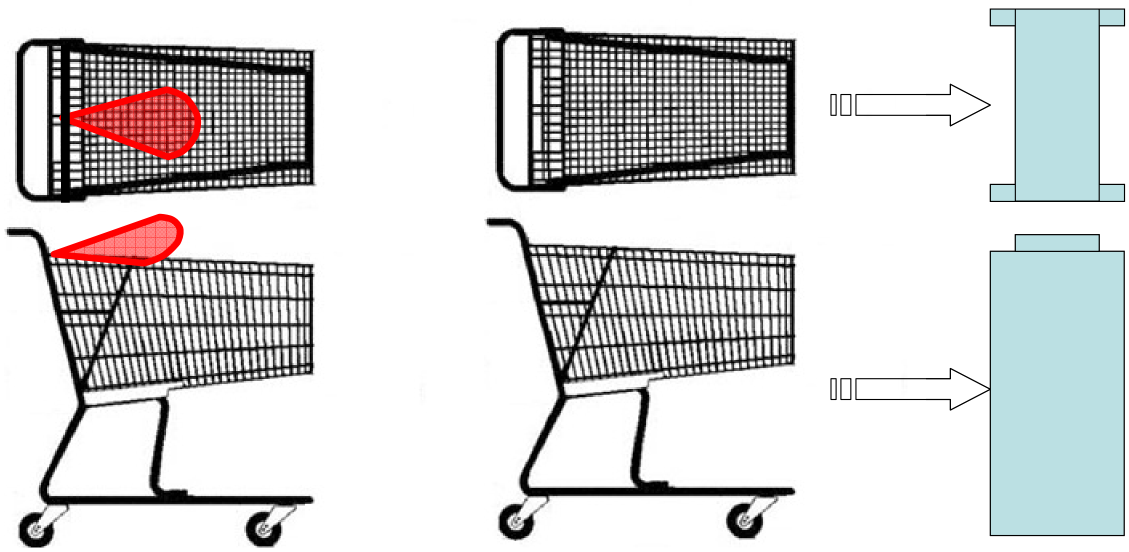

Fig. 2. a) Small beam on the shopping cart, b) Cart passing through a reader gate

1.4 Passing through an RFID reader gate

In this operating mode the shopping cart with RFID equipped wares is passed through via a gate with high power RFID gate. If a conveyor belt can be used, the proper time inside the RFID reader field can be set. Further benefit of this solution is the possibility of shielding, which enables more powerful RF field for the problematical wares. When this operating mode is active, the other modes of operation are disabled by the local embedded cart computer.

The above mentioned operating modes can be used separately, but can be combined together. The customer can check the ware price using the operation mode mentioned in the mode 3. After the price checking customer puts the ware into the shopping cart, while the ware passes through the thin radio wave field of RFID reader to register, that the ware is inside the cart. Then the time division scanning can be used to check the internal content of the cart. At the end of shopping process, the gate operating mode can be used to check the cart content, and the final invoice can be done.

1.5 Suggested operation mode

The main operation mode of the shopping cart is the thin beam of the gate of the shopping cart. This operating mode works with a sharply beam formed radio field, which creates a thin layer at the top of the shopping cart. All wares, which put into the cart, travel trough this thin radio field. While the ware is traveling, the RFID recognition process can be done, and the wares in the cart can be registered. The detection of the direction of the traveling is not important, because counting the number of traveling through is enough to know, whether the ware is inside or outside of the cart. The blind area of the gate is covered mechanically to keep from putting the wares behind the radio waves. Radio frequency absorbers are used to prevent the reflections distorting the wave field.

1.6 Shopping carts

Typically to major types of carts are in use:
- Metal Carts
- Plastic Carts

1.6.1 Metal carts

Metal nesting carts usually covered with a long life Nickel Chrome finish and acrylic coating. These carts are more resistance to weather conditions. Another version of these carts have a Tech-Seal gray finish for added rust and corrosion resistance. These types of shopping carts are used worldwide.

1.6.2 Plastic carts

Plastic nesting carts with chrome finish metal frame and gate. High density polyethylene basket is tough, will not rust, compliments a store decor and is lighter than an all metal basket, but has the same price.

1.6.3 Our cart

The typical measures of these carts vary in a range. There are nine values witch describes the cart (Figure 3.).
The width of the cart can be measured in three different places: front, top and bottom (wheels). The height has four different value: basket front, basket rear, front total, and rear total. The length of the basket and the cart of course also important. These values are summarized in Table 1.

	W1	W2	W3	L1	L2	H1	H2	H3	*H4*
Min	19[1]	19	15	30	28	37	33	13	*17*
Typical	23	22 1/2	18	39 1/2	37	40 3/4	36	15	*19 1/2*
Max	*25*	*24*	*20*	*44*	*42*	*41*	*37*	*16*	*21*

Table 1. Interntional RFID Frequency Regulations [3]

From these values the typical cart have the following dimensions:
- Top Basket Capacity: approx 11,000 Cu. In.[2]
- Approx. 23" W; 41" H; 40" L
- Weight: 60 lbs[3]

[1] Values are in inch. 1 inch = 0.0254 meters
[2] 1 Cu. In. (cubic inch) = 0.016387064 dm^3
[3] 1 lbs (pounds) = 0.45359237 kilograms (kg)

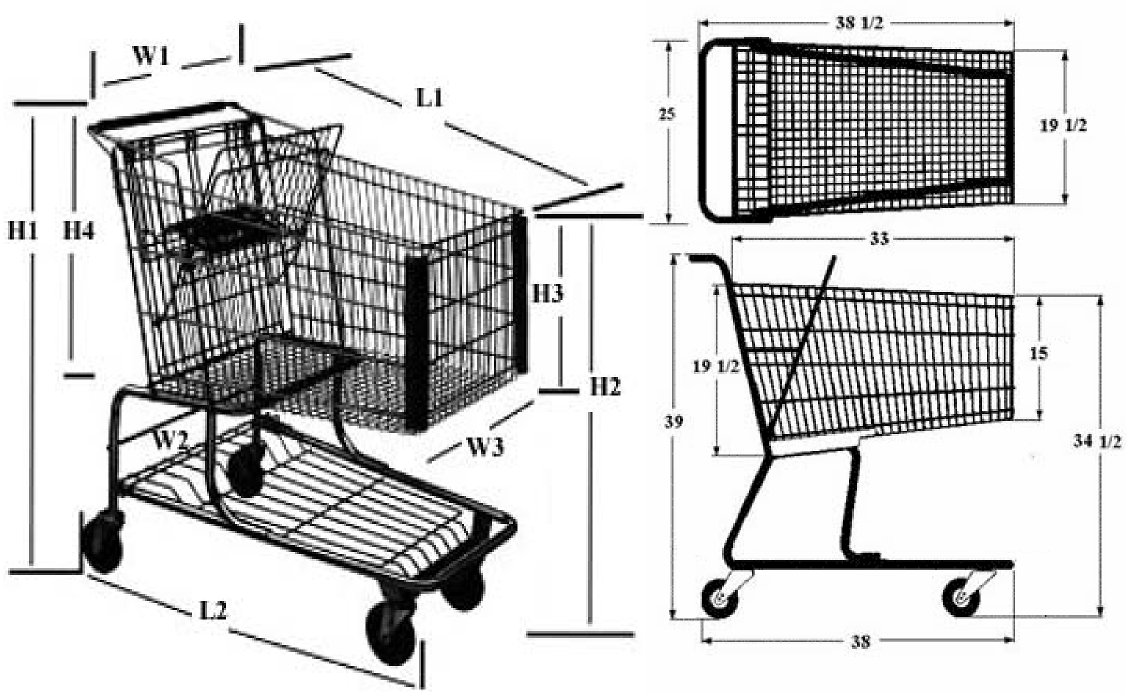

Fig. 3. Cart dimensions: a) main dimensions b) a typical cart [5]

2 Performance degradations

2.1 The effects of near metallic and liquid materials

The main factors that may affect the performance of a RFID system are the tags (transponders), readers (interrogators), and the environment in which they are operating. The channel influences in the communication between the tags and reader there are such effects as channel attenuation, multi-path propagation, and interference from other readers and RF devices.

In real world situations, the tags are attached to various materials that have different characteristics. The material of the physical object marked by a tag can also affect the characteristics of the antennas therefore the tag's performance. Many common materials to witch the tags are attached such as metal and water have considerable effects on the performance of the tags. Water and metal affects tag performance in many ways: They provide multi-path, create fading zone.

Changes in impedance bandwidth, detuning the resonance frequency of the antenna, and reduction in power transfer efficiency, are some of the factors that change the amount of power being delivered inside the tag from the antenna to the chip. The environmental effects at UHF frequencies can be classified into three categories: material effects observed with conductors, dielectrics, and in free air.

Most of the antennas that are used by the tags are resonant antennas. It is known that the presence of high dielectric materials – like water– in the near field of the tag, changes the resonant frequency of the antennas, so the antenna would resonate at a lower frequency. Spacing the tag a small distance away from the material can significantly reduce this effect (if the tagged object make it possible). If the tags are used always in the same environment, theirs antenna may be pretuned to the special environments, but in this case these tags can not be used in free space. Nevertheless recovery of the full free space reading range in the proximity of the material is unlikely to be achievable. This difference is due to power absorption by the material, because in situations where an electromagnetic wave meets a boundary between two dissimilar materials, some of the energy is reflected at the surface and some of the energy passes into the material. The proportion of the energy that passes into the material is a function of its physical properties (known as its dielectric constant).

Radio frequency waves can not pass through conductive surfaces like many metallic materials, because metals reflect RF energy, therefore the reading of tags behind such kind of materials is not possible. If conductive materials are in close proximity to the tag, they can also detune the tag so it cannot be read by the reader. Tags at certain distances in front of the metal plates – where the original backscattered signal coming from the tag and the signal coming from the tag (in opposite direction), but reflected by the metal are in reverse phase – can also not be read.

It is also considerable, that the presence of metal plates can be used to boost the performance of tags, namely at certain distances (where the two signal are in the same phase) behind the tag the presence of a parallel metal plate can significant increase the strength of the backscattered signal thus the reading distance between the tag and the reader. Nowadays there are many so called “metal tags” available at the market. These type of tags either have a layer of a dielectric material (such as polyurethane foam, ferrite, etc.) between the inlay and the surface that is applied on metal and this dielectric material gives the tag the air gap needed to modulate backscatter, or they have a so called microstrip or patch antenna instead of the dipole design.

In the first case the antenna of the tag is designed to use the metal to witch it is attached as a reflector actually improving the performance when placed on metal.

In the second case the microstrip antennas have an “inbuilt” metal plane as ground plane, so the presence of metal behind this type does not affect the performance of the tag, they can work fine in free space too, but only in one direction. All the performance metrics of the tags are frequency dependent. Also, the ISM band in UHF frequencies varies among countries (See more details in the classification chapter). Thus if the tag is designed to be used globally, it should operate well across the spectrum.

A material is called RF-lucent or RF-friendly for a certain frequency if it lets radio waves at this frequency pass through it without any substantial loss of energy. A material is called RF-opaque if it blocks, reflects, and scatters RF waves. A material can allow the radio waves to propagate through it but with substantial loss of energy. These types of materials are referred to as RF-absorbent. All these properties are frequency dependent. Table 2 shows the RF properties of some common materials.

Freq. / Material	LF	HF	UHF	Microwave
Clothing	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Dry wood	RF-lucent	RF-lucent	RF-lucent	RF-absorbent
Graphite	RF-lucent	RF-lucent	RF-opaque	RF-opaque
Drinks and Shampoos	RF-lucent	RF-lucent	RF-absorbent	RF-absorbent
Metals	RF-lucent	RF-lucent	RF-opaque	RF-opaque
Motor oil	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Paper products	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Plastics (some types)	RF-lucent	RF-lucent	RF-lucent	RF-lucent

Table 2. RF properties of Example Material types [3]

2.2 Effects of Lossy Dielectrics and Metals

At UHF and microwave frequencies, the wave attenuation (loss) is caused mainly by the water content (moisture content) of any dielectric substance, which commonly has in dry state a permittivity only between 2-6. The value of the complex dielectric constant of the free-water varies with frequency from its low frequency (static) value ε_s, to its very high frequency value ε_∞. For a material with a single relaxation mechanism, Debye expressed the frequency dependence of the complex dielectric constant as:

$$\varepsilon^* = \varepsilon_s + (\varepsilon_s - \varepsilon_\infty) / (1 + j\omega\tau)$$

where ω is the angular frequency of the electromagnetic field and τ is the relaxation time. The parameters: ε_s , ε_∞ , τ are varied with temperature T as given in Tables.

2.3 Other effects on performance

An associated effect, which can also reduce the reading range of a tag, is its proximity and orientation in respect to other adjacent tags (because tags can detune each others resonant frequency) and its orientation respect to the polarization of the reader antenna.

In the first case the effect is greatest where tags are parallel with each other since this produces the highest level of mistuning and absorption. A similar situation arises where a second tag is positioned a short distance behind the first one and in line with the transmission path from an interrogator. The tag nearest to the interrogator creates a "shadow", which reduces the field available to power the tag that is further away.

In the second case it is also important, whether the tag uses a single dipole, or a dual dipole or similar antenna, and whether the antenna of the reader is linearly or circularly polarized.

If the reader has a linearly polarized patch antenna, the orientation of the single dipole designed tag antenna must be parallel with with the read field, namely with the polarization of the reader's antenna, otherwise these tags can not be read.

The dual dipole RFID tag antenna design, or a circularly polarized reader antenna eliminates the problem of read-orientation sensitivity. In these cases the orientation relative to each other doesn't matter.

2.4 Shielding

A particular difficulty with systems operating at UHF is that the signal transmitted by an antenna may extend over a significant distance. Therefore it is possible, that tags, outside the wanted interrogation zone will be inadvertently activated and the responses from these unwanted tags may be read by the interrogator. It is important for installers to be aware of this problem and ensure that the size of the interrogation field is the minimum necessary and does not extend into areas that may contain unwanted tags. This requirement may create particular difficulties in situations where adjacent interrogation zones and storage areas are physically close to each other. There are two possible approaches, to shield the unwanted zones:

- reflection of the transmitted signal;
- absorption of the transmitted signal.

The reflective approach involves placing an electrically conductive surface in the path of the transmitted signal. The radio signal is unable to pass through the conductive surface but instead is reflected off it. But in this case some consideration must be given to the likely destination of the reflected signal, since the reflected signal may bounce off yet further surfaces and end up in other unwanted areas. It is also important to note that the reflections may create holes in the field (due to standing wave nulls), which may prevent the activation of wanted tags. Reflective materials have the advantage that they are low cost. A thin metal sheet works well although it is also possible to achieve a very acceptable performance using wire mesh materials.

In the second case materials with good properties of electromagnetic absorption may be used to prevent the reading of unwanted tags outside the interrogation zone. As the signal passes into the absorptive material its energy is largely dissipated. What energy remains either passes through the absorbing material or is reflected by it to emerge at much reduced levels. It is important that the material selected is of the correct thickness and suitable for the intended frequency band. Materials with phase shifting properties may also reduce field levels but they should be used with great care. Correctly applied, EM absorbent materials will help overcome the problem of reading unwanted tags outside the interrogation zone.

Absorption materials are significantly more expensive and less robust than reflective materials, and they need to be protected from the effects of the environment (in case of external use), which may reduce their efficiency. However in situations where the presence of reflected waves is not acceptable, absorption materials may provide the most satisfactory technical solution. [4]

3 Preliminary Measurements with the Shopping Cart

In the following chapter we present the preliminary results derived from several measurements done with a metal shopping cart and several RFID devices, analyzers, signal generator and some other tools:

- Alien Gen1 and Gen2 RFID tags
- Alien RFID reader with two antennas
- Intermec 751G Pocket PC
- IP4 RFID reader (EN 300 220)
- Metal cart (having a grid with ca. 3-5 cm spacing and 5 mm thickness on one side and on the bottom)
- Rohde&Schwarz SMIQ 03HD signal generator
- Rohde&Schwarz FSH handheld spectrum analyzer
- Rohde&Schwarz FSP spectrum analyzer
- Rohde&Schwarz TS-EMF antenna (80 MHz – 3 GHz)
- Agilent Infiniium 54832B oscilloscope
- HP Omnibook notebook + Rohde&Schwarz RFEX softwer
- Log-periodic antenna (700 MHz – 5 GHz)
- Dipole antenna (750 MHz – 1 GHz)
- Other accessories (cables, tripod, etc.)

The following measurements were done:

1. Investigation of the RF environment
2. Investigation of inner radiation coming out of the cart (e.g. tags on selves)

3. Time-domain analysis
4. Investigation of the influence of nearby metal surface (shielded cart)
5. Functional test of RFID devices
6. Readability of tags inside the cart

3.1 Investigation of RF environment

The evaluation of the distortion of the transmitted signal in the following three frequency ranges were done:

- 433-435 MHz
- 865,6-867.6 MHz
- 2400-2483 MHz

866 MHz range used by later-discussed RF devices is of the most importance, but also 434 MHz and 2450 MHz carrier frequencies have been investigated (other RFID frequencies).

Signals were generated by SMIQ signal generator and radiated by a log-periodic antenna. In the cart, the TS-EMF antenna placed in various positions. Measurement was performed by FSH spectrum analyzer with the help of measuring software running on notebook in several places of the cart's container (basket).

At each frequency, the measument series started with a reference measurement, when direct wave propagation was not blocked by the metal grid Radiated power of the sinewave signal: -10 dBm at 866.6 MHz and +10 dBm at other two frequencies.

Power level increased in order to maintain approximately the same power on the receiver side.

Remarks

- At 434 MHz, the log-periodic antenna could not deliver satisfying signal level.
- At 2450 MHz, greater attenuation had to be compensated.

3.1.1 Field-strength and power density

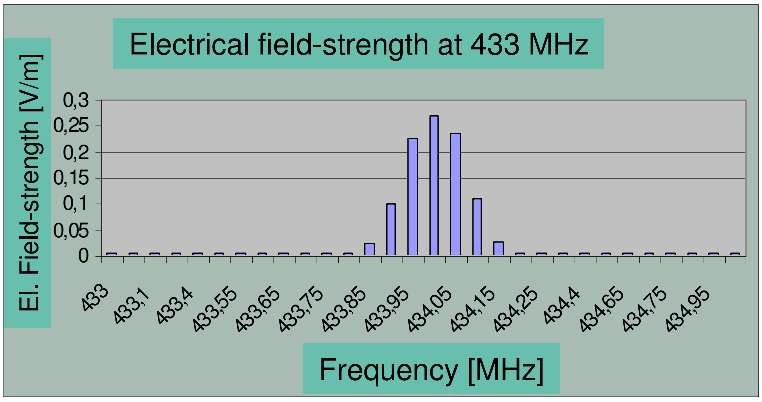

Fig. 4. Electrical field-strength at 433 MHz

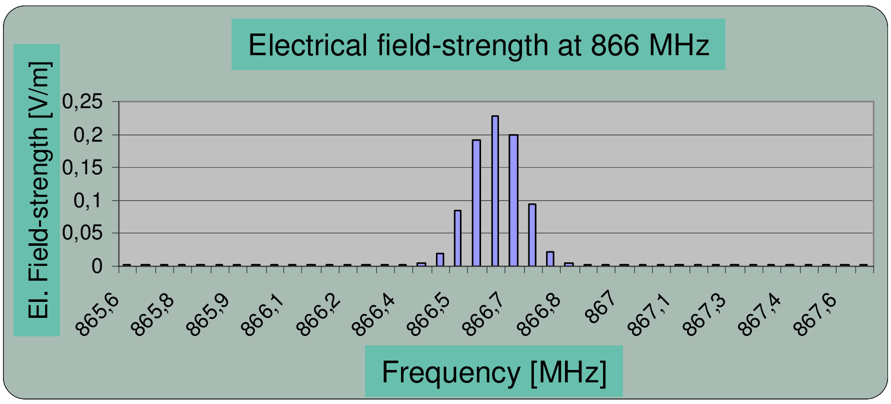

Fig. 5. Electrical field-strength at 866 MHz

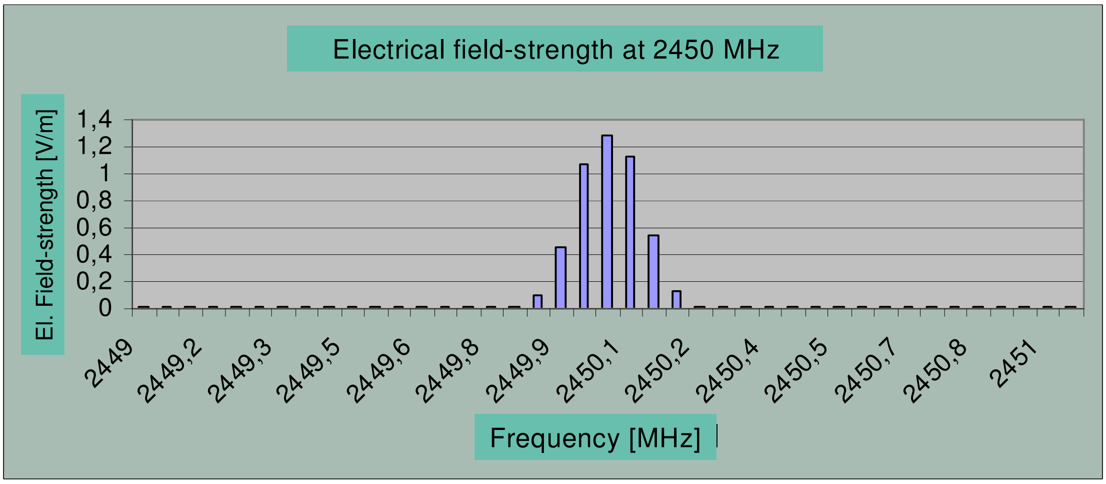

Fig. 6. Electrical field-strength at 2450 MHz

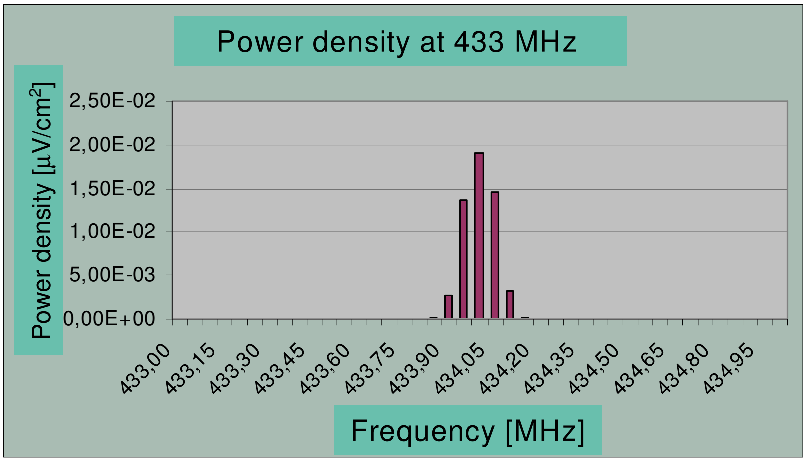

Fig. 7. Power density at 433 MHz

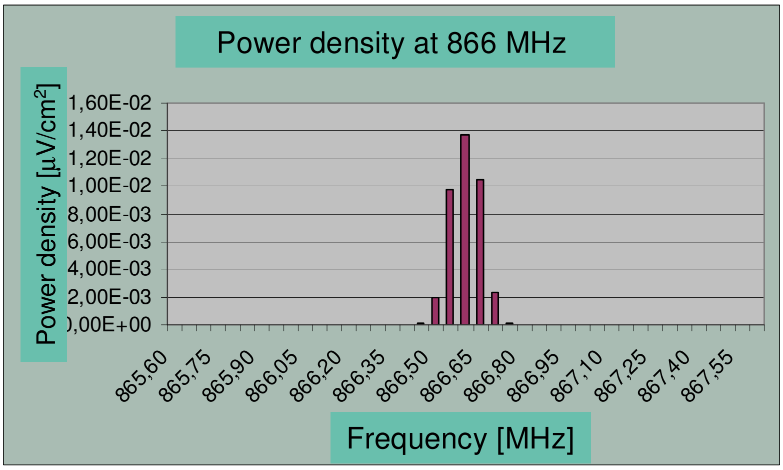

Fig. 8. Power density at 866 MHz

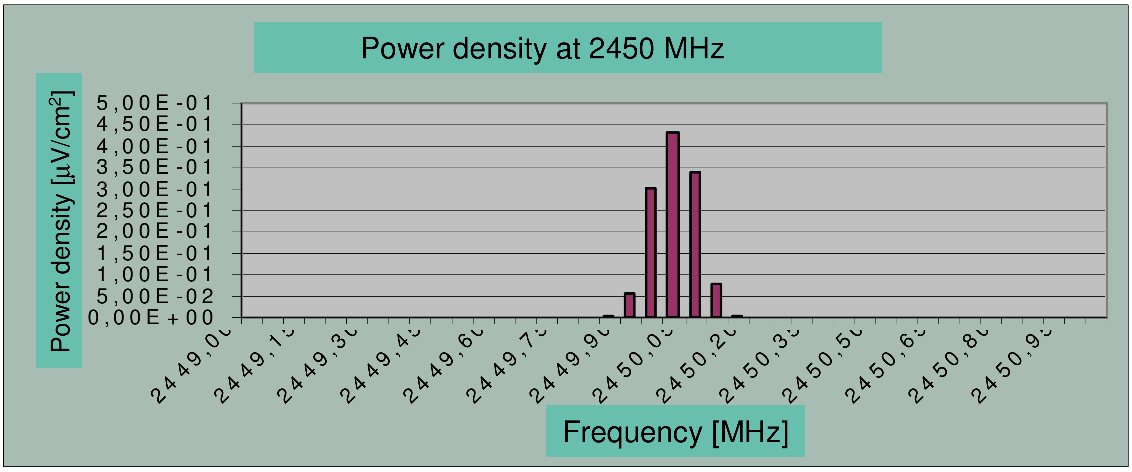

Fig. 9. Power density at 2450 MHz

3.1.2 Shielding effect

The absolute field strength and power density values are **not** the primarily important parameters to characterize the shielding. The best way is to define the ratio of the peak signal related to the reference value. We measured it using different frequencies and antenna positions, as can be seen on the following figures.

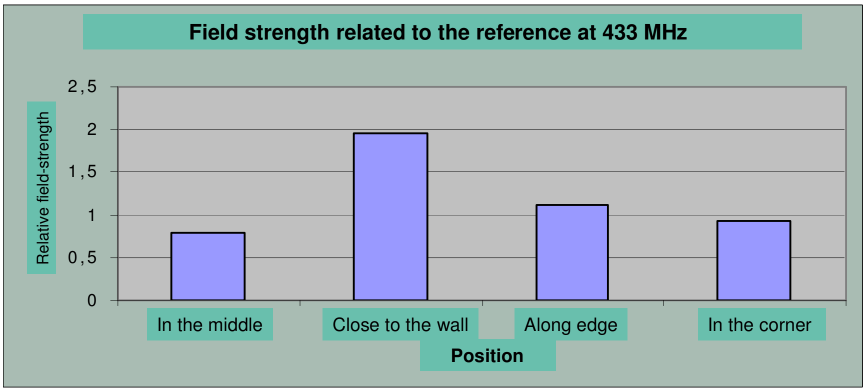

Fig. 10. Field strength related to the reference at 433 MHz

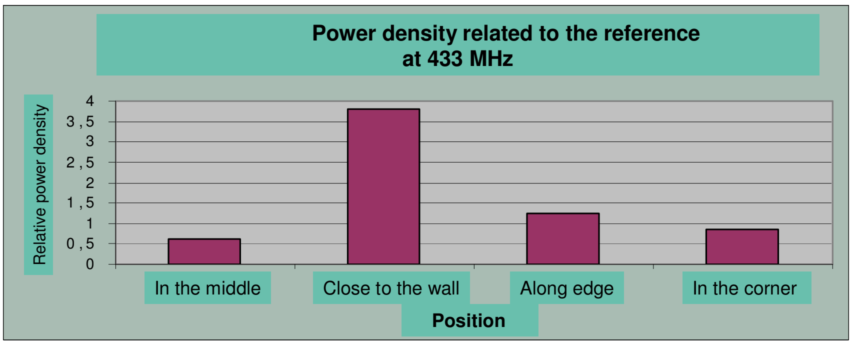

Fig. 11. Power density related to the reference at 433 MHz

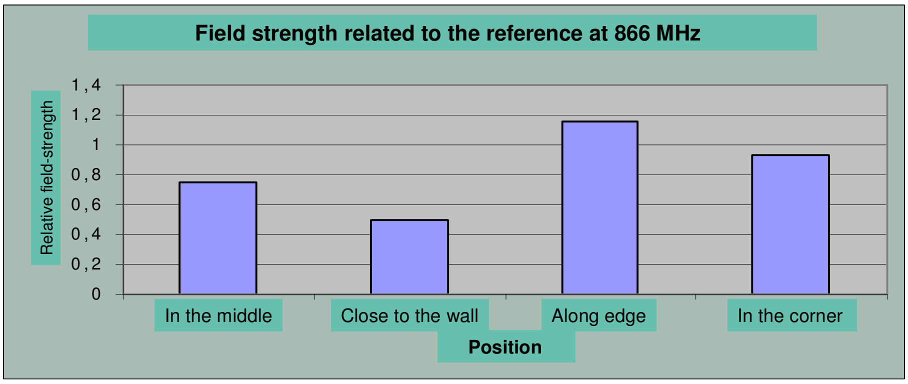

Fig. 12. Field strength related to the reference at 866 MHz

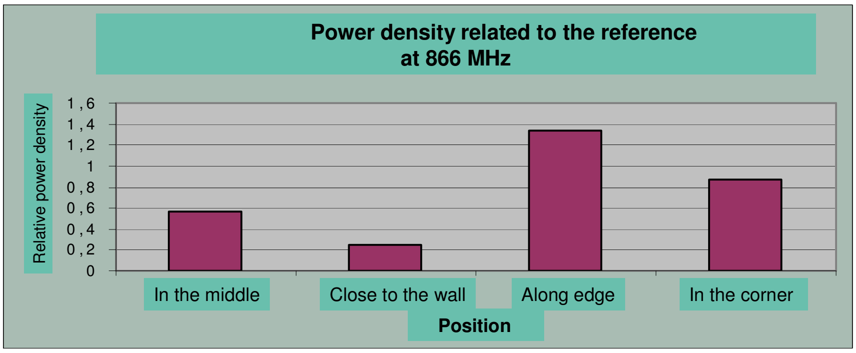

Fig. 13. Power density related to the reference at 866 MHz

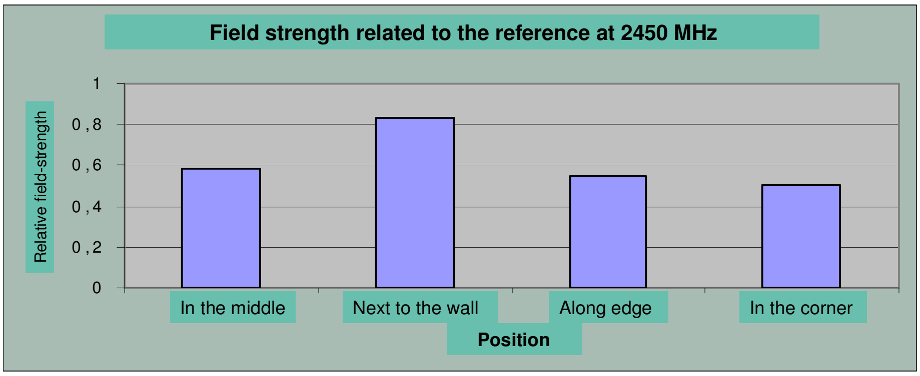

Fig. 14. Field strength related to the reference at 2450 MHz

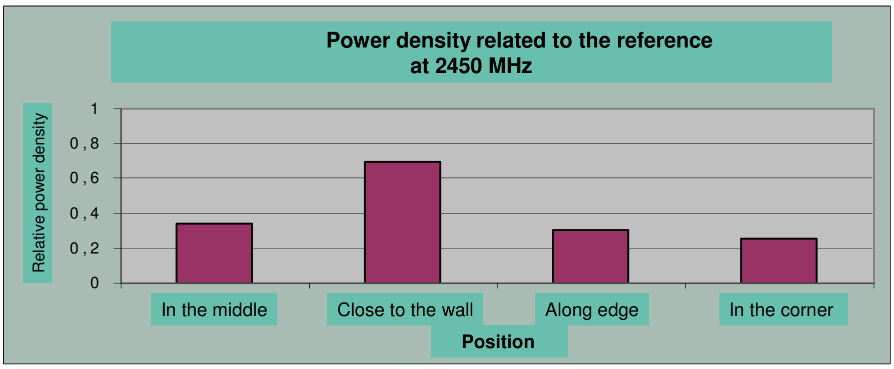

Fig. 15. Power density related to the reference at 866 MHz

3.1.3 Measurements with dipole antenna

Due to the shape of TS-EMF antenna, it could not be placed close enough to the container's wall, so some measurements with a small dipole antenna were done to clarify the influence of the vicinity of the metal wall. We did only 3 measurements (reference, in the middle and by the wall), since there was no significant difference in comparison with the previous results

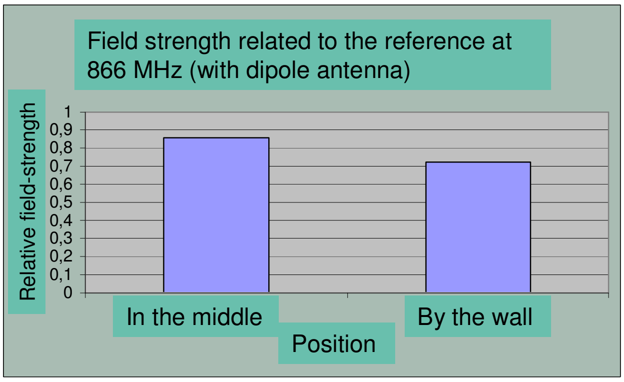

Fig. 16. Field strength related to the reference at 866 MHz (with dipole antenna)

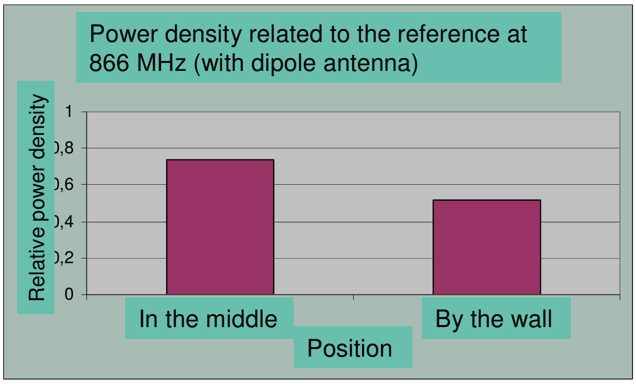

Fig. 17. Power density related to the reference at 866 MHz (with dipole antenna)

3.2 Radiation coming out of the cart

Significant deviation of field strength and power density has not been observed. The radiation values stay slightly under external radiation. Three measurements (reference, in the middle and next to the metal surface) were done.

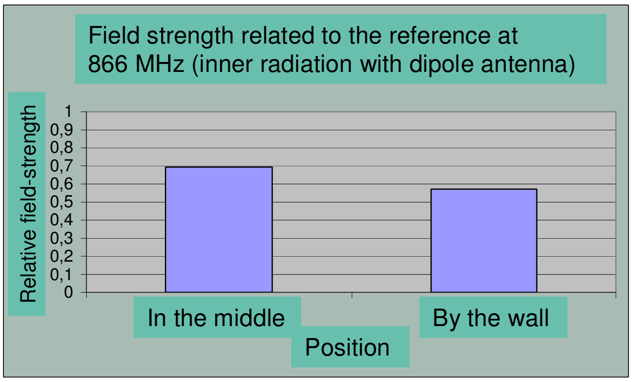

Fig. 18. Field strength related to the reference at 866 MHz (inner radiation with dipole antenna)

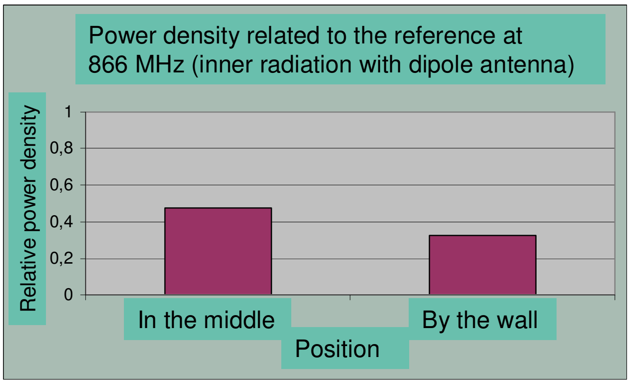

Fig. 19. Power density related to the reference at 866 MHz (inner radiation with dipole antenna)

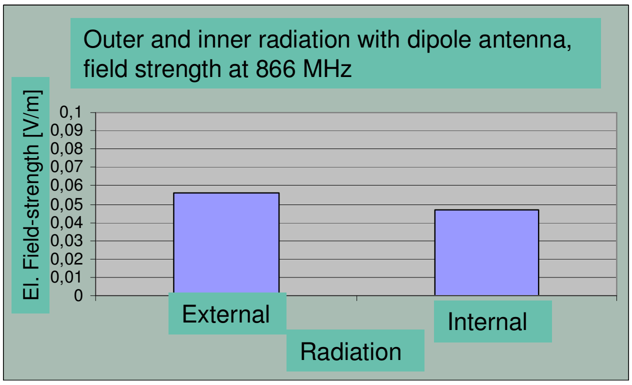

Fig. 20. Outer and inner radiation with dipole antenna, Field strength at 866 MHz

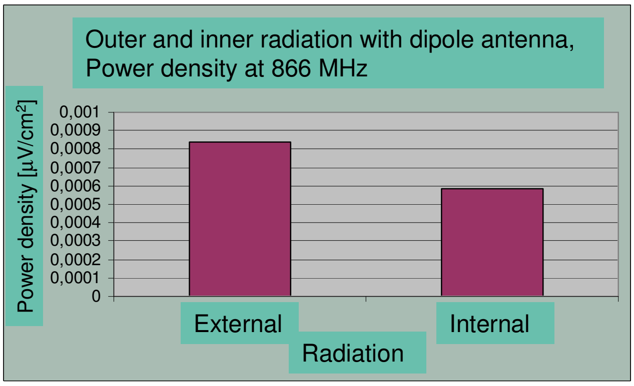

Fig. 21. Outer and inner radiation with dipole antenna, Power density at 866 MHz

3.3 Time-domain analysis

The distortion of the RF signal has been investigated, the transmitter was a dipole antenna connected to R&S SMIQ signal generator and placed into container. The receiver was a R&S measuring antenna and Agilent 54836B oscilloscope. As a carrier frequency 866.6 MHz was used, with a radiated power level +10 dBm.

To meet the features of RFID devices, amplitude modulation was used and modulation depth of the ASK signal was set to two values (50% and 90%)

Other parameters:

- Signal shaping: Gauss-filter (BT=0,3)
- The symbol rate: 10 000 symbol/s
- Repeated bit sequence: 1011 1010 1111

For comparison, the modulated signal transmitted by cable connection, too (yellow).

3.3.1 Modulation depth (cable transmission) as a reference

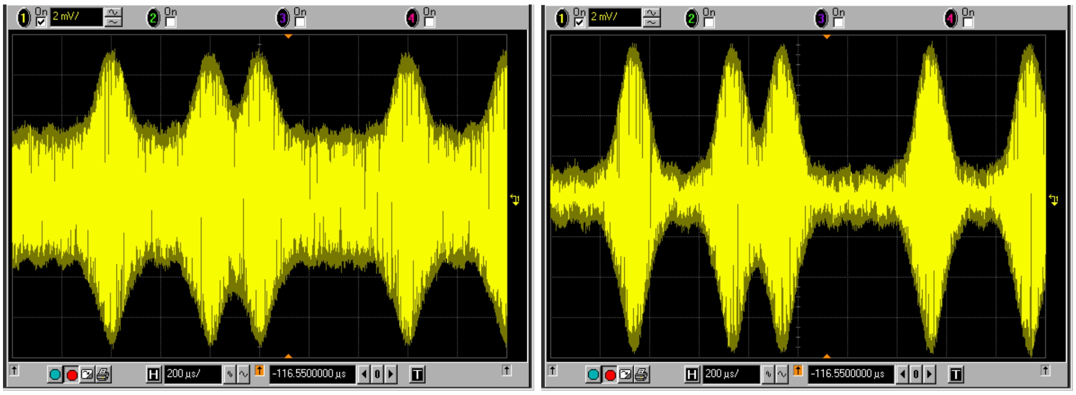

Fig. 22. a) Modulation depth as a reference (50%), b) Modulation depth as a reference (90%)

Smaller amplitude represents „1” symbol, the greater one the „0” symbol

3.3.2 Radio transmission (in the middle)

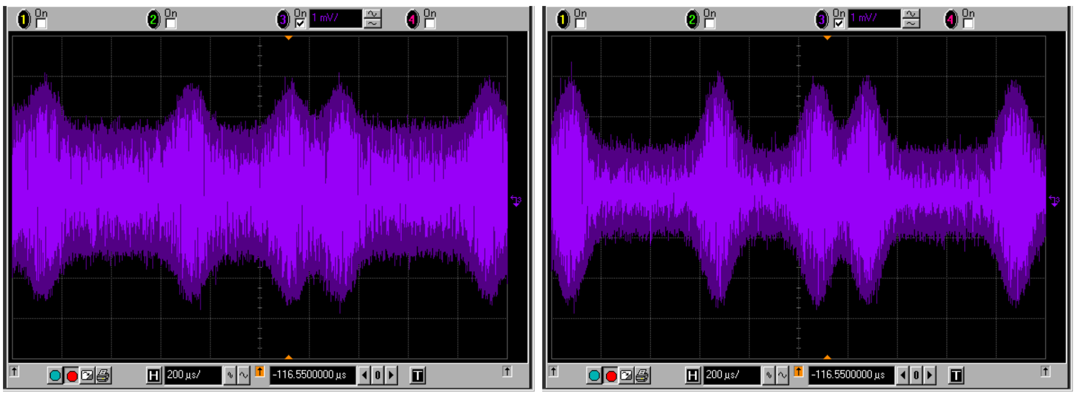

Fig. 23. a) Radio transmission in the middle (50%), b) Radio transmission in the middle (90%)

System is loaded by significantly greater noise as seen on Fig 64 and 65, compared to the reference (yellow).

3.3.3 Radio transmission (near the cart's wall)

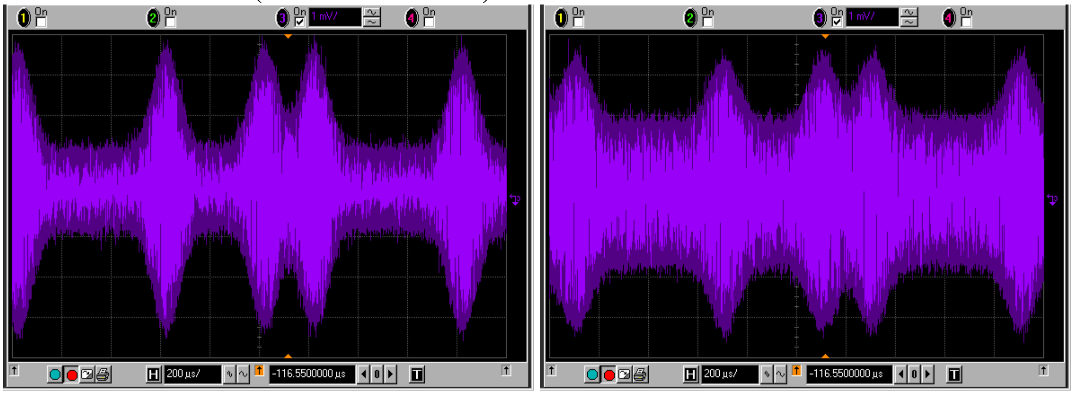

Fig. 24. a) Radio transmission near the cart's wall (90%), b) Radio transmission near the cart's wall (50%)

3.3.4 Consequences

- The noise makes significantly harder to distinguish the symbols
- It happens that in case of „0" symbol the level drops to the amplitude range of symbol „1"
- Close to a metal surface this effect may be stronger (due to the coupling with the RFID tag)
- Cart acting as an antenna is sensitive to other external RF interferences, too
- If the different symbols follow each other with too high speed the signal -depending on the frequency response of the transmitter filter-cannot reach neither the maximum nor the minimum value
- Thus the amplitude difference between the two symbol levels becomes even smaller
- Used modulation depths were pretty high (50%, 90%)
- In case of great modulation depth, the signal peak factor becomes also great, causing the amplifier unit to operate with bad efficiency
- This solution is unfavorable in cases of strongly limited resources (the passive RFID tag utilizes only energy of the radiated signal)
- In realization, care must be taken to the proper balance of the two factors
- In the cart -due to reflections- the signal amplitude is exposed to pretty high changes
- The changes depend on the position of the RFID tag
- Further investigation: Behavior in presence of a close metal surface (e.g. a closed cart, which helps reducing unwanted reading of tags on shelves)

3.4 Influence of near metal surface

The vicinity of a metal surface significantly reduces amplitude of the signal radiated by the tag and also reduces the antenna impedance as a consequence, antenna becomes mismatched and antenna radiation efficiency becomes bad. For this reason the radiated power decreases (power can be about 5-8 dB lower) and the RFID tag can be unidentified if the environmental noise power is relatively high, the signal-to-noise ratio drops to a level, which makes the correct demodulation impossible as a consequence of higher bit error ratio, the tag can not be identified.

3.4.1 The measurement

For a radiator a log-periodic antenna placed closely to a metal surface, and as a receiver dipole antenna was used. The radiated signal parameters were the following:

- 0 dBm power
- 90% modulation depth,
- 10 ksymbol/s symbol rate
- ASK signal

Signal amplitude changes as a function of the antenna distance from the metal surface observed on oscilloscope. The following figures show it as a function of the distance.

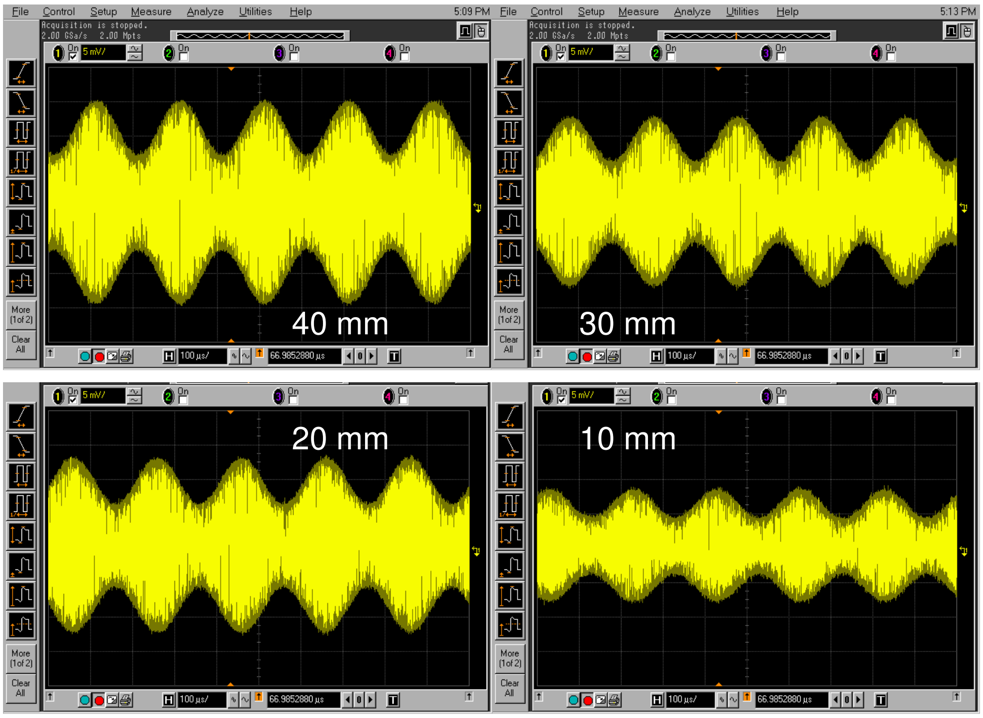

Fig. 25. Radio transmission (90%)

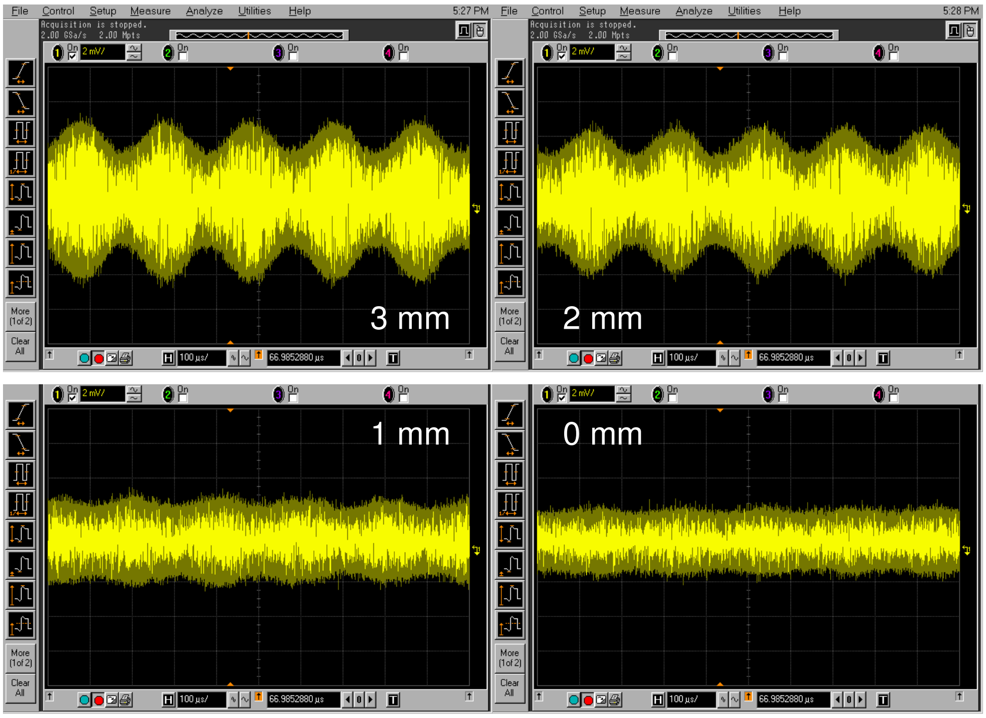

Fig. 26. Radio transmission (50%)

3.4.2 Peak voltage values

We measured the peek-to-peek antenna voltage as the function of the distance from the container's metal surface. (see Figure 27) Placing antenna directly on the metal surface, the signal level drops down to noise level, thus reading the tag would be impossible.

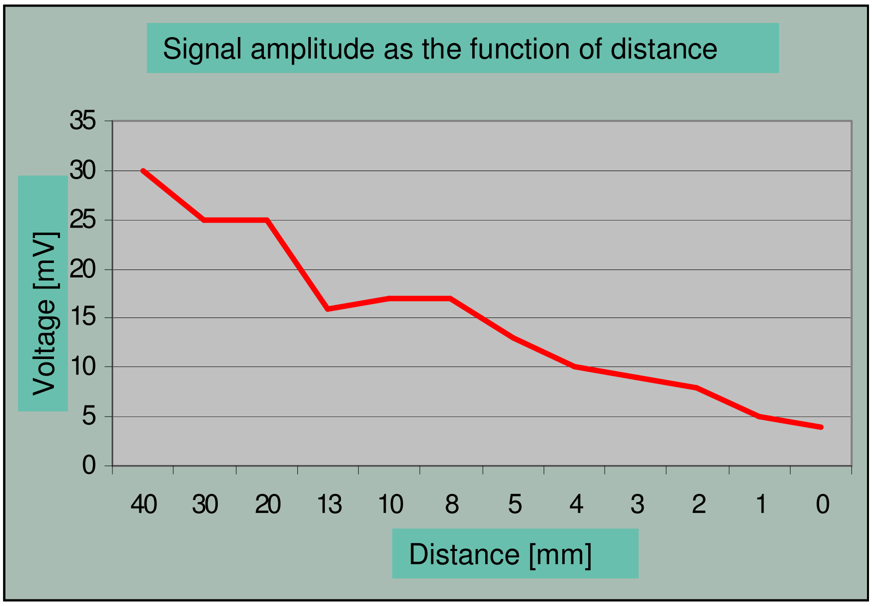

Fig. 27. Signal amplitude as the function of distance

3.5 Functional test of RFID devices

This measurement was done to test the possibility of reading the content of the cart at a gate. Effects of signal distortion and amplitude decreasement examined for normal RFID operation. Both 1st and 2nd generation RFID tags (Gen1, Gen2) with amplitude modulation were used and two reading antennas were placed facing the side of the cart.
RFID tags were placed into the cart, as the distance between cart and antenna was about 1.5 meters.

3.5.1 General conclusions

RFID tags mostly readable, however, their identification was highly dependent on placing, i.e.:

- whether the tag's plane was perpendicular or parallel to the antenna's radiation direction
- their distance from the metal surface
- inserting some object with given εr permitivity (paper - e.g. book)
- changes were not noticed, the identification was correct

Propagation path blocked by some object containing water (e.g. human hand) tag was unidentified, and when part of the cart's wall changed to solid metal surface, tags placed behind the solid metal became unidentified.

3.5.2 Gen1 and Gen2 results

Different behavior of the two tag types were detected. Readability of Gen2 tags were better than that of Gen1 tags.
Bad Gen1 results were detected:

- identification highly reduced when the tag's plane oriented parallel to antenna's direction
- identification impossible when the tags placed on the cart's inner metal surface (modified cart)

2nd generation tags identified with better confidence:

- the identification failed only if tags placed on metal surface parallel to the propagation of the direct signal and if tag itself placed parallel, too
- in other cases, the bigger Gen2 tags operated properly, although not with 100% confidence.
- placing Gen2 tags on parallel metal surface, the identification became impossible

3.5.3 More tags under real conditions

About 100 tags tested under real conditions, sixteen Gen1 RFID tags were used simultaneously:

- At 1 m reading distance, all 16 tags identified
- At 2 m reading distance, 14 tags identified
- Behavior of tags when moving them also tested. The duration of motion in front of the reader was about 3 seconds (normal walking velocity) 10-12 tags were identified

Nineteen Gen2 RFID tags at disposal:
- All 19 tags identified from the distance of 2.5 m
- In case of moving cart (duration of motion in front of the reader: 3 seconds) 17-18 tags identified
- Testing case of slower container motion (6 seconds reading time) all the 19 RFID tags identified

Reading Gen 1 and Gen 2 tags in steady position:
- Out of 36 tags, 22-24 tags identified
- Less tags identified when grouped closely side by side each other

Fig. 28. measurements with higher tag population

3.6 Reading tags inside the shopping cart

Mostly Short dipole Rafsec tags (see Figure 29) were used, but at pure performance some tags were replaced by Alien Omni Squiggle tags (see figure 30) for better results.

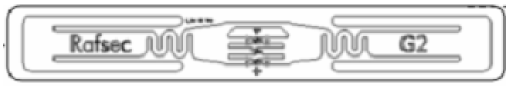

Fig. 29. Rafsec tags

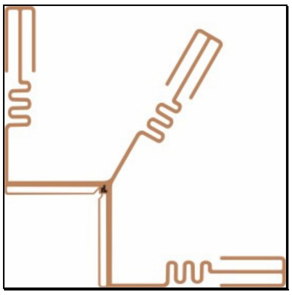

Fig. 30. Alien tags

The tags were placed inside the cart and were hanged on plastic tapes to provide more space between tags (see Figure 31 and 32).

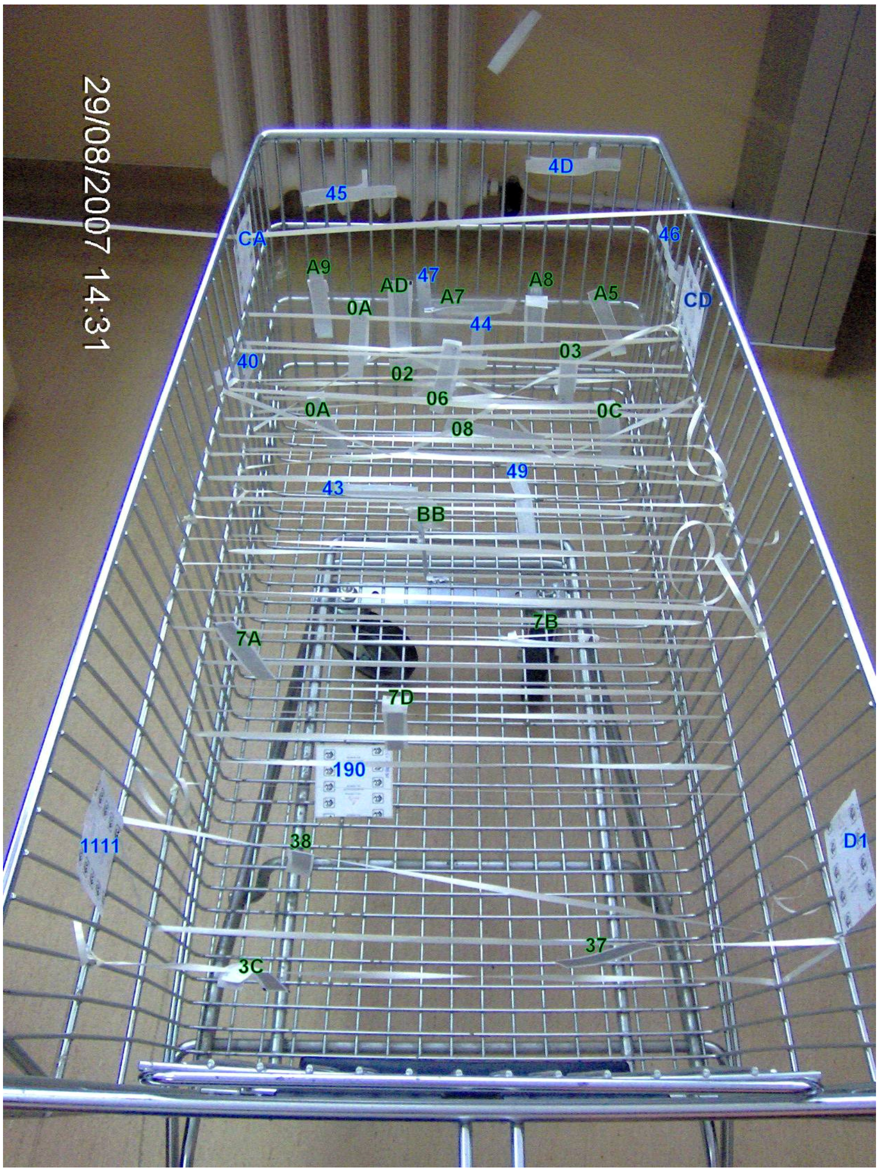

Fig. 31. The first measurement arrangement.

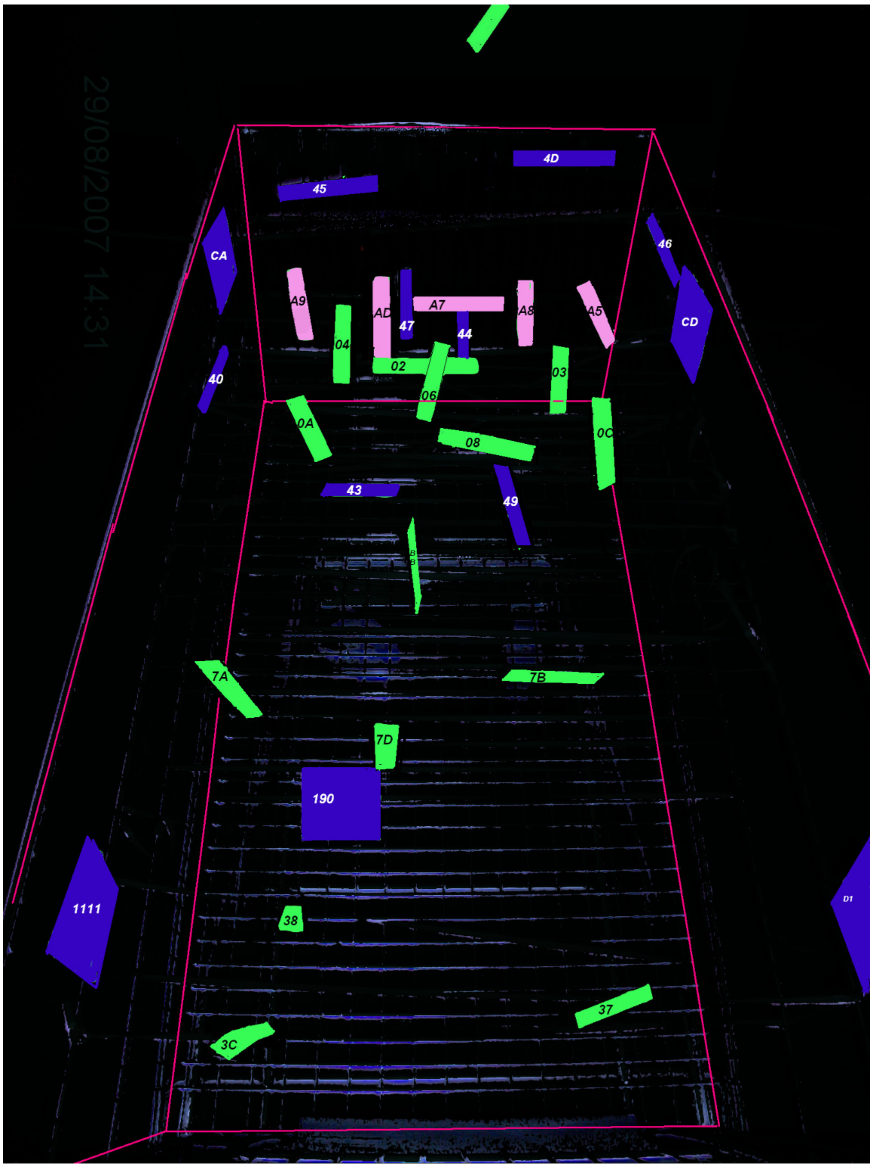

Fig. 32. The first measurement arrangement with different tag groups marked with the same color.

3.6.1 The Measurements

In the measurements we used the Intermec 751G Pocket PC connected to an Intermec IP4 UHF RFID reader. The communication between the PDA and the RFID reader is based on a so called “lightpipe“, which is actually a wired IRDA port with a maximal speed of 115kbps. The reader operates in compliance with the ETSI standard EN 300 220, the EN 302 208 is not suppported.

The reader operated with the Gen2 standard defined parameter “Q” set to 4. During the measurements two parameters were varied: the radiated power of the device and the position of the device in comparison with the shopping cart. The radiated power was set to 100, 85, 75, 65, 55, 45, 35 and 25 percent of the maximum possible 1W power level (Note: the standard allows only 0,5 W to radiate out but it is possible that the radiated power level is below 0,5W and the scaling of the device is false).

The first reader position was at the handle of the cart, the plane of the PDA enclosed at an angle of 10 degree to the horizontal plane. The second reader position was at the position of the so called “child’s seat”, the third position was at the bottom of the cart, approximately at 1/3 cartlength from the back wall of the cart.

Fig. 33. The first reader position

Fig. 34. The second reader position

Fig. 35. The third reader position

During each measurement the position of the reader was fixed and all the measurements were done about 30 read cycles long with the Intermec Corporation's IP4BRI v0.47 software using continuous read mode.

3.6.2 Problems with the article identification using the IP4 RFID reader

Continuous monitoring of the space over the cart
The continuous reading is regulated in the EN 300 220 standard. The standard states that the readers may not be operated with greater than 10% duty cycle. However, the time interval of the reading is not defined strictly, only the 1:9 relation between the reading and listening phase is important. The second problem is that the reader firmware freezes for a short interval after a certain number of read cycles.

Periodical reading of the whole cart content
This situation is problematic because of the tag positioning: there are some positions (see later) in which the tags can not be read. The second problem is that the wire-netting of the cart is not dense enough to read only the

cart's area. However, if it was denser, the number of the non-readable positions in the cart would increase due to the standing wave nulls caused by the metallic wall of the cart.

Manual reading of articles marked by a tag
This solution is the simplest case, but it has a human disadvantage: if the customer doesn't read all the articles he buys.

3.6.3 Tags (labels) in the shopping cart

Tags on the cart's wall
The tags marked blue on Figure 32. was placed on the wire-netting wall of the cart. These tags can be classified into several categories:

- the tag Nr. **190** was placed at the bottom of the cart close to the reader,
- tags Nr. **43** and **49** were placed also at the bottom of the cart but far from the reader
- tags on the cart's front wall
  - Nr. **45** and **4D** above
  - Nr. **44** and **47** below
- Tags on the cart's side wall
  - Near to the reader (Nr. **1111** and **D1**)
  - Far from the reader (Nr. **CA**, **CD**, **40**, **46**)

The tags can be further classified in compliance with the tag types (Alien or Rafsec)

Readability depends on the radiated power level: higher levels caused more tags to be readable in all three reader positions. In case of the first reader position at lower power level (23dBm) only tag Nr. **45** was readable. Increasing the power, tag Nr. **190** was the second at 27dBm, then Nr. **40** at the maximum possible setting of 30dBm.

The other tags belonging to this category weren't readable in the first reader position. (see figure 33) In the second reader position (seen on figure 34) the tags Nr. **47** and **49** were also readable using the highest power level.

The third reader position (see Figure 35) wasn't any better than the second. Moreover, the tag Nr. **40** wasn't readable any more.

All the mentioned tags in this measurement were made by Rafsec. Placing additional – this time, Alien – tags at similar positions to the tag Nr. **40** (these were Nr. **CA** and **CD**) and near to the reader (**1111** and **D1**) we found that these tags are performing much better than the Rafsec tags: they all were readable in all the three reader positions, however, in the second and third reader positions the tags Nr. **1111** and **D1** were behind the reader's antenna. This result can be explained by the direction characteristic of the reader's antenna, which also radiated backwards (tested by placing a tag behind the reader).

On the other hand, there were some tags that were not readable in neither of the three reader positions and radiated power levels like tag Nr. **43**, which was placed on the bottom of the cart. The tag Nr. **4D** did not perform much better than the **43**, however, it was placed apparently in a similar position to the Nr.**45**.

The tags Nr. **44** and **46** in front and on the bottom of the cart were also unreadable, due to the effect of the cart's denser bottom wire-net, and there were more tags between the reader and the named tags. In this situation, replacing the Rafsec tags with Alien tags didn't help either, however, in all the situations mentioned before the replacing caused good readability thanks to the greater form factor of the Alien tags.

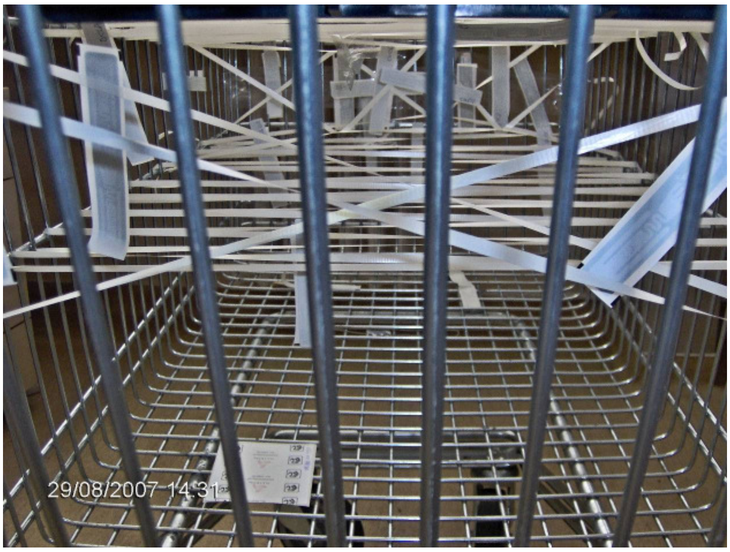

Fig. 36. Tags behind each other

The detection of the tags placed on the bottom of the cart was improved by placing a thin (0,33mm) plastic sheet between the tag and the cart's bottom wire-net.

Labels in the cart, near to the reader

This category contains the tags Nr. **37**, **38**, **7A**, **7D** (tag's plane perpendicular to the cart's bottom plane, and near parallel to the readers plane, the tag faces upward) , **3C and 7B** (tag's plane perpendicular to the cart's bottom plane and the readers plane, the tag faces sideward) and **BB** which was parallel to the cart's side walls and its plane was perpendicular to the readers plane.

It can be generally declared that these tags (except the 7A) were readable using the lowest radiated power level and in all three reader positions. Nr. 7A was readable only from 27dBm in the first reader position, but this tag performed better in the other positions.

Labels in the cart far from the reader

This category contains the tags whose first digit was 0 or A. Beside these we can differentiate more subcategories (tags face sideward or upward, tags behind others). For example tag Nr. 08 was placed in front of the others, which can be harmful because the antennas are made from metal. Thus, this tag shields the other one. On the other hand, they can mutually detune each others resonant frequency because of the added parallel capacitance caused by the near metallic material.

These tags performed very well during the reading tests. At 30 and 27dBm power levels all of them were readable, at 25dBm tag Nr. 03 was no more readable, at 23dBm its signal was again detectable but at lower levels no more. Nr. 02 performed a little better, at 21dBm power level its read count was about half of the read count of the others and at lower levels it wasn't readable any more. At the lowest possible power level setting, even the signals of tags Nr. 08 and 0C were not detectable any more.

The tags whose tag ID started with "A" were almost always readable (only the AD wasn't at 15dBm)

Labels outside the cart

It can be seen on Figure 33 that there were also tags outside the cart's area. Unfortunately the reader could read these with good efficiency. The tag placed in front of the cart was almost always readable (below 17dBm no more). The measurement results of the tags placed beside the cart were a little better: the two nearest were almost always readable, the second nearest were readable only at higher levels than 23dBm. The farthest were never readable (not even at the highest power level).

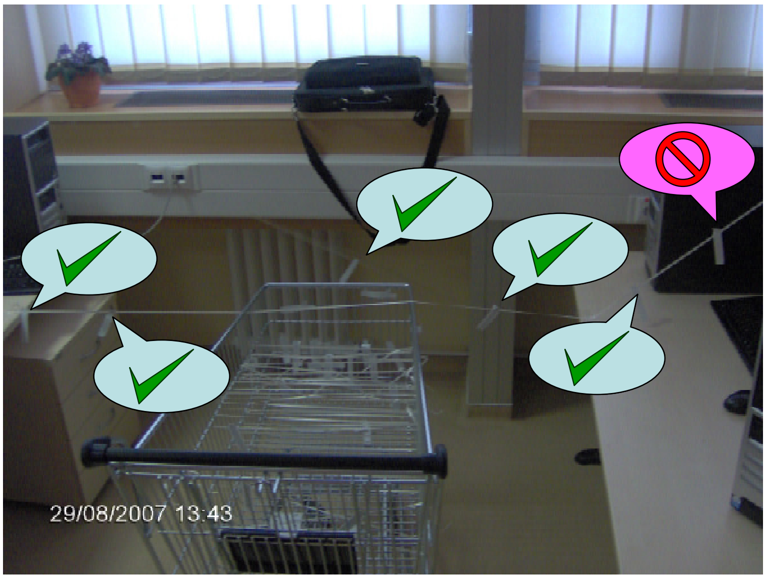

Fig. 37. Tags outside the cart

It can be said that if we use tags made by Alien, the readability can be improved. In measurements with higher tag populations there were also some positions in which the Rafsec tags weren't readable (tags on the cart's wall; tags behind each other) but if we replaced these with Alien tags the readability improved.

4 Conclusion

In this paper we summarized requirements and the possible operation modes of an Intelligent Shopping Cart. We presented the main problems that can arise in this environment. Finally we presented results from several measurements with a metallic shopping cart. Based on this, we can conclude, that there are several steps ahead to make a secure, reliable and easy-to-use "Intelligent Shopping Cart"

5 Acknowledgement

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