Antenna Concepts for RFID on Forklift Trucks

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Abstract

Using radio frequency identification (RFID) antennas with forklift trucks to identify goods and stock shelves automatically will help to increase efficiency of logistic processes. RFID components designed for integration into forklift trucks have not been investigated yet. This paper discusses different approaches to integrate RFID antennas into a forklift truck. The different influences to RFID systems are discussed by consideration of logistic environments. Different antenna concepts are introduced and benchmarked by using simulation and measurement of electric field strength as well as functional tests. The results lead to an optimal system design for different tasks.

Keywords: RFID antennas, forklift trucks, warehouse management, logistics

1. INTRODUCTION

Forklift trucks are used for transport applications when flexibility and high turnover rates are the major requirements. It is more challenging to connect such systems to a warehouse management system than a fixed conveyor system. Communication must be carried out by wireless LAN. Position data of forklift truck and information about goods must be determined to track and trace the material flow.

RFID has a high potential for cost saving and helps to improve processes in production and material flow technology. If turnover points and goods or goods carriers are equipped with RFID transponders they can be identified automatically.

RFID readers and antennas are designed for fixed antenna gates. If they are mounted on a forklift truck, performance is influenced by several effects. Different antenna technologies have been put into consideration. This paper will show the major influences to RFID systems on a forklift truck and characterize the antenna technologies eligible for different applications.

In this contribution, we focus on RFID systems which are able to perform read and write operations with an RFID transponder integrated into box cages or pallets. For this application UHF RFID systems are preferred due to the wide communication range. For write operation, only one single RFID transponder should be used to avoid inconsistent data on different transponders. Usually the RFID transponder is mounted in the middle of the ground plate to allow operation from all sides.

2. ANTENNA TECHNOLOGIES FOR FORKLIFT TRUCK RFID SYSTEMS

A. Positions for Integration of RFID Antennas

Integration of RFID antenna on a forklift truck is restricted mainly by the limitation of places on forklift truck´s front side. The antenna must radiate in direction of the goods. To identify goods in several lifting heights, antennas must be moved with forks simultaneously. Two different positions for integration of antenna elements must be considered: An antenna can be integrated into the forks carrier or into the forks. Two different types of forks carriers, named type A and B can be distinguished according to [1]. Only a slim slot between forks carrier and ground allows antenna integration if the mounting position in the forks carrier is preferred. Moreover, due to mechanical abrasion of forks this space will be reduced. If the RFID antenna shall be integrated into the forks carrier, this effect must be considered over time. Additionally, if the RFID antenna is mounted on the forks carrier, it will easily be destroyed during operation.

Otherwise, if the antenna is integrated into the forks, it must be considered that forks have to be changed if thickness is reduced to 90 percent of a new fork.

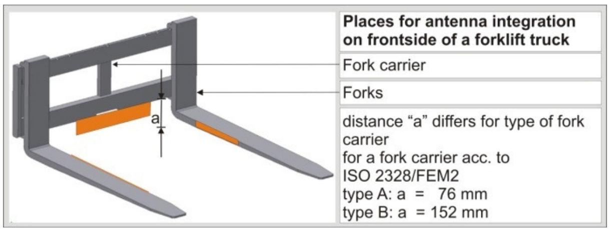

Figure 1 Antenna integration into front-side of a forklift truck

For operation in a warehouse only UHF systems have enough reading range between antenna and transponder since they use electromagnetic waves instead of inductive coupling for communication. If using an inductively coupled system the maximum range decreases with decreasing antenna diameter. In a system using electromagnetic wave the propagation antenna geometry can be designed much smaller. This facilitates integration into a forklift trucks fork or forks carrier.

Using an UHF RFID system linear and circular field polarization must be distinguished. The antenna design determines which kind of polarization can be emitted. For a circular polarization, the active area of the antenna must be rectangular. Such design can not be integrated into forks since a fork allows only slim antenna geometries. Slim antenna geometries can only be achieved by using linear antenna polarization. If the field of the propagation antenna has a linear polarization, an RFID transponder antenna with linear polarization must be aligned to the field. To meet also legal restrictions, the antenna design must be well-considered.

In this contribution, we describe measurements with three different types of antennas. All antennas have linear polarization due to the available space.

B. Patch Antenna for Integration into Forks Carrier

A patch antenna with integrated reader unit was designed for integration into the forks carrier by deister electronic. The front plate can be changed easily in case of destruction due to an accident. In practical application, the reader can be damaged by objects on the ground. The RFID reader unit and power supply is integrated into the unit. Connection to forklift truck terminal PC is established by a four-line wire on the lift pole. For mechanical protection the wire was put into an empty tube of the hydraulic system. In figure 2 an additional sensor is shown which is used to detect a goods carrier on the fork to control the RFID system.

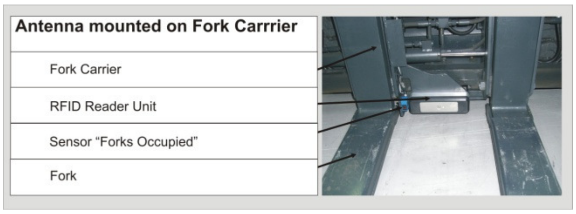

Figure 2 Patch antenna for integration into forks carrier

C. *Patch Antenna for Integration into Forks*

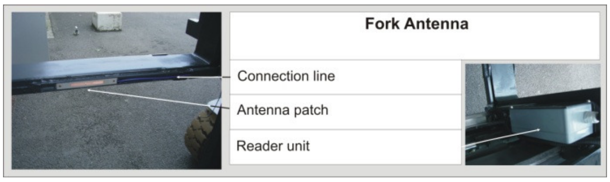

Figure 3 Patch antenna integrated into fork and reader unit

A patch antenna was mounted on the inner side of a fork. The distance between the middle of the antenna and the forks carrier is 50 cm. This position is chosen due to the minimum distance between patch antenna and RFID transponder in the middle of the ground plate of a goods carrier. The patch antenna is connected with an HF line to the reader unit. The reader unit is integrated into the forks carrier as shown in figure 3.

D. *Slot antenna for Integration into Forks*

It is also possible to integrate a slot antenna into the fork by cutting a slot into the inner side of the fork to work as an RFID antenna. An explicit description of this antenna is shown in [25]. The RFID reader unit integrated into the forks carrier which feeds the patch antenna integrated into the fork can be used to feed the slot antenna. The orientation of the linear field is turned by 90 degrees compared to the patch antenna. If this antenna is used, tag orientation must be changed. In this paper the slot antenna is not investigated.

3. INFLUENCES TO FUNCTION OF RFID SYSTEMS

Performance of RFID systems depends on several influences. Nikitin [2] and Lodewijks [3] have given a short summary. In the following section the influences are divided in transponder properties, reader properties, environment conditions and influences by application.

A. *Transponder Properties*

1) chip sensitivity

Chip sensitivity denotes the minimum of energy that is needed to empower the RFID transponder. With a low chip sensitivity it is possible to achieve a high reception range [3]. Input impedance of an RFID chip is tuned for the minimum of power at maximum reception range. Input impedance changes depending on antenna power. For a lower reception range, RFID chip and antenna are detuned [5].

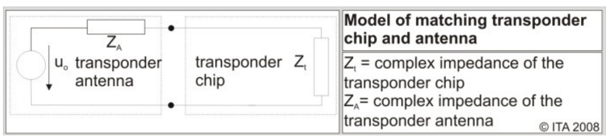

Figure 4 Model of matching transponder chip and antenna

2) antenna gain

The beam power density P_{max} in the main beam direction of the antenna is higher by the antenna gain *G* than the power of an isotropic radiator P_i. It can be expressed by

$$P_i \cdot G = P_{max}$$

The antenna gain *G* shows the direction sensitivity of an antenna.

3) polarization

The vector of the electric field strength is used to determine the polarization of an electromagnetic wave. If the end of this vector moves on a line, polarization is linear. If the vector rotates on a circle around the direction of propagation, polarization is called circular.

A wave which is always in a plane between the vector of the electric field strength and the pointing vector has a linear polarization [6]. In particular, when the electromagnetic field has a linear polarization, orientation must be considered. If both antennas are aligned orthogonally, no energy will be transmitted.

4) impedance matching between transponder chip and transponder antenna

Both transponder chip and transponder antenna have a complex impedance. A model used in some contributions to make theoretic derivations is shown in [7]. Complex impedance of RFID transponder chip and antenna are defined as

$$Z_a = R_a + jX_a$$

$$Z_t = R_t + jX_t$$

For an optimal power transmission, it can be derived

$$R_a = R_t$$

$$X_a = -X_t$$

This model does not consider the influence of the connection between RFID transponder chip and antenna. The influence of the assembly process and the deviation of chip impedance due to the production process were not investigated sufficiently yet. The capacity of the connection between RFID transponder chip and antenna depends on several process factors such as bond force, bond-line thickness, bond temperature and used adhesives given in [8].

Antenna impedance can change due to oxidation of the antenna surface. Complex impedances depend on frequency.

As denoted before, chip impedance changes due to power absorption. If the power transmitted from antenna to chip is reduced due to a mismatch, system performance decreases.

5) antenna design

Characteristic design parameters of an antenna are the active antenna area, the number of particular antennas and the antenna shape. The active area should be large enough to adsorb as much energy as possible from the field. The antenna substrate should be well exploited. Antenna performance also depends on the number of antennas. Two dipole antennas with orthogonal polarization may lead to better results than one single antenna. Such design helps to reduce orientation sensitivity. There are many possibilities for the design of the antenna shape. Especially broadband behavior of the antenna can be influenced. An antenna with better broadband characteristic decreases the influence of different materials in the proximity of RFID transponder [9].

B. *Environmental Conditions*

1) path losses

The path losses in an open area are called free space attenuation. Path losses describes how field power of an electromagnetic wave decreases on the propagation path between transmitter and receiver depending on environment properties. This effects have been investigated for RFID systems by Nikitin and Rao [2][10].

2) transponder detuning

Resonance frequency of an RFID transponder changes when particular materials are approached. Detuning of RFID transponder decreases the system performance [11]. If there are different objects in an RFID system, all equipped with RFID transponders, they all may have different resonance frequencies, even if the same type of transponder is used, due to this effect. Reception range of an RFID system decreases if resonance frequency of the RFID transponder and working frequency of the RFID reader differ. In [9] a concept is shown to produce transponders with different resonance frequencies by using different positions to place the RFID chip on the antenna. Experiments show a strong deviation of the resonance frequency when placing RFID transponders on different objects [7][11].

3) interference effects

Overlap of waves with the same frequency are denoted as interference and cause local minima and maxima of the signal amplitude. This effect is caused by the superposition principle [12], waves do not have mutual influence. For a specific location, the signal strength can be determined by addition of the single amplitudes. The frequency of the resulting signal is the same as of the single waves [13]. Interference effects are a challenge when investigating RFID systems since they can cause local amplification or attenuation of the signal, but they can also amplify the noise level [13] which makes it more complicated to detect the signal. Interference effects are supported by additional sources of electromagnetic waves, i.e. other RFID readers [14] and reflections. The area where transponders can communicate with an RFID reader becomes smaller if more transponders are in the field, because communicating RFID transponders are also a source of electromagnetic waves [4] causing additional interferences. Reflections of UHF signals can occur on metallic surfaces [13]. Since RFID systems are implemented in areas with many metallic objects, such as production areas, logistic centers and warehouses, these effects must be investigated well.

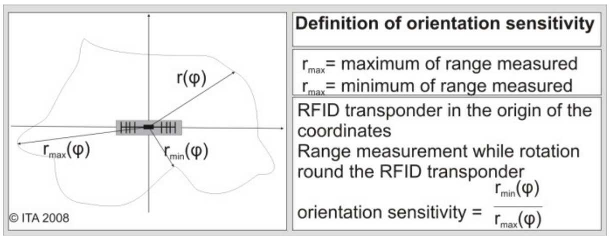

Figure 5 Orientation sensitivity according to Nikitin [3]

C. Influence of the Reader Unit

1) EIRP (equivalent isotropic radiated power)

The equivalent isotropic radiated power (EIRP) is used for measuring the transmitter power and is limited by law. In Germany, EIRP has a maximum of 2W at 868 MHz [16].

Usually, better identification results are expected by users if radiated power is increased. In reality, the reception range increases if radiated power is increased but more and more areas without communication occur, where identification is impossible. Due to these areas without communication, the reliable communication range decreases [16]. Furthermore, improvement of the reception range is limited by the energy the RFID transponder is able to reflect given by a point of saturation, where the reception range cannot be increased. This effect was investigated by Nikitin [3].

2) RFID reader sensitivity

The RFID reader sensitivity is defined in the same way as the chip sensitivity. It is the minimum signal strength received by the reader which is needed to communicate with an RFID transponder. The signal must be distinguished from the noise. The signal-to-noise ratio is the relation of signal power and the noise power. It can be influenced by interferences or other RFID reader units [14].

D. Influences by the Application

1) alignment of RFID transponder and reader unit

Influences of the alignment of RFID transponder and reader antenna can decrease RFID system performance. The sensitivity of an RFID transponder depends also on orientation.

The orientation sensitivity is the ratio between minimum and maximum of range in different orientations [17], as shown in figure 5. Furthermore, the wideness of the communication range from one side to the other changes with different orientations of the RFID transponder [3].

2) properties of the object on which an RFID transponder is applied

Materials and design of objects equipped with RFID transponders influence RFID system performance. Metal environments or water can decrease the communication range. System performance is also decreased near to stone, cardboard or wood [4]. In logistic applications many of these effects influence the system. Transport units are often made of cardboard, wooden pallets or box cages. They are placed on floors made of concrete or metal.

3) insufficient time for identification

High conveying velocity can influence RFID system performance, if there is not enough time to identify a single transponder. If the RFID transponder is moved in relation to the RFID reader unit, problems can appear, for example at an RFID gate. Investigations for a relative speed up to 100 km/h were made by Baum [18] for 13.56 MHz systems.

4) mutual influence of RFID transponders

A minimum distance between RFID transponders must be considered. Because of interference effects and local absorption of energy, identification is disturbed. If there are many RFID transponders next to each other, system performance is decreased [4].

4. INTERFERENCE EFFECTS DUE TO ANTENNA TECHNOLOGY AND PLACEMENT

In this contribution, we focus on interference effects which influence an RFID systems performance. An RFID transponder integrated into the pallet is normally tuned for this environment, so detuning effects can occur only due to goods transported or shop floor. For good performance of the RFID system, field strength must be sufficient at the position the RFID transponder is mounted.

A. Communication gaps due to interference of electromagnetic waves in simulation

In figure 6 a simulation of field strength is shown. In this simulation, a forklift truck with RFID patch antenna integrated into forks carrier picks up a box cage. Simulation shows areas with a weakening of field strength compared to other areas. The pallet is lifted by one meter.

If field strength is not sufficient for the RFID transponder communication will not work. After lifting up the pallet several inches, communication starts. This is mainly caused by interference of electromagnetic waves.

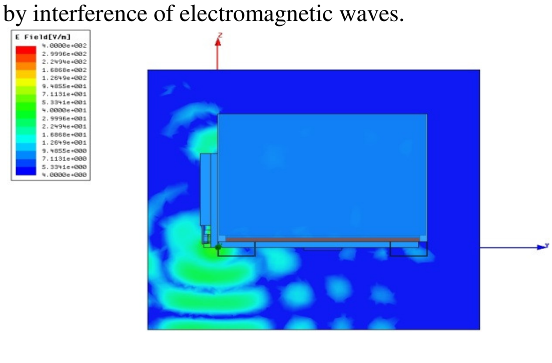

Figure 6 Simulation of Field Strength for a box cage lifted 1m by forklift truck and RFID antenna integrated into forks carrier

To investigate this effect, a forklift truck was equipped with an RFID patch antenna integrated into the forks carrier. A box cage with an RFID transponder in the middle of the ground plate was picked up and slowly lifted. At every cm a measurement was made. It was tested if communication is possible. As shown in figure 7 there are gaps in communication when lifting the box cage. The dimensions of the gaps match to simulation data shown before.

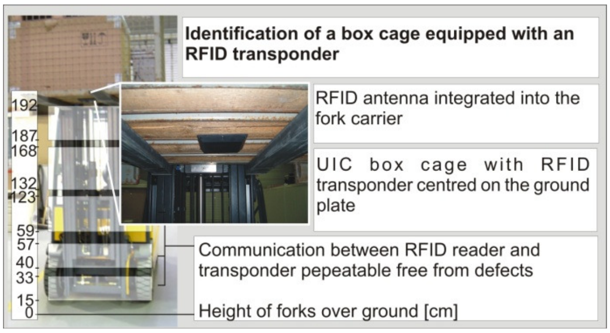

Figure 7 Practical measurements to find communication gaps when lifting a box cage

B. *Measurement of the Field Strength*

We define transponder sensitivity as the minimum of field strength needed for safe transponder operation. To measure transponder sensitivity, we increase the distance between RFID antenna operating with 2W EIRP and RFID transponder under test until communication stops. The electric field strength is measured at the position of the RFID transponder. If the transponder sensitivity is higher than the field strength the communication is impossible.

The transponder sensitivity is denoted in figure 8 as a black line. The antenna integrated into the fork has a maximum of field strength in the middle of the measurement range. The field strength was measured in different lifting heights. It is preferred to mount the RFID transponder in the middle of the ground plate of a goods carrier to achieve optimal reading results in all directions. The dimensions of standard goods carriers like the European pool pallet or the pallet box is 1.2 x 0.8 meters. To achieve good reading performance, an RFID antenna integrated into the forks should be used to identify such goods carriers.

5. SUMMARY

RFID antennas integrated into forklift trucks allow identification of goods and locations. Different types of antennas were developed according to requirements of this application. The performance of an RFID system depends on many influences, as explained in this paper. Interference effects lead to local variations of field strength. If the field strength is below the transponder sensitivity, the RFID system will not work.

It was shown that the maximum field strength is located around the middle of the ground plate of a goods carrier when using an antenna integrated into forks. This ensures proper function when using a forklift truck to identify RFID transponders on this position. To communicate with a transponder mounted on a stock shelf an antenna integrated into the forks carrier is preferred.

Forklift trucks are used in harsh environments with mechanical stress for every component. Also, the antenna design must be robust to prevent damages. The RFID transponder orientation must be fixed when using antennas with a linear polarization. It must be considered that a fork is changed several times in lifecycle of a forklift truck. It must be accepted by the customer that an “intelligent” fork is more expensive than a standard fork.

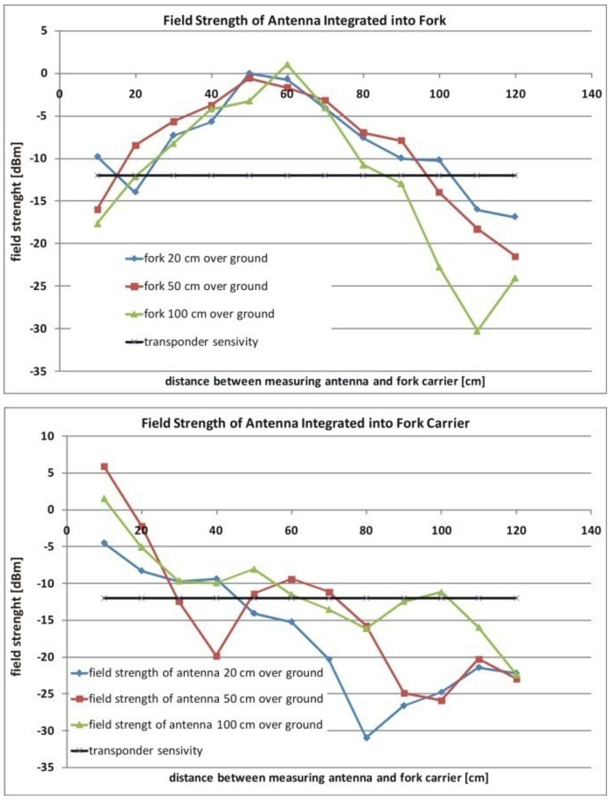

Figure 8 Measuring field strength at the middle of the grounds plate of a box cage with antenna integrated into fork (above) and antenna integrated into forks carrier (below)

6. ACKNOWLEDGEMENT

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