Influence of different setups of a dynamic test bench on the readability of UHF-transponders

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Abstract

The identification of pigs and cattle is currently based on a normal visual ear tag, but electronic animal identification is gaining in importance. The electronic identification of sheep and goats has been obligatory in the European Union since 2012. It is a question of time until this identification system becomes obligatory in other animal species, such as cattle and pigs. One possibility of electronic animal identification is an ultra-high-frequency (UHF) ear tag. The benefits of this frequency band are the high range, the possibility of simultaneous reading and a high data transmission rate. First systematic laboratory tests will be carried out before testing these UHF ear tags in practice. Therefore, a dynamic test bench was built. The aim of the experiments with this test bench was to compare different UHF ear tags under standardised conditions and select the most suitable for practical use. This test bench had a variety of settings, such as velocity, reader settings, transponder orientation, number of rounds, and material of the transponder holder. The influence of these parameters was to be tested and the development of one method to evaluate the quality of the transponder was sought. The experiments showed that the number of rounds (10 vs. 15 vs. 20) had no significant influence on the average readings per round of the different transponder types. Differences between the transponder holders (polyvinyl chloride vs. extruded polystyrene) were shown for one transponder type, whereas significant difference between the velocities ($1.5\,\text{m}\,\text{s}^{-1}$, $3.0\,\text{m}\,\text{s}^{-1}$) was determined for all transponder types.

Keywords: RFID, UHF, test bench, animal identification, ear tags

1 Introduction

Electronic animal identification has gained in importance over the last few years. This technology provides great benefits not only regarding process control on farms, animal or disease monitoring, prevention of fraud, and registration of movements, but also other administrative purposes (Artmann, 1999; Geers, 1994). The identification of individual animals using radio waves is one possibility of electronic animal identification and is known as radio-frequency identification (RFID).

Today, RFID is regarded as a key technology, which covers a wide spectrum (Klindtworth, 2007). The technology behind this system is based on the communication between a transponder (attached to the animal) and a reader (mobile or static) via radio waves. Both transponder and reader contain an antenna for transmission and reception, and a chip for processing the radio signals. The communication between both units occurs remotely with coded radio waves, which are decoded by the respective electronic circuit (Finkenzeller, 2012; Kern, 2006). Distinctions are made between active RFID transponders which generate their power from an integrated battery and passive RFID transponders with no battery. The
passive transponders receive their power from the signal transmitted by the antenna (Jansen & Eradus, 1999; Zhu, Mukhopadhyay, Kurata, 2012). Passive systems are predominantly in use in animal production, apart from a few applications. Three frequency bands are mainly usable in animal identification: low-frequency (125-135 kHz), high-frequency (13.56 MHz) and ultra-high-frequency (868 MHz, 915 MHz) (Kern, 2006). The electronic identification of sheep and goats has been obligatory in the European Union since 2011 for all animals born after 31/12/2009 (EC No. 21/2004, amended by EC No. 1570/2007). The identification of pigs and cattle is currently based on a normal visual ear tag, but the replacement of a visual ear tag with an electronic ear tag is already permitted (EC No. 1760/2000). It is a question of time before the electronic identification system becomes obligatory for other animal species, such as cattle and pigs. Nevertheless, low-frequency (LF) systems may be described as state-of-the-art in animal husbandry (Fröhlich, Böck, Thurner, 2007).

1.1 Ultra-high-frequency RFID in animal husbandry

Another possibility of electronic animal identification are ultra-high-frequency (UHF) systems. UHF systems are increasingly used in other industries, such as the pharmaceutical and retail industries (Desmons, 2006; Impinj, 2006; Umstatter et al., 2012) as well as for the “identification of goods containing liquids or metal” (Catarinucci et al., 2013). The clear benefits of this frequency band are the high range, the possibility of simultaneous reading (anti-collision system) and a high data transmission rate (Baadsgaard, 2012; Finkenzeller, 2012; Umstatter et al., 2012). Because of their high absorption rate, such systems were considered as unsuitable for animal identification; however, over time, there were further developments in terms of performance and robustness (Catarinucci, Colella, Tarricone, 2012; Finkenzeller, 2012; Stekeler, Herd, Jungbluth, 2011). There have only been a few projects testing UHF for animal identification in pigs, sheep, cattle, and deer (Cooke, Diprose, Brier, 2010; Hartley, 2013; Hogewerf, Dirx, Verheijen, Ipema, 2013; Swedberg, 2012; Taylor, 2013). In these projects, the UHF transponder was tagged to the animal in the form of a rigid or flexible ear tag. The material of the item to which the tag was attached or embedded, the size and stability, the orientation of the tag to the reader, and the environment in which the system operates were named as reasons for performance degradation and reliability problems (Baadsgaard, 2012; Chawla & Ha, 2007).

1.2 Test benches

Test benches are well-suited to test transponders under laboratory conditions. Wehking, Siepenkort, and Rahn (2007) built a test bench to test UHF transponders for application in the logistic. That test bench consisted of a nine-metre haulage road with a conveyor speed of 0.5 m s\(^{-1}\). Loading units up to a weight of 300 kg could be examined. There were two UHF antennas centred on both sides of the conveyor and one LF antenna mounted. On this test bench, mainly the transponder orientations (2- and 3-dimensional) and the content of small load carriers could be varied. Ten thousand cycles were performed for each test series (Wehking, Siepenkort, Rahn, 2007). In the agricultural sector, Mc Carthy, Ayalew, Butler, McDonell, and Ward (2009) developed a test bench similar to Wehking et al. (2007). The movement of different packaging boxes, to which the transponders had been attached, was facilitated with a Belcon Mini variable-speed conveyor belt system. The boxes were filled with atmosphere-packaged meat. One empty box was used for reference purposes. The arrangement of the transponders on the boxes, the direction of motion, the velocity, and the antenna-transponder distance could be varied (Mc Carthy, Ayalew, Butler, McDonell, Ward, 2009). Kern (2006) described simple methods of testing for UHF transponder-reader applications for the RFID user. Reading ranges, reading rates and coupling curves can be determined with these different test benches. However, Kern (2006) emphasised that all of these test benches were made for practical applications. Measuring accuracy and repeatability do not correspond with scientific approach (Kern, 2006). An anechoic chamber should be used to test UHF transponders under real standardised conditions in an environment free of reflection and RF disturbances. The European EPC Competence Centre
(2011) tests transponders in an anechoic chamber which “consists of a mechanical test bed and a RF test apparatus”. Both are operated by a controlling unit. This “setup allows test sequences without interaction of test personnel” (EECC, 2011). Derbek, Steger, Weiss, Preishuber-Pflügel, and Pistauer (2007) also carried out their experiments on this breadboard construction. They collected sensitivity threshold, read range and backscatter range of various transponders in a band from 800 MHz to 1 GHz. Directional characteristics of the transponder were analysed by a controllable turntable (Derbek, Steger, Weiss, Preishuber-Pflügel, Pistauer, 2007).

1.3 Objectives

This project is concerned with the production and testing of in-house designed flexible UHF ear tags. Before testing these UHF ear tags in practice, first systematic laboratory tests will be carried out. One central part of the laboratory tests will be conducted with a dynamic test bench. The aim of this test bench is to produce an environment within which the quality of an UHF transponder can be reproducibly tested. A proper methodology and test bench settings have to be calculated for testing different UHF ear tags under standardised conditions. The hypothesis of this study was that the number of readings per round differs in terms of transponder type and test bench settings. With the aid of the dynamic test bench, the influence of the velocity, the number of rounds, the materials of the ear tag holder, the transponder orientation and the reader settings to the number of readings per round could be analysed. This publication focusses on the influence of the velocity, the number of rounds and the materials of the ear tag holder.

2 Materials and methods

2.1 Construction of the test-bench

Traunecker et al. (2012) described a dynamic test bench which constitutes the basis of this breadboard construction. The dynamic test bench consists of a right-angled timber frame secured by metal elbow brackets at the corners (Fig. 1). These elbow brackets are used to secure the axes and V-belt pulleys. One of the four V-belt pulleys is driven by a direct current transmission motor (24Volt, RE40/GP42C, Maxon Motor). Thus, a variable stepless adjustment of the V-belt speed is possible.

Figure 1 – Simplified model of the test bench construction
The transponder ear tags can be fixed into a holder which can be easily attached to or removed from the V-belt. One type of holder is made of polyvinyl chloride (PVC) and the other is made of extruded polystyrene (XPS, Styrodur®) (Fig. 3). XPS was chosen because of its low influence on electromagnetic radiation (Webster & Eren, 2014). Three transponder ear tags could be attached to the PVC holder. Only one transponder ear tag per holder is used in the following experiments to eliminate a possible interaction of transponders during the reading process. Six different transponder orientations (reader to ear tag) are practicable with the holders currently used (Fig. 2).

![Figure 2 - The six possible transponder orientations](image)

![Figure 3 - Transponder holder](image)

The rounds are counted by a lap counter using a light barrier. The reflector of the light barrier is also attached to the V-belt right in front of the transponder holder. Every circuit the transponder passes the reading area of the reader, the number of readings is recorded. The reader is located at ground level at a fixed point on one of the long sides of the test bench and radiates upwards. Any kind of UHF reader could be used here. A reader with a circular radiation and an opening angle of 90° is used for the experiments presented. It works with a total output of one watt (Effective radiated power). The distance between the reader and transponder could be varied by changing the length of the test bench legs. The distance between reader and transponder is fixed at 105 cm in the experiments presented. All of the test settings are managed by software developed in-house and are stored in a database. Several transponders are used (A, A1, B1, B2, B3, B3-4, B4, B4-4, C0, C1, ZT) to test the effects of various test bench settings sufficiently. These transponders mainly differ in their antenna construction (antenna length, antenna arrangement and electrical ground) and, therefore, in their directional radio pattern. Transponder type B1, B2, B3, and B4 shows the structure of a PIF antenna. Transponder type B3-4 and B4-4 represent a second generation of B3 and B4. Transponder type A is a commercially available transponder with a dipole antenna. It was glued onto a normal plastic cattle ear tag by the authors. Transponder type ZT has the same structure as type A, but it was included in a plastic ear tag by the manufacturer.

### 2.2 Statistical evaluation and experiments

An ANOVA was used to test whether the velocity, number of rounds and holder materials have an influence on the number of readings per round. The average of readings per round was used as a dependent variable in all studies.

\[
\text{Average of readings per round (ARR)} = \frac{\sum \text{Number of readings}}{\sum \text{Number of rounds}} \quad \text{(for all copies of one type)} \quad (1)
\]

The parameters investigated were set as fixed effects. The number of rounds one transponder ear tag was driven on the dynamic test bench only represented measurement repetitions and no real repetitions. The real repetitions were caused by the copies of the transponder types. Statistical significance was considered at P < 0.05. All calculations were carried out with IBM® SPSS® Statistics 22.
Three experiments with eight different transponder types (A, B1, B2, B3, A1, B4, C0, and C1) in total were carried out to measure the influence of the velocity. Six copies of each type in six orientations were tested. Two velocities (1.5 m s\(^{-1}\); 3.0 m s\(^{-1}\)) were compared.

In order to test whether the number of rounds a single transponder ear tag is driven on the test bench has an influence on the ARR, three different numbers of rounds were compared (10, 15 and 20). The reason why this experiment was conducted is the time-saving for further experiments. Here, six types with six copies each were tested in six orientations and one velocity (3.0 m s\(^{-1}\)).

Whether the holder material of the test bench has an influence on the electromagnetic radiation and, thus, on the ARR should be analysed by an experiment with three transponder types and six copies of each. Six orientations and two velocities (1.5 m s\(^{-1}\); 3.0 m s\(^{-1}\)) were used. There was a comparison between XPS and PVC.

3 Results and Discussion

3.1 Influence of velocity

On the basis of Table 1, it can be seen that the velocity of the transponder has a significant influence on the ARR. Experiments one to three showed that the ARR is significantly higher at a velocity of 1.5 m s\(^{-1}\) than at 3.0 m s\(^{-1}\). Obviously the velocity has an influence on the reading success. The type of transponder did not have an influence here.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Transponder</th>
<th>Velocity [ms(^{-1})]</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A, B1, B2, B3</td>
<td>1.5</td>
<td>14.3(^{a})</td>
<td>9.3(^{b})</td>
</tr>
<tr>
<td>2</td>
<td>A, A1, B4</td>
<td>3.0</td>
<td>12.0(^{a})</td>
<td>7.9(^{b})</td>
</tr>
<tr>
<td>3</td>
<td>A, C0, C1</td>
<td>1.5</td>
<td>13.7(^{a})</td>
<td>8.9(^{b})</td>
</tr>
</tbody>
</table>

Note: The average of readings per round (ARR) of a transponder type was used as a dependent variable. SD: Standard deviation. N: Repetitions. \(a, b, \ldots\): different letters within a line indicate that values diverge significantly (P < 0.05)

The reason for that circumstance is probably the shortened length of stay of the transponder in the reading field of the reader. The maximum number of readings a transponder-reader system can achieve depends on several factors, such as data volume per transponder, data transmission rate and transponder distance (Kern, 2006; Wehking et al., 2007). That result has already been shown in other experiments with UHF transponders. Mc Carthy et al. (2009) also concluded that the readability of a transponder with higher velocity is more difficult. In their experiments, they attached the transponders to containers and placed them onto a conveyor belt travelling at 0.5 m s\(^{-1}\) and 1.0 m s\(^{-1}\). Here, an increased velocity from 0.5 m s\(^{-1}\) to 1.0 m s\(^{-1}\) showed a decreased mean detection rate from 62 % to 57 %. Penttilä, Sydanheimo, and Kivikoski (2004) described similar results that an increase in speed will result in a decreasing coupling capability of the system. UHF systems have an advantage compared to other systems due to the fact that they have a high data transmission rate and the possibility of detecting a high number of transponders per time unit (Clasen, 2007).

3.2 Influence of number of rounds

When a large number of different transponders are to be tested, time looms large concerning the implementation of experiments. Statistically, the number of rounds are not real repetitions, but a higher number of rounds results in a lower variance of the ARR of one transponder type copy. The first completed experiments in the project were performed with 20 rounds per passage. With this experiment, whether there is a difference in the ARR between 10, 15 and 20 rounds should be tested.
Table 2 - Test of significance in terms of the number of rounds.

<table>
<thead>
<tr>
<th>Transponder</th>
<th>Number of rounds</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>A</td>
<td>14.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>B3-4</td>
<td>12.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>B4-4</td>
<td>15.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: The average of readings per round (ARR) of a transponder type was used as a dependent variable. SD: Standard deviation. N: Repetitions. a, b,…: different letters within a line indicate that values diverge significantly (P < 0.05).

The results of these experiments (Table 2) show that there is no significant difference between the number of rounds. It will be tested if there is a higher variance between the number of rounds. Ten rounds were used for the following experiments.

3.3 Influence of the transponder holder

Kern (2006) and Chawla and Ha (2007) described the influence of different materials as a reason for reading gaps in UHF systems. The influence of the readability of the transponder through environmental influences should be reduced to a minimum on the dynamic test bench. An experiment with two different holders was carried out to test whether the transponder holder has influence on the ARR or not. XPS should carry less weight than PVC, where an absorption of the electromagnetic radiation would be expected. Table 3 shows that no significant difference could be determined for transponder type A and C0, whereas transponder type C1 shows a difference.

Table 3 - Test of significance in terms of transponder holder.

<table>
<thead>
<tr>
<th>Transponder</th>
<th>Transponder holder</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PVC</td>
<td>XPS</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>31.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.4</td>
</tr>
<tr>
<td>C0</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.1</td>
</tr>
<tr>
<td>C1</td>
<td>2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Note: The average of readings per round (ARR) of a transponder type was used as a dependent variable. SD: Standard deviation. N: Repetitions. a, b,…: different letters within a line indicate that values diverge significantly (P < 0.05).

The results of this experiment could not be confirmed in the literature. Wheking et al. (2007) glued transponders onto small charge carriers filled with aluminium, steel, chipboard, or fibreboard. Empty charge carriers were used for reference purposes. Reductions of 20 % for aluminium, steel and water were shown. A reduction of 5 % was shown for chipboard and fibreboard. However, the location of the transponders on the small charge carrier played a decisive role. Derbek et al. (2007) also attached their UHF transponders to different mounting materials and analysed the sensitivity and read range. It was shown that, depending on the frequency (800 to 1000 MHz), the read range differed between free air and metal, and was the lowest with water and metal (Derbek at al., 2007). For reference purposes in other experiments XPS was used, because of its minimal influence on electromagnetic radiation (ε<sub>r</sub> = 1.03) (Derbek et al., 2007; EECC, 2011; Webster & Eren, 2014). Despite the different results XPS will be used in further experiments because of the proved minimal influence on electromagnetic radiation.

4 Conclusions

It could be shown that the methodology of the dynamic test bench can be used to show differences between transponder types. Their behaviour in terms of various velocities, number of rounds and transponder holder materials could be reliably determined. All of these results were repeatable. Because of the good repeatability the need of an anechoic chamber
is not seen. Further experiments to the influence of the transponder orientations and reader settings as well as the differences between various transponder types will be published in another publication. Also the comparison between laboratory and practical results will be drawn.

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6 References


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