An automated static test bench for UHF-RFID ear tags

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Abstract

UHF-RFID offers a wide range of applications in animal husbandry, e.g. monitoring of group-housed animals and localization in terms of activity monitoring. UHF transponders and readers are currently in development especially for use with cattle and pigs within a joint research project. A static test bench was developed for the purpose of measuring detection area and signal strength characteristics of different transponders. The test bench allows for the automated measurement of the RSSI in a defined coordinate grid. With this data, a differentiated analysis of the detection area of transponders is possible. The influence of methodical parameters, e.g. grid spacing and order of coordinates, as well as reproducibility of the measurements, were examined in pretests. Additionally, effects of the transponder holder were determined. Results showed good reproducibility and suitability of the current test setup. In the next step, the test bench will be used for comparative transponder tests and pretests for the development of a system for animal monitoring and localization.

Keywords: UHF-RFID, electronic animal identification, transponder, test bench

1 Introduction

Electronic animal identification is well established in modern animal husbandry. Its applications range from the mandatory tagging of small ruminants to assure animal traceability (Schwalm & Georg, 2011) through the use of identification data of dairy cows or sows for farm management (Ruiz-Garcia & Lunadei, 2011; Trevarthen & Michael, 2008), to complex data recording on research farms (Bütfering, 2011). In addition to standard identification systems, which are compliant to ISO 11785 and based on low-frequency radio frequency identification (LF-RFID, 134.2 kHz), research has been carried out on the use of RFID in the high-frequency band (HF-RFID, 13.56 MHz) (Hessel & Van den Weghe, 2013; Maselyne et al., 2014) and ultra high-frequency band (UHF-RFID, 860-960 MHz) (Hogewerf, Dirx, Verheijen, & Ipema, 2013; Mun Leng Ng, Kin Seon g Leong, Hall, & Cole, 2005; Stekeler, Herd, Rößler, & Junghuth, 2011) in the last few years. This is because anticollision procedures are applicable to LF-RFID systems only to a very limited extent. Furthermore, the reading range of LF transponders is a maximum of 1 m. In comparison to this, a quasi-simultaneous reading of multiple transponders is already possible with HF-RFID (Hessel & Van den Weghe, 2013). Along with the simultaneous recording of tags, a substantially higher read range beyond 3 m can be achieved with passive transponders in the UHF band (Ruiz-Garcia & Lunadei, 2011). This results in a great variety of possible applications for UHF transponders in animal husbandry, such as the simultaneous detection of large animal groups, monitoring of feeding behavior or localization for the purpose of activity monitoring in group-housed animals. However, disadvantages, such as absorption in water or body tissue and also reflections on electrically conducting surfaces, are associated
with the higher operation frequency. Thus, transponder antennas have to be optimized for
the use in animals (Finkenzeller, 2012; Kern, 2007).

UHF transponders are currently in development especially for the identification of cattle and
pigs in a joint research project together with readers for simultaneous detection and
localization (Forschungsinformationssystem Agrar/Ernährung, 2012). Experimental models of
different transponder types are tested in the laboratory before the application in animals for
the selection of suitable antenna designs, with a special regard to sufficient reading range,
appropriate directional radio pattern and readability close to water. In addition to dynamic
experiments, in which transponders are moved through the antenna field of a reader at a
defined speed (Hammer, Adrion, Gallmann, & Jungbluth, 2013), static tests are conducted to
measure the detection area of transponders. For this purpose, the transponder has to be
positioned in the antenna field of a reader at defined coordinates of a grid in different
orientations (Kern, 2007). An automated test bench was constructed to conduct these
time-consuming experiments efficiently. The aim was to build the test bench in a way that also
allows for the testing of transponders in other RFID frequency bands. Beside the analysis of
detection areas, the test of other applications, e.g. monitoring of feeding place or localization
of transponders, had to be possible under definable test conditions. In the following, the
setup, function and test of methodic parameters of this test bench will be described.

2 Materials and methods

2.1 Setup and function of the test bench

The main components of the test bench are two linear drives spanning a horizontal operating
area of 350 cm by 350 cm, 34 cm above the floor. They form an x- and y-axis of the area
within so that every coordinate can be approached by a slide mounted on the x-axis. The
y-axis carries and guides the x-axis in its center (Figure 1). A pillar 125 cm high made of
extruded polystyrene foam (XPS, Styrodur®) is mounted on the slide and serves as a holder
for the transponder ear tags. This material was chosen because of its flexibility and its
minimal influence on the electromagnetic radiation of the reader \(\varepsilon_r = 1.03\) (Webster & Eren,
2014). It is also used for mounting purposes in standardized transponder tests in anechoic
chambers (EECC European EPC Competence Center, 2011). The ear tags can be
positioned in any orientation to the antenna of the reader with exchangeable blocks of
polystyrene foam on top of the pillar. Thus, the transponders are located 165 cm above the
floor during the experiments. Single or multiple reader antennas can be placed at variable
locations and in different orientations around the test bench according to test requirements.
Placement of the antennas at a greater distance from the test bench is also possible to
ensure measurements of transponders with a high read range at maximum transmission
power of the reader. The accuracy of the positioning of the transponders relative to the
reader antenna is about 1 cm, taking into account all sources of error, especially the
allowance for clearance of the parallel guide of the x-axis, the placement of the transponders
in the holder and the alignment of the reader antennas.
The servomotors of the linear drives and the reader are operated by a central controller. The
user can configure the test bench, call up, start, and run tests fully automated with a software
application. The tests are generated in advance with configuration software and are stored in
a central test database (Phenobyte GmbH & Co. KG, Ludwigsburg, Germany). Important
parameters, such as the coordinate area tested, grid spacing, transponder number,
transponder orientation, reader configuration, and antenna orientation, are specified at this
working step. All readings of a test are stored in the database together with the coordinates
where the readings were registered.
2.2 Test procedure and data measured

A test implies the measurement of one transponder in one orientation with a defined configuration and position of the reader. The specified coordinate grid is processed automatically by the controller during a test. In this procedure, the coordinates can be approached in a randomized, ascending or descending order on both axes. The slide is stopped at each coordinate. Then, after a short waiting time (<1 s), the reader is switched on for a defined time (0.1 s to 65 s) and the readings of the transponder are registered during this time. The number of readings is mainly dependent on different reader settings, e.g. the interval in which the inventoried flag of the transponder is reset during the anti-collision procedure. However, the energy supply of the transponder also has an influence on the number of readings per unit of time. Fewer readings are obtained at the edge of the detection area. The reader measures an indicator for the received power of the transponder signal (Received Signal Strength Indicator, RSSI) with every reading event. This value depends mainly on the distance $d$ between the reader antenna and transponder (Equation 1) (Choi, Lee, Elmasri, & Engels, 2009; Finkenzeller, 2012). Moreover, the supply power of the reader antenna $P_r$, the antenna gains of the reader $G_r$ and transponder $G_t$, the wavelength $\lambda$, and the backscatter loss ratio $L$ influence the RSSI measured. In the following, the RSSI is shown both as a non-dimensional power level in decibel milliwatt (dBm) and in milliwatt. The conversion from decibel into milliwatt can be calculated with Equation 2. The mean of the RSSI from all readings at each coordinate is calculated for data analysis. A differentiated description of the reading range or detection area of the transponder is possible regarding the RSSI. Additionally, the distance between transponder and reader antenna can be determined by respective fitting of a calibration curve.

$$\text{RSSI} = P_r G_r^2 G_t^2 \lambda^4 L (4\pi d)^{-4} \quad (\text{Eq. 1})$$

$$\text{RSSI} [\text{mW}] = 10^{\text{RSSI [dBm]} / 10} \quad (\text{Eq. 2})$$
2.3 Methodic pretests

Pretests were conducted to determine sufficient test routines after the start of operation of the test bench. At first, the influence of test parameters, such as the order of coordinates and the grid spacing, was tested as well as the reproducibility of the results. Additionally, the influence of the polystyrene transponder holder on the results was examined. An overview of the parameters analyzed and the variants chosen is shown in Table 1.

Table 1: Overview of parameters analyzed.

<table>
<thead>
<tr>
<th>Parameter Tested</th>
<th>Variants</th>
<th>Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid spacing</td>
<td>10 cm</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>17 cm</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>25 cm</td>
<td>2</td>
</tr>
<tr>
<td>Order of coordinates</td>
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</tr>
<tr>
<td></td>
<td>In lines, y ascending</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>In lines, y descending</td>
<td>2</td>
</tr>
<tr>
<td>Reproducibility of the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>results</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Influence of the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>transponder holder</td>
<td>Ear tag in open air</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ear tag completely embedded in polystyrene foam</td>
<td>2</td>
</tr>
</tbody>
</table>

2.4 Pretests: Materials and Methods

A commercially available passive transponder label (UPM Web™) which is optimized for applications in logistics was used for the pretests. It has a high maximum reading range of about 5 to 9 m (UPM RFID, 2011). Additionally, its directional radio pattern is symmetrical because of its folded dipolar antenna structure (Detlefsen & Siart, 2009; UPM RFID, 2011). This offers great advantages for methodic experiments. The transponder was glued onto a cattle ear tag (FlexoPlus, Caisley International GmbH, Bocholt, Germany) for the pretests. It was fixed in the holder with its front side directed to the reader and turned 90 degrees to the left. Thus, the plane of maximum radiation power of the transponder antenna was in line with the center of the reader antenna. This transponder will serve as a reference type for all tests with transponders developed in the project. The reader used in the pretests was a functional model (deister electronic GmbH, Barsinghausen, Germany; Agrident GmbH, Barsinghausen, Germany) with an internal antenna. It was installed vertically 165 cm above the floor and centrally in front of the test bench in the origin of the coordinate system, shown in the results section of this article. The center of the reader antenna was at the same height as the center of the transponder. The effective radiated power (ERP) was 1 W with circular polarization and a beam width of 90 degrees. Communication between reader and transponder followed the EPC Class 1 Generation 2 specifications (GS1 EPCglobal Inc., 2013).

Unless one of these parameters was deliberately changed, the following settings were used for all pretests. Grid spacing was 17 cm. The coordinate range lay between -170 cm and 170 cm on the x-axis and between 61 cm and 401 cm on the y-axis. The coordinates were processed in lines, driving in a positive y-direction and starting at positive x-values in each case (“in lines, y ascending”). The waiting time and reading duration at each coordinate were 1 s. The interval for a reset of the inventoried flag of the transponder was set to 200 ms to limit the number of readings. Consequently, transponders could not be read more than five times per coordinate.

3 Results and Discussions

The analysis of the tests with varied grid spacing showed a coincidental reproduction of the RSSI curve at the line x = 0 in all variants. However, the 25 cm grid was too coarse for graphical analysis of the detection area with interpolated contour plots. Hence, grid spacing
in the range of 15 cm is considered suitable for all future tests. In this case, the duration of one test is about one hour. Only exact analyses of RSSI characteristics demand a finer grid. The detection area of the transponder UPM Web is presented in Figure 2 as a contour plot and point diagram to illustrate the results using a 17 cm grid. A decline of the RSSI up to a distance of about 250 cm from the reader antenna in a y-direction is clearly visible. The RSSI is more strongly influenced at a greater distance by reflections and resulting interferences in the surroundings of the test bench. Additionally, the lower limit of the measuring range of the reader is reached here. This limit can be estimated from the measurements between -60 dBm and -70 dBm (1·10⁻⁶ mW and 1·10⁻⁷ mW, respectively). Reading gaps in the outer regions of the detection area are distinctly visible in both figures.

Figure 2: RSSI [dBm] in the detection area of the tag UPM Web, grid spacing 17 cm; a) contour plot (linear interpolation) and b) point diagram.

No influence of the order of coordinates on the experimental results was found. The standard deviation between the three variants at the line x = 0 was 0.4 dBm or 3.2·10⁻⁷ mW on average (Figure 3a). This good agreement of the results was achieved by switching off the antenna field of the reader between the measurements at two coordinates. When the reader is permanently transmitting, passive UHF transponders show the effect that their read range is higher when the transponder is moved out of the antenna field of the reader than in a movement into the field (hysteresis). This can be explained by the fact that the amount of energy required for activation of the transponder chip is higher than its threshold for deactivation (Knop, personal communication, 2014). Based on these findings the coordinates can be processed in a sorted order in all future tests. Thus, experiment time can be saved in comparison to tests with a randomized coordinate order.

The test presented in Figure 2 was repeated four times to test the reproducibility of the results (Figure 3b). The four repetitions of the RSSI measurements on the line x = 0 had a standard deviation at each coordinate of 0.5 dBm or 1.8·10⁻⁷ mW on average. Only the second repetition showed greater differences to the other measurements at two coordinates (78 cm and 95 cm). The values measured notably deviated from the ideal curve shape in distances to the reader of 129 cm, 197 cm and 231 cm. These disturbances in the course of the RSSI, which were caused by reflections in the test bench surroundings, occurred at identical coordinates in all four repetitions.

In summary, it can be stated that a good reproducibility of the results is ensured with the experimental setup and procedure chosen. Deviations are at the lower limit of the measuring range of the reader. However, a higher statistical accuracy may be obtained with repeated measures of different exemplars of one transponder type.
A comparison of the measurements with and without the polystyrene foam holder showed an increasing RSSI due to the influence of the polystyrene of 1.1 dBm on average on the line $x = 0$ (Figure 4). Accordingly, the values measured were increased by a factor of 1.3. The reason for this is probably a shifting of the resonance frequency of the transponder caused by the surrounding holder. The manufacturer of the transponder also discovered a higher reading range due to affixing the transponder on plastic (UPM RFID, 2011). This effect improves the reading range of the transponder when it is attached to the product that has to be identified. Nevertheless, extruded polystyrene foam is a favorable material in high-frequency experiments because there is hardly any material with such little electromagnetic influence. After the test, the holder was modified so that the ear tags are covered homogenously with polystyrene in all orientations to ensure a uniform influence on the transponders during the tests. In this way, the flexibility of this material can be utilized for the mounting of the ear tags accepting a tolerable influence on the measurements.
4 Conclusions

The suitability of the test bench presented for comparative measurements of detection areas of UHF transponder ear tags has been shown. The results are reproducible with the current experimental setup, but reflections in the surroundings of the test bench have an influence on the RSSI measurements. The robustness of the test methodology against these reflections will be tested in further experiments. Nevertheless, it seems possible to calculate calibration curves for the localization of transponders from the data. In the next step, comparative tests of different functional models of UHF transponder ear tags will be conducted. These transponder ear tags are optimized especially for the identification of cattle and pigs. In the course of these experiments, the influence of water close to the transponders on the detection area and the RSSI will be examined. Additionally, tests are planned which focus on a spatial limitation of the detection area in different positions and orientations of the reader antenna. The main parameters for observation of barn areas, such as feeding and resting places, will be obtained in these experiments before on-farm tests. Finally, the development of a system for the localization of UHF transponder ear tags will follow.

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6 References


