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Methodology of a dynamic test bench to test ultra-high-frequency transponder ear tags in motion

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ABSTRACT

The electronic identification of sheep and goats has been obligatory in the European Union since 2010 by means of low-frequency radio-frequency identification systems. The identification of pigs and cattle is currently based on a visual ear tag, but electronic animal identification is gaining in importance. The European Union already offers the additional use of electronic identification systems for cattle in their council regulation. Besides the low-frequency radio-frequency identification, an ultra-high-frequency ear tag is a possibility for electronic animal identification. The benefits of the latter frequency band are the high range, the possibility of quasi-simultaneous reading and a high data transmission rate. First systematic laboratory tests were carried out before testing the ear tags in practice. Therefore, a dynamic test bench was built. The aim of the experiments presented in this study was to compare different ear tags under standardised conditions and select the most suitable for practical use. The influence of different parameters was tested and a standard test procedure to evaluate the quality of the transponder ear tag was developed.

The experiments showed that neither the transponder holder material (polyvinyl chloride vs. extruded polystyrene) nor the reader settings examined (triggered read vs. presence sensing) had a significant influence on the average of readings of the different transponder types. The parameter 'number of rounds' (10 vs. 15 vs. 20) did not show a significant effect either. However, significant differences between speed (1.5 m s^{-1}, 3.0 m s^{-1}), transponder orientation and the fourteen transponder types were found. The two most suitable transponder ear tags for cattle and pigs have been determined by comparison.

1. Introduction

Electronic animal identification in livestock farming has gained in importance over the last few years. The identification of individual animals using radio waves is one possibility of electronic animal identification and is known as radio-frequency identification (RFID). 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 for other administrative purposes (Artmann, 1999; Doluschitz et al., 2006; Geers, 1994). The RFID technology will be explained more precisely in the following.

1.1. RFID technology

RFID is regarded nowadays as a key technology which covers a wide spectrum of applications (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 reader antenna (Jansen and Eradus, 1999; Zhu et al., 2012). Passive systems are predominantly in use in animal production. Three frequency bands are mainly usable in animal identification: low-frequency

Abbreviations: ARR, average of readings per round; ERP, effective radiated power; PS, presence sensing; PVC, polyvinyl chloride; TR, triggered read; XPS, extruded polystyrene.

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(120–135 kHz), high-frequency (13.56 MHz) and ultra-high-frequency (868 MHz, 915 MHz) (Kern, 2006).

1.2. Low-, high- and ultra-high-frequency RFID in animal husbandry

The electronic identification of sheep and goats has been obligatory in the European Union for all such animals born after 31/12/2009 (EC, 2004). The identification of pigs and cattle is currently based on a visual ear tag, but replacement of the latter with an electronic ear tag is already permitted for cattle (EC, 2000). Currently, systems working with low-frequency (LF) are state-of-the-art in animal husbandry (Fröhlich et al., 2007). The structure of the animal number and the functional principle are controlled by the ISO standards 11784 and 11785 (ISO 11785, 2008; ISO 11784, 2010). The combination of the country code (ISO 3166, 2013) and the national animal number ensures a unique number for an individual animal (Schwalm et al., 2009). Besides the unique number, which is obligatory for the legal regulations, free memory on the ear tag can be used for further management applications, such as the recording of animal characteristics (sex, size, weight) or medical treatments.

The farmer has many possibilities to attach the transponder to the animal. Starting with a rather expensive collar, a transponder integrated into a bolus or an encapsulation for implantation, and ending up with a transponder attached to an ear tag. There are many different agricultural applications on the market using LF systems. Low-frequency is mainly used in extensive husbandry conditions with sheep and goats to improve the traceability of individual animals and to reduce the risk of spreading diseases (Ribó et al., 2001). Low-frequency is very useful in sow keeping and dairy farms when combined with automatic feeding stations. An individual feeding schedule for each animal and stage can be implemented and food intake can be measured (Blair et al., 1994; Chapinal et al., 2008). This technique is offered by many companies for barn equipment. Junge et al. (2012) showed that the registration of drinking events and the calculation of a minimal walking distance for each sow is also feasible with LF technology (Junge et al., 2013). Using this information, as well as a preparation of the data by software, the health status of each individual animal could be monitored. The biggest benefit of this technology is the low susceptibility against shadowing by metal or liquids. Problems arise when reading many animals at the same time and over a greater distance (Caja et al., 2005; Thurner and Wendl, 2007), whereby some LF transponders with an anti-collision algorithm have already been tested by Burose et al. (2010). Even if the so-called anti-collision systems, where quasi-simultaneous reading of different transponders is possible, can be used with basically all RFID systems, the reading rate will be reduced (Burose et al., 2010).

Another possibility for animal identification are high-frequency (HF) systems. The HF systems offer a higher data transfer rate than LF systems (Chawla and Ha, 2007). Thus, the identification of moving transponders is feasible even when using anti-collision algorithms. The HF systems are mainly used in access control systems, smart cards and different logistic areas (Thurner and Wendl, 2007). Fröhlich et al. (2007) think that the commitment of HF transponders in animal identification would have its benefits in the industry-wide movement of goods from the point of animal production right through to transportation and slaughter. Hessel et al. (2008) used a self-made circular HF antenna on top of two different feeding troughs to read ear tags in piglets. The reading rate of both feeding troughs was around 97%. The high activity of the piglets, the water content of their bodies, the material of the feeding station and the orientation of the transponder to the antenna of the reader are seen as reasons for missed reading events (Hessel et al., 2008; Reiners et al., 2009). Further experiments with a round feeder were performed by Maselyne et al. (2014). Eight antennas connected to a single reader using a multiplexer were installed above the troughs of the feeders. The RFID system was validated by video observation of 20 focal pigs (two HF ear tags each). Therefore, several time window sizes were tested and examined. A sensitivity of 88.58% and a specificity of 98.34% were achieved (Maselyne et al., 2014).

A third possibility of electronic animal identification are ultra-high-frequency (UHF) systems. The 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 quasi-simultaneous reading (anti-collision system) and a high data transmission rate (Baadsgaard, 2012; Clasen, 2007; Finkenzeller, 2012; Umstatter et al., 2012). Such systems were considered as unsuitable for animal identification because of the high absorption potential of water in the UHF band; however, over time, there have been further developments in terms of performance and robustness (Catarinucci et al., 2012; Finkenzeller, 2012; Stekeler et al., 2011). There have only been a few projects testing UHF for animal identification in pigs, sheep, cattle and deer (Baadsgaard, 2012; Cooke et al., 2010; Hartley, 2013; Hogewerf et al., 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 operated were named as reasons for performance degradation and reliability problems (Baadsgaard, 2012; Chawla and Ha, 2007).

1.3. Test benches for RFID transponders

Test benches are well-suited to test transponders under controllable and comparable conditions. Burose et al. (2010), for instance, built a test bench to analyse LF transponders with an ISO standard and with an anti-collision algorithm. This test bench consisted of a plastic slide which was drawn by a wire rope hoist on two wooden tracks. Using this test bench, the following parameters could be varied: the distance to the ground, the velocity, the number of transponders and the orientation of the transponder to the reader (Burose et al., 2010). Barge et al. (2013) also used a test bench to move LF transponders (HDX, FDX) through a reader field under standardised conditions. This test bench consisted of a wooden trolley pulled by a rubber belt and driven by an electric motor, simulating a group of animals passing a reader gate. Different combinations of transponders and velocity could be varied (Barge et al., 2013). Thurner and Wendl (2007) designed a test bench for testing HF transponders and readers. In this case, up to four parallel running V-belts clamped to two bicycle rims and powered by an electric motor carried the transponders through the reading field. Six holders carrying up to five transponders each were attached to one V-belt. The height of the reader, orientation of the transponder, velocity and direction could be varied on this test bench (Fröhlich et al., 2007; Thurner and Wendl, 2007). Wehking et al. (2007) built a test bench to test UHF transponders for application in logistics. Their test bench consisted of a nine-metre haulage road with a conveyor speed of 0.5 ms^{-1}. Loading units up to a weight of 300 kg could be examined. There were two UHF antennae centred on top of both sides of the conveyor. Additionally, one LF antenna was centred on each long side of the conveyor. On this test bench, mainly the transponder orientations (two- and three-dimensional) and the content of small load carriers could be varied. Ten thousand cycles were performed for each test series (Wehking et al., 2007). McCarthy et al. (2009) developed a test bench in the agricultural sector similar to Wehking et al. (2007). The movement of different packaging boxes, to which the transponders had been attached, was facilitated with a 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 (McCarthy et al., 2009). Kern (2006) described simple methods of testing for LF, HF and UHF transponder-reader applications for the RFID user. Reading ranges, reading rates and coupling curves could be determined with these different test benches. However, Kern (2006) emphasised that all of these test benches were especially made for practical applications, by which limitations concerning accuracy and repeatability may occur. 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 (EECC, 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 et al. (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 et al., 2007).

1.4. Objectives

This study is part of a research project which is concerned with the production and testing of in-house designed flexible UHF ear tags for animal identification. First systematic laboratory tests were carried out before testing these UHF ear tags in practice. One central part of the laboratory tests was conducted with a dynamic test bench. The aim of this test bench was to produce an environment within which the quality of an UHF transponder can be reproducibly tested. A proper methodology and test bench settings had to be determined for testing different UHF ear tags under standardised conditions. The hypothesis of this study was that the number of readings achieved on the test bench differs in terms of transponder type and test bench settings. The results should give a reliable assessment of the quality of a transponder under laboratory conditions.

With the aid of the dynamic test bench, the impact of the parameters

- speed (1.5 m s^{-1} vs. 3.0 m s^{-1}),
- number of rounds (10 vs. 15 vs. 20),
- material of the ear tag holder (PVC vs. XPS),
- reader setting (TR vs. PS),
- transponder orientation (six orientations 1–6), and
- transponder type (fourteen types)

on the number of readings per round were analysed.

2. Materials and methods

2.1. Construction of the test bench

Traunecker et al. (2012) described a dynamic test bench which constituted the basis of this breadboard construction. The dynamic test bench consisted of a rectangular timber frame secured by metal elbow brackets at the corners (Fig. 1). These elbow brackets were used to secure the axes and V-belt pulleys. One of the four V-belt pulleys was driven by a direct current transmission motor (24 V, RE40/GP42C, Maxon Motor). Thus, a variable stepless adjustment of the V-belt speed was possible.The transponder ear tags could be fixed into a holder which could be easily attached to or removed from the V-belt.

One type of holder was made of polyvinyl chloride (PVC) and the other was made of extruded polystyrene (XPS, Styrodur®) (Fig. 2). The XPS was chosen because of its low influence on electromagnetic radiation (Webster and Eren, 2014). Three transponder ear tags could be attached to the PVC holder. Only one transponder ear tag per holder was used in the following experiments to eliminate a possible interaction between transponders during the reading process. Six different transponder orientations were feasible with the holders currently used (Fig. 3). All of the main orientations between transponder and reader were tested.

The transponders were tested during several rounds. The rounds were counted by a lap counter using a light barrier. The reflector of the light barrier was also attached to the V-belt right in front of the transponder holder. The number of readings was recorded each circuit the transponder passed the reading area of the reader.

The reader was located at ground level at a fixed point on one of the long sides of the test bench and radiated upwards. Any kind of UHF reader could be used here. A reader with an internal antenna emitting circular polarised radiation with an opening angle of 90° was used for the experiments presented. A robust IP67 housing protected the integrated antenna and the electronics of that reader. The reader adjusted itself to its environment with an auto-tune function. It worked with an effective radiated power (ERP) of one watt where the antenna gain is already included and a frequency between 865 and 868 MHz (EU). Different reader settings were chosen by changing the software settings. The reader setting "triggered read" (TR) was mostly used. At that setting, the antenna field was switched on and off manually. The transponder reset time (reset of the inventoried flag in the anti-collision procedure) was set at 100 m s. A second setting was selected to examine if another reader setting could be used for our purposes. At that setting, called "presence sensing" (PS), the antenna field switched on after a predetermined time (100 m s) and looked for a transponder answer. If no answer was detected, the antenna field turned off immediately. If a transponder answered, the antenna field remained active and the reader started the reading process. When the transponder left the antenna field, the field stayed on for another 500 m s and then turned back to the 100 m s sensing interval.

The distance between reader and transponder was fixed at 1050 mm in the experiments presented. All of the test settings were managed by software developed in-house and were stored in a database.

2.2. Transponder types and characteristics

Several transponders were used to test the effects of various test bench settings sufficiently. Not only the test bench settings, but also the quality of the transponders were analysed. The subjects of the investigation were passive transponder patterns developed in the project (A1, B1, B2, B3, B3-4, B4, B4-4, B5, C0, C1, C1-4, C2) and a commercially available passive UHF transponder cattle ear tag (ZT). One commercially available passive transponder was part of each experiment for reference purposes (A) (Table 1).

These transponders mainly differed in their antenna construction (antenna length, antenna arrangement and mass) and, therefore, in their directional radio pattern.

Transponder types B1, B2, B3 and B4 showed the structure of a PIF antenna. These antennas belonged to the group of dipole antennas, where the length of the antenna can be shortened if the mass

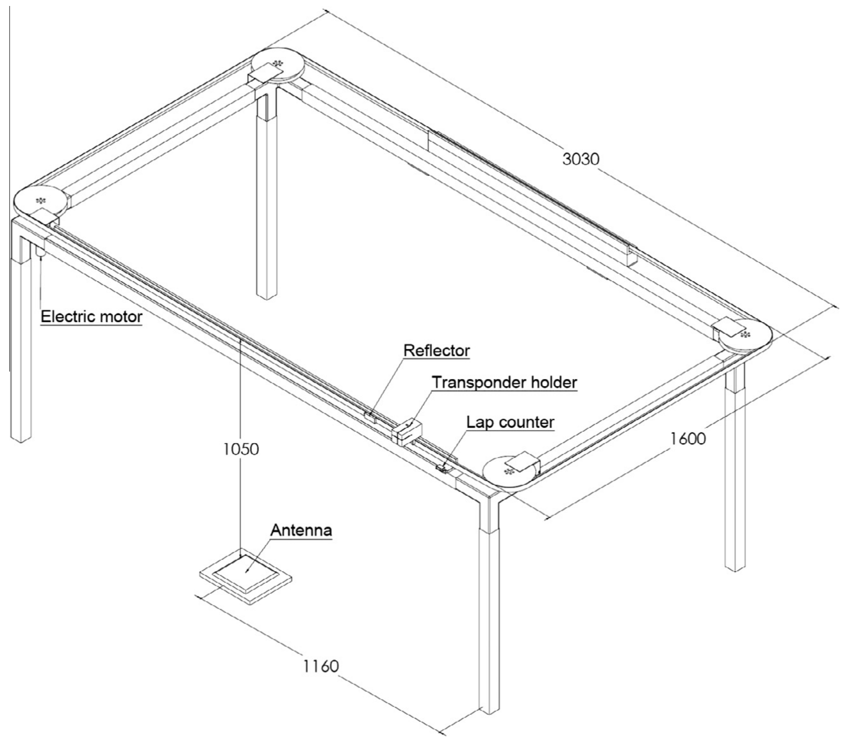


Fig. 1. Construction of the test bench (dimension in mm).

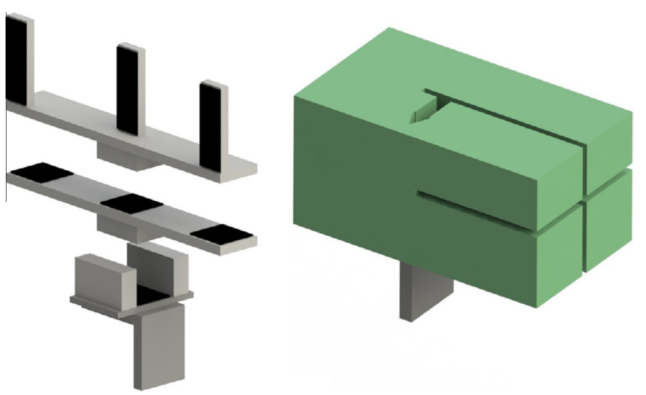


Fig. 2. Transponder holder. PVC holder (left), two attachments for six orientations. XPS holder (right), one holder for six orientations.

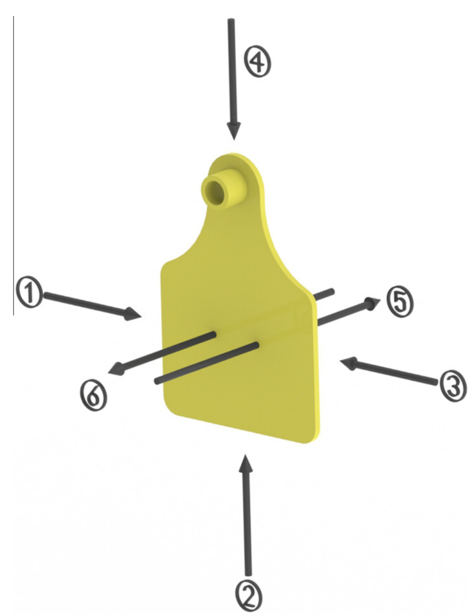


Fig. 3. The six possible transponder orientations. Reader radiates at the left narrow side (1), bottom side (2), right narrow side (3), top side (4), front side (5) and back side (6) of the ear tag.

area is big enough (Schoblick and Schoblick, 2005). The four transponder types named differed in the length of the last part of their antenna. The shorter the antenna of a transponder, the higher the transponder's resonance frequency. The aim of the different antenna constructions was the adjustment to the influence of ear tag material and ear tissue. These materials reduce the resonance frequency through their permittivity.

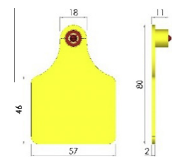
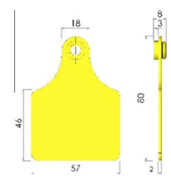
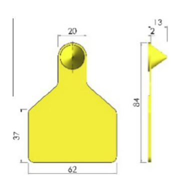
Transponder type B3-4 and B4-4 represented a second generation of B3 and B4 because the high potential of these types was observed in pretests. Transponder type B5 was a further development of B4-4. Here, the antenna length was shortened again to increase the resonance frequency. Furthermore, the label material was changed to polyimide foil for the second generation and transponder type B5.

Transponder type A was a transponder with a folded dipole antenna, which was originally made for use and application in a metal-rich environment. The suitability for use in a metal-rich environment is based on the pre-detuning of the antenna. The resonance frequency desired could be achieved by interaction with metallic substances underground. Transponder type A was glued onto a normal plastic cattle ear tag by the authors. Transponder type ZT had the same structure as type A, but it was included in a plastic ear tag by the manufacturer.

Types A, ZT, and B1 to B5 (including B3-4 and B4-4) had an appropriate size for cattle ear tags. The antenna structure of transponder type A1 was inspired by transponder type A, but was just minimised in size.

Types C0 and C1 showed the structure of a Pif antenna, too. They were also built in a smaller size for application in ear tags

Table 1
Overview of the passive transponder patterns and their characteristics used for the experiments. Figures show the dimensions of the ear tags used with the transponders.

Transponder type		Characteristics
A		– Commercially available – UPM Web, now SMARTRAC® – Folded dipole antenna – Reference transponder – Part of every experiment – Glued onto a cattle ear tag
A1	Ear tag design is equal to transponder type A	– Developed in-house – Sized for pig ear tags – Antenna design inspired by type A – Label material: layers of adhesive aluminium foil – Grouted into a cattle ear tag
B1, B2, B3, B4		– Developed in-house – Sized for cattle ear tags – Antenna design: Pif antenna – Variation of antenna length (shorter from B1 to B4) – Label material: layers of adhesive aluminium foil – Grouted into a cattle ear tag
B3-4, B4-4	Ear tag design is equal to transponder types B1, B2, B3 and B4	– Second generation of B3 and B4 – Different label material: polyimide foil
B5	Ear tag design is equal to transponder types B1, B2, B3 and B4	– Further development of transponder type B4-4 – Variation of antenna length – Label material: polyimide foil
C0, C1	Ear tag design is equal to transponder types B1, B2, B3 and B4	– Developed in-house – Sized for pig ear tags – Antenna design: Pif antenna – Variation of antenna length (shorter from C0 to C1) and design – Label material: layers of adhesive aluminium foil – Grouted into a cattle ear tag
C1-4	Ear tag design is equal to transponder types B1, B2, B3 and B4	– Second generation of C1 – Different label material: polyimide foil
C2	Ear tag design is equal to transponder types B1, B2, B3 and B4	– Further development of C1-4 – Variation of antenna length and design – Label material: polyimide foil
ZT		– Commercially available – Sized for cattle ear tags – UPM Web, now SMARTRAC® – Folded dipole antenna – Transponder embedded in an air-filled pocket between two plastic tabs

for smaller animals, such as pigs. Type C1-4 and C2 also represented a further development of type C1 with a higher resonance frequency and a polyimide foil as the label material.

2.3. Statistical evaluation and experiments

An analysis of variance (ANOVA) was used to test whether the speed, transponder orientation, number of rounds, holder materials and reader settings have an influence on the number of readings per round. The average of readings per round (ARR) was used as a dependent variable in all studies (Eq. (1)).

$$\text{Average of readings per round} = \frac{\sum \text{Number of readings}}{\sum \text{Number of rounds}} (\text{for all exemplars of one type}) \quad (1)$$

The parameters investigated were set as fixed effects. The number of rounds one transponder ear tag was driven on the dynamic test bench represented measurement repetitions. Repetitions for the factor transponder type were caused by the exemplars of the transponder types. A mixed model was calculated to compare the quality of the different transponder types. Again, the parameters investigated were set as fixed effects, while the interaction between transponder type and transponder exemplar was set as a random effect. Statistical significance was considered at $P < 0.05$. All calculations were carried out with IBM® SPSS® Statistics 22.

2.4. Experiments

A more detailed description of the six experiments implemented is given below.

2.4.1. Influence of speed

Three experiments were carried out to verify whether the speed has an influence on the ARR or not. Experiment one included transponder types A, B1, B2 and B3. Experiment two included the types A, A1 and B4. The holder material PVC was used in both experiments. The third experiment included the transponder types A, C0 and C1 and the holder material XPS was used. Six exemplars of each type in six orientations (Fig. 3) were tested in each experiment. The reader setting TR was used in all experiments. Two speeds (1.5 m s^{-1}; 3.0 m s^{-1}) were compared.

2.4.2. Influence of the number of rounds

Three different numbers of rounds were compared (10, 15 and 20) in order to test whether the number of rounds a single transponder ear tag was driven on the test bench had an influence on the ARR. The reason why this experiment was conducted is the time-saving for further experiments. Here, three types (A, B3-4, B4-4) with six exemplars each were tested in six orientations (Fig. 3) at one speed (3.0 m s^{-1}). The holder material XPS and the reader setting TR were used.

2.4.3. Influence of the holder material

Whether the holder material, PVC or XPS (Fig. 2), of the test bench had an influence on the electromagnetic radiation and, thus, on the ARR was analysed by an experiment with three transponder types (A, C0, C1) and six exemplars of each. The reader setting TR was also used in this experiment. Six orientations (Fig. 3) and two speeds (1.5 m s^{-1}; 3.0 m s^{-1}) were used.

2.4.4. Influence of the reader settings

The setting options of UHF readers are diverse. Two reader settings, TR and PS, were compared and analysed in this experiment regarding their influence on the ARR. The number of transponder types, exemplar orientations and speeds did not differ from the experiment testing the holder material. Only XPS was used as a holder material for this experiment.

2.4.5. Influence of transponder orientation

Five transponder types (A, B3-4, B4-4, B5, C2) were tested due to the difference in their directional radio patterns. Five exemplars of each type were included in this experiment. All the exemplars were tested at a speed of 3.0 m s^{-1}. The performance of the reader was reduced to an ERP of 0.5 Watt for this experiment to see the differences in transponder orientation more clearly. Six orientations which covered the main sides of the transponder ear tags were compared (Fig. 3). Again, the reader setting TR was used.

2.4.6. Test of the transponder types

The main task of this test bench was to test the quality of different transponder types. An evaluation of the suitability of the transponder ear tags for practical use will be deduced from the results of these experiments. Fourteen types of transponder ear tags were tested at different test bench settings mentioned above. A joint evaluation of many experiments was performed to compare the different transponder types. Transponder type A was used in all experiments as a reference transponder and represented a connection between the experiments. Depending on the experiment, PVC or XPS as a transponder holder (Fig. 2) and TR or PS as a reader setting was used. All the experiments were performed at 3.0 m s^{-1}.

3. Results and discussion

3.1. Influence of speed

On the basis of Fig. 4, it can be seen that the speed of the transponder had a significant influence on the ARR. Experiments one to three showed that the ARR was significantly higher at a speed of 1.5 m s^{-1} than at 3.0 m s^{-1}. Obviously, the speed had an influence on the reading success. This result was independent of

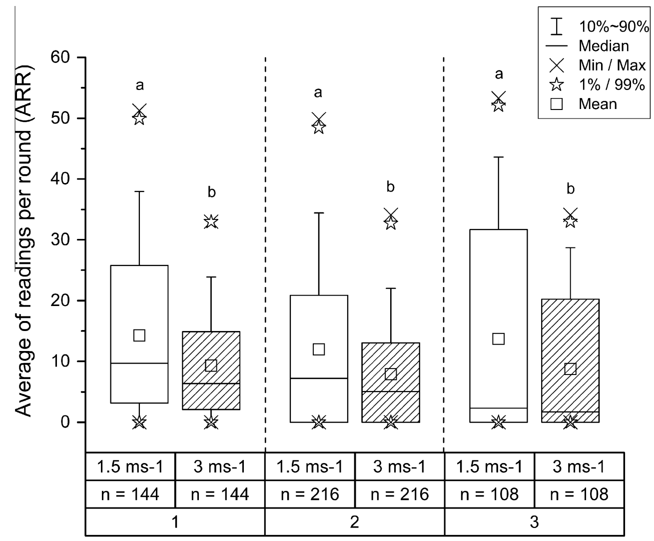


Fig. 4. Differences between the average of readings per round (ARR) in terms of speed (1.5 m s^{-1}, 3.0 m s^{-1}) analysed in three experiments. Experiment 1: transponder types A, B1, B2, B3, holder material PVC; Experiment 2: transponder types A, A1, B4, holder material PVC; Experiment 3: transponder types A, C0, C1, holder material XPS. Reader setting 'triggered read' was used in every experiment. n: repetitions, a, b: different letters within an experiment indicate that values diverge significantly ($P < 0.05$).

the transponder type. The interaction of transponder type and speed always showed a significant difference.

The reason for the reduced number of readings per round could be the shorter 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 transmitted 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. McCarthy et al. (2009) also concluded that the readability of a transponder at a higher speed 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}. Consequently, an increased speed from 0.5 m s^{-1} to 1.0 m s^{-1} showed a decreased mean detection rate from 62% to 57%. Penttila et al. (2004) described similar results that an increase in speed will result in a decreasing coupling capability of the system.

3.2. Influence of the number of rounds

The influence of the number of rounds in the sense of the repeated measurements on the ARR was tested. Statistically, the number of rounds are measurement repetitions, but a higher number of rounds resulted in a lower variance of the ARR of one transponder type exemplar. The first completed experiments in the project were performed with 20 rounds per passage. Whether there is a difference in the ARR between 10, 15 and 20 rounds was tested with this experiment.

The results of these experiment (Fig. 5) show that there was no significant difference between the number of rounds. The lower ARR compared to other experiments could be explained by the use of the fast speed (3.0 m s^{-1}). 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.

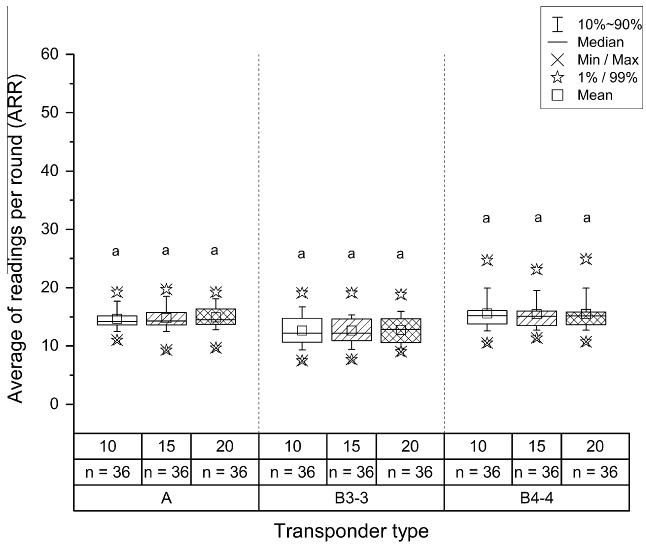


Fig. 5. Differences between the average of readings per round (ARR) in terms of varying the number of rounds (10 vs. 15 vs. 20) based on three transponder types. Holder material XPS and reader setting 'triggered read' with a speed of 3.0 m s^{-1} were used. *n*: repetitions, a, b: different letters within a transponder type indicate that values diverge significantly ($P < 0.05$).

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 had an influence on the ARR or not. The XPS should carry less weight than PVC, where an absorption of the electromagnetic radiation and a reduction of the ARR would be expected. Transponder types C0 and C1 were chosen for this experiment because of their moderate performance. Fig. 6 shows that no significant difference could be determined for transponder type A and C0. Whereas transponder type C1 shows a difference between the two holder types ($P = 0.01$).

A different reaction of different transponder types attached to changing material was not described. There is no explanation for the different effects regarding the transponder types. The directional radio pattern is not expected to be the reason because of the six transponder orientations tested. Wehking et al. (2007) glued transponders onto small charge carriers filled with aluminium, steel, water, chipboard or fibreboard. Empty charge carriers were used for reference purposes. Reductions of 20% of the reading rates 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 (800–1000 MHz), the read range differed between free air and metal, and was the lowest with water and metal (Derbek et al., 2007). The XPS was used for reference purposes in other experiments because of its minimal influence on electromagnetic radiation ($\varepsilon_r = 1.03$) (Derbek et al., 2007; EECC, 2011; Webster and Eren, 2014).

Barge et al. (2014) attached HF transponders to cheese and to polystyrene for reference purposes. The maximum reading distance was measured with polystyrene and defined as 100%. Depending on the transponder orientation (frontal, +180°), the results with cheese varied between 0% and 100%. It was shown that cheese had an influence on the reading distance of the HF transponders compared to polystyrene. Because XPS enables all possible variants of transponder orientations and other authors also confirmed its low influence on electromagnetic radiation, XPS will be used for further experiments.

3.4. Influence of the reader setting

Industrial readers for UHF applications have a wide spectrum of settings. Easy operability and robustness are paramount for the farmer and use in agriculture. The manual operability has its advantages for laboratory experiments, but an automatic switch-on of the antenna field is preferable for daily use on farms. The settings TR and PS were chosen to compare a setting for experimental purposes and a setting for use on farms. Whether the results of three transponder types vary significantly in their ARR was examined with this experiment. No significant differences between the two reader settings appeared (Fig. 7).

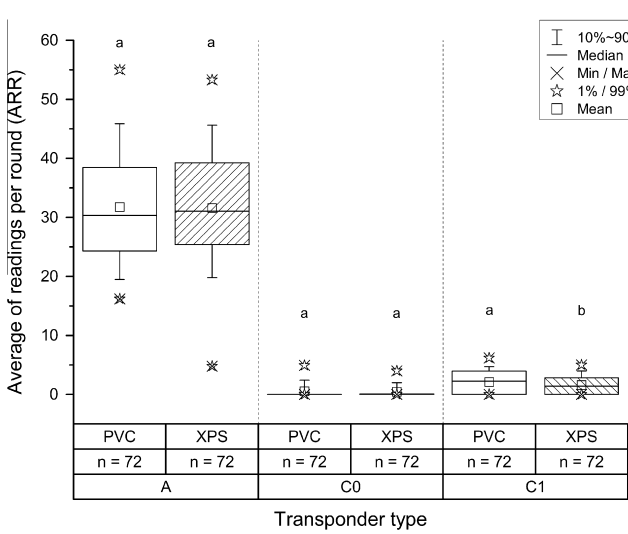


Fig. 6. Differences between the average of readings per round (ARR) in terms of two different transponder holders (PVC vs. XPS) based on three transponder types. Reader setting 'triggered read' and two speeds (1.5 m s^{-1}, 3.0 m s^{-1}) were used. *n*: repetitions, a, b: different letters within a transponder type indicate that values diverge significantly ($P < 0.05$).

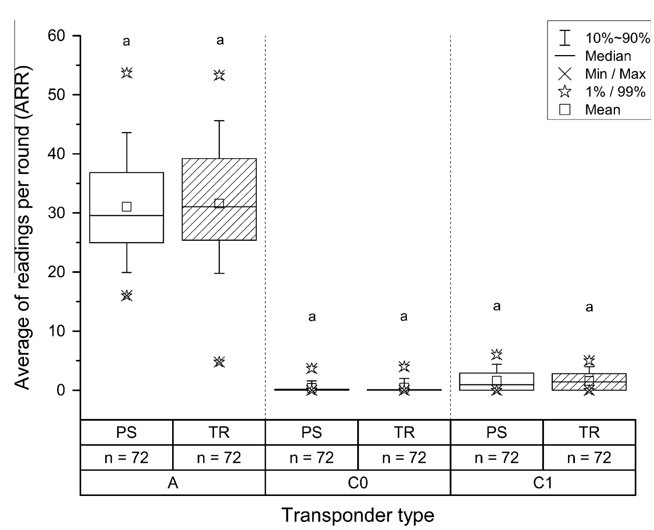


Fig. 7. Differences between the average of readings per round (ARR) in terms of two different reader settings ('presence sensing' (PS) vs. 'triggered read' (TR)) based on three transponder types. Holder material XPS. Two speeds were included (1.5 m s^{-1}, 3.0 m s^{-1}). *n*: repetitions, a, b: different letters within a transponder type indicate that values diverge significantly ($P < 0.05$).

PS would be more suitable for practical use on farms because of the mostly switched-off reading field. The reader is able to identify the passing animals, but does not radiate continuously. The farmer and the animals are not continuously exposed to the antenna's radiation. In addition, there is no need for the farmer to think about switching the reading field on and off. However, a continuously switched-on reading field (TR) has its benefits for laboratory work. Transponders with low performance, which would not be used in practice, can at least temporarily be identified with TR because they have more time to harvest energy. In general, the switching-on threshold for passive transponders is higher than the switching-off threshold. Because of this, they need more energy to get activated when coming into a reading field than to keep on operating when leaving the field (Knop, 2014).

3.5. Influence of transponder orientation

Table 2 shows significant differences in the orientations (Fig. 3) of the transponders. The differences in the ARR per orientation can be partly explained by the simulated directivities of the three basic antenna types (Figs. 8–10).

Transponder type A showed its best orientations upwards and downwards in the simulation. These two orientations were designated as 2 and 4 in the experiments. The worst orientations in terms of performance would be to the sides designated as 1 and 3 in the experiments (Fig. 8). The orientations 5 and 6 (from front and back side) should be in between. The transponder types with the PIF antenna showed a different directivity (Fig. 9). In theory, orientations 5 and 6 should be the best, followed by 1 and 3. Orientations 2 and 4 should be the worst. Transponder type C2 showed a similar directivity to the B transponder types. The only difference was that the radiation of this type was more asymmetric and, thus, more directed to one side (orientation 3). In this orientation, the ARR of that type should be the highest (Fig. 10).

In the following it could be shown that the results of this experiment only partly met the expectations of the simulation.

A closer look at transponder type A showed that this type had the highest ARR in orientation 2, followed by orientation 3. This is analogue to its simulated directivity. The lowest ARRs were detected for orientation 5 and 6. These results do not match the simulated directivity. Orientation 4 achieved an ARR in between orientation 1 and 3 and 5 and 6. With the background of the simulated directivity, an ARR comparable to orientation 2 was expected here.

That the transponder types B3-4, B4-4 and B5 might have their best ARR in orientation 5 and 6 could not be confirmed with these experiments. Rather, orientation 1 could be described as the best. B5 showed no significant difference between orientations 2, 4, 5 and 6. Transponder type C2 had its best orientation in 3, followed by 1 and 6. Orientation 2 and 4 showed significantly lower ARRs. The measurements of this transponder type matched the simulation best.

The partial mismatching of test results and simulated directivity patterns of the transponders can be explained by the suboptimal test set-up. In this dynamic application, the transponder was never read only from one side. Capable transponders (A, B3-4, B4-4 and B5) were sometimes even read on the opposite sides of the test bench. Consequently, readings from other orientations counted regarding the intended orientation observed. The transmitting power of the reader should be reduced to minimise the number of unwanted readings from other orientations. However, in that case, only transponders with the same read range could be tested, otherwise the poorer performing transponders could no longer be read. Alternatively, the test bench would have to be rebuilt in such way that the transponder could be lead behind the reader and, therefore, behind the reading field, on three sides of the test bench. Furthermore, it cannot be ruled out that parts of the test bench, such as the V-belt and the frame, had an influence on the antenna field of the ear tags so that the measurements could not fit the simulation. The suitability of dynamic applications and, thus, the dynamic test bench to examine differences in transponder orientations should be rethought.

McCarthy et al. (2009) also determined large differences in the number of UHF transponders detected by varying the orientation of the transponders and polarisation of the reader antenna. In this case, the bottom longitudinal-oriented, bottom transversal-oriented and top transversal-oriented transponders (oriented along the *y*-axis) were most frequently detected, regardless of whether the linear or circular polarisation of the reader antenna was used (McCarthy et al., 2009). Wehking et al. (2007) also detected differences in the reading rates while testing various UHF transponder orientations. They arrived at the result that the transponders attached to the long side of a box were read to 100%, whereas the reading rates from the transponders on the front of the box remained below that percentage. An orientation of 45° between antenna and transponder (conveyor) was seen as the best because of the radiation vector of the reader antenna (Wehking et al., 2007).

Both LF and HF systems showed differences in the reading rates depending on the orientation of the transponder. Barge et al. (2013) examined the orientations of HDX and FDX LF transponders. They also ascertained that the parallel, perpendicular and coil plane orientations towards the centre of the reader antenna had high differences in the detection zone of the reader. In this experiment, four antenna types and six transponder types were used (Barge et al., 2013). Some experiments with LF ear tags in seven orientations were also carried out by Burose et al. (2010). They compared an LF transponder with ISO standard and a prototype LF transponder which worked with an anti-collision algorithm. Orientation 1 (horizontal, with the coil plane oriented towards the reader) was detected as the worst orientation, while 6 and 7 (holder rotated by 135° and 180°, transponder vertical and longitudinal to the driving direction) were detected as the best orientations. Here, the transponder type did not matter. Fröhlich et al. (2007) examined similar tests with HF transponders. They defined two orientations (0° = transponder antenna and reader antenna are

Table 2
Differences between the average of readings per round (ARR) in terms of the transponder orientation to the reader.

Type	Orientations						n
	1 (left side)	2 (bottom side)	3 (right side)	4 (top side)	5 (front side)	6 (back side)	
A	26.84^{b}	32.36^{a}	28.38^{ab}	22.06^{c}	19.06^{c}	18.18^{c}	35
B3-4	31.80^{a}	22.62^{c}	23.06^{c}	26.28^{b}	25.98^{b}	22.82^{c}	35
B4-4	32.00^{a}	30.29^{ab}	26.24^{c}	28.42^{bc}	26.12^{c}	26.94^{c}	35
B5	31.26^{a}	26.96^{b}	23.02^{c}	26.92^{b}	25.80^{b}	25.30^{b}	35
C2	3.30^{ab}	1.00^{b}	7.70^{a}	0.00^{b}	0.10^{b}	3.28^{ab}	35

Note: Holder material XPS, reader setting 'triggered read' and a speed of 3.0 m s^{-1} were used; n: repetitions; a, b,...: different letters within a line indicate that values diverge significantly ($P < 0.05$).

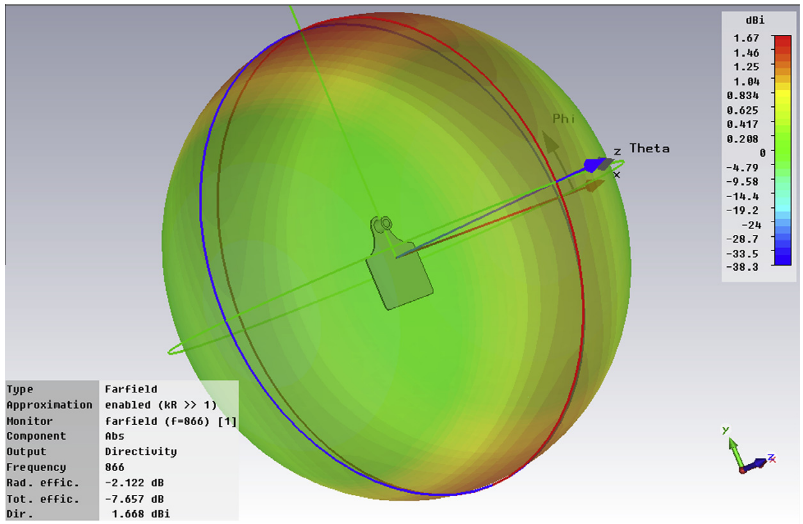


Fig. 8. Directivity of the folded dipole antenna of transponder type A (figure: deister electronic GmbH, CST Microwave Studio®).

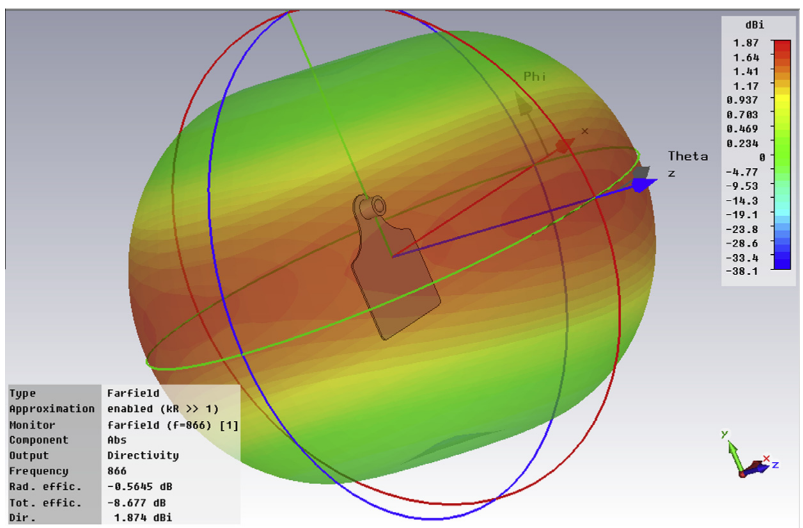


Fig. 9. Directivity of the PIF antenna of transponder types B3-4, B4-4 and B5 (figure: deister electronic GmbH, CST Microwave Studio®).

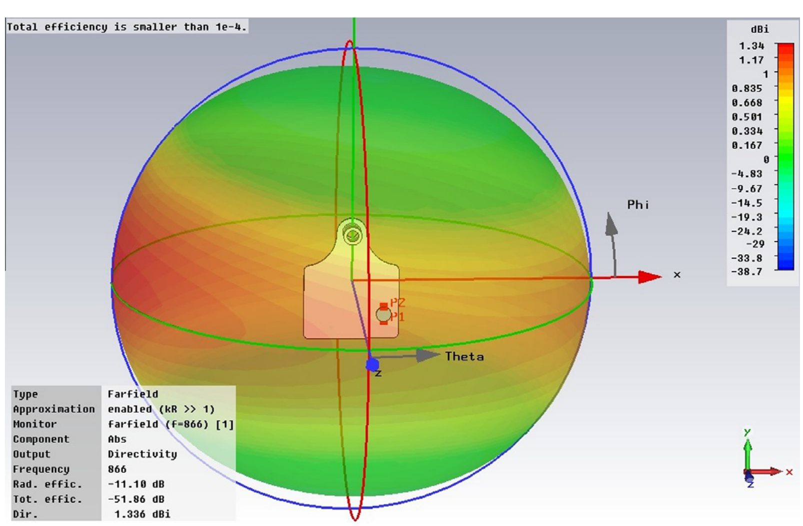


Fig. 10. Directivity of the PIF antenna of transponder type C2 (figure: deister electronic GmbH, CST Microwave Studio®).

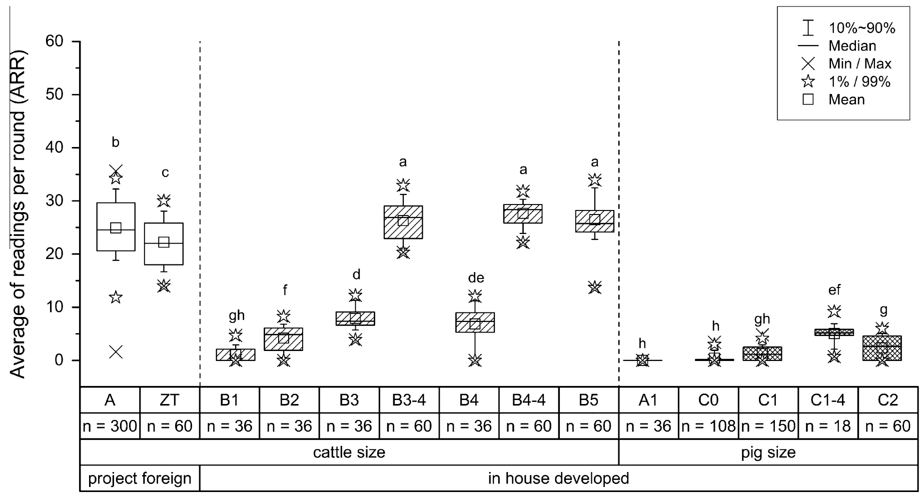


Fig. 11. Test of statistical significance of the average of readings per round (ARR) in terms of the different transponder types. Depending on the experiment, PVC or XPS as a transponder holder and 'triggered read' or 'presence sensing' as reader setting was used. All the experiments were performed at 3.0 m s^{-1}. *n*: repetitions, a, b: different letters indicate that values diverge significantly ($P < 0.05$).

parallel; 90° = antennas are perpendicular) on a dynamic test bench. In this experiment, the 0° orientation achieved a greater reading range. As could be seen here, the orientation of a transponder in a reading field had a big influence on whether the transponder could be read or not, no matter which frequency band was used. Generally, it can be stated that transponders which show fewer differences in the ARR between the orientations are more suitable for practical use on farms than other transponders. The orientation of the transponder ear tag (attached to an animal) to the reader cannot normally be influenced. A transponder which can be read from many sides ensures a good readability in the barn and will vary due to the movement of the animal shaking its ears.

3.6. Differences between transponder types

The main aim of this test bench was to select the best transponder ear tag for practical use under various conditions. Against this background, fourteen different transponder types were tested. Fig. 11 shows the results and significant differences between these transponder types. The second generation of types B3 and B4 (B3-3, B4-4) and B5 achieved the best results and highest ARRs. These three types were grouted into a commercial cattle ear tag and showed their potential for practical use in cattle production. Type A was declared as the second best. This type was the commercially available transponder glued to a plastic ear tag, which was used for comparative purposes. The third best results and AARs were achieved by the commercial transponder ear tag ZT.

Surprisingly, ZT did not show equivalent results to type A, even though it was the same transponder, albeit not glued on but embedded in an air-filled pocket of a cattle ear tag. The reason for that was probably the absorption of the electromagnetic radiation and a shift in the resonance frequency of the transponder through the surrounding plastic of the ear tag. Nevertheless, this type is the right size for cattle and showed good performance. However, the practical use might be problematic. The transponder was embedded in an air-filled pocket between two plastic tabs. Moisture and gases could penetrate and corrode or even destroy the transponder within the ear tag. The first generation of the B3 and B4 transponders designed in-house have already shown good results in some pretests with cattle, which was the reason for developing a second, improved generation. The higher ARRs of the second generation (B3-4, B4-4) were the result of a different label material (Kapton®, Polyimide) being used, which was more resistant during grouting than the aluminium foil of the first transponder types. Furthermore, the sprue quality of the transponder was improved. However, due to a non-disclosure agreement, this procedure cannot be specified here. Type B1 and B2 did not show satisfactory results for their size. The transponder size of these two types matched the size of the types B3-4, B4-4 and B5. Higher ARRs are possible for such transponders, as was shown. These two types will not be considered in further developments.

The pig-sized transponder types A1, C0, C1 and C2 can also be rejected. These types would not serve their purpose in practical use either. Transponder type A1 did not perform well despite the fact that its antenna design was similar to type A. In the group of the small transponders, C1-4 showed the highest ARRs. This type also benefited from the better label material. That transponder size could be used in pig husbandry after further development. However, a UHF antenna fitting in a pig ear tag would not reach the reading distance and ARR of a larger transponder. The larger the size of a transponder, the farther the reading distance is (Catarinucci et al., 2012).

Derbek et al. (2007) compared a UHF transponder with dipole antenna and a UHF transponder with an omnidirectional antenna. They arrived at the result that these transponders differed in their sensitivity. Lorenzo et al. (2011) analysed the return loss and gain, radiation pattern, relative permittivity and read range of a UHF transponder with dipole antenna and slot antenna. The differences between the performance of the transponders in free air and attached to wood were also shown. McCarthy et al. (2009) also carried out their experiments with five different UHF transponder types. They also achieved significant differences between the types considering distance, speed and reader antenna. Barge et al. (2014) compared UHF transponders from various manufacturers in terms of distance between tag and reader antenna with two antenna polarisations (circular vs. linear). Significant differences between the UHF transponder types were determined in the experiment.

It can be concluded from all these findings that antenna design and antenna size are important factors for UHF transponder performance. It also can be concluded from the dynamic tests that the transponder label material and the resulting manufacturing quality of the ear tag also have a major influence on the transponder performance.

4. Conclusions

It was demonstrated in the experiments that the methodology of the dynamic test bench can be used to show differences between transponder types. Their behaviour in terms of various speeds, transponder holder materials, reader settings and number of rounds could be reliably determined. All of these results were repeatable. Only the transponder orientations did not always match the directivity of the different antenna structures. Here, the test bench needs to be adapted for further experiments. The comparison of the fourteen different transponder ear tags could demonstrate the one most suitable for either cattle or pigs. Because of the good repeatability of the results, it is sufficient for this purpose to use the dynamic test bench, and we did not see the need to do all the tests in an anechoic chamber.

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