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Evaluation of a UHF RFID system for livestock

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Prof. Dr. Thomas Jungbluth

Evaluation of a UHF RFID system for livestock

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Dedicated to my father

Thies Christian Kollhorst

*20.12.1956 † 21.09.2014

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1 Introduction

It is expected that the demand for and the production of animal products will rise on a worldwide basis. The consumption particularly of animal products in developing and emerging countries is increasing on a year-to-year basis. Even though a stagnation of the consumption of meat for the European countries could be registered compared to the previous year (2013), the European Union represented the second largest meat and the largest milk producer worldwide in 2014 (DBV, 2014).

1.1 Animal husbandry in Germany

Animal husbandry is also of great importance in Germany. More than 70 % of the agricultural holdings there keep livestock. About 49 % of these holdings keep cattle, followed by laying hens (20 %) and pigs (18 %) (DBV, 2014; Statistisches Bundesamt, 2014). Between 54 and 60 % (20-25 billion Euro) of the German agriculture proceeds are generated by animal products (DBV, 2014). The production of pig meat in Germany increased by 26 % in the last decade, while the production of chicken meat has even doubled during that time. Milk and egg production have also increased in recent years. Only the production of beef has decreased by 21 %. Germany has changed from a net importer to a net exporter of pig and chicken meat and also cheese within the last ten years (Wissenschaftlicher Beirat Agrarpolitik beim BMEL, 2015).

Furthermore, a structural change within German animal production could be observed. Whereas the number of livestock holdings decreased, the number of animals per livestock holding increased. This primarily affected the holdings keeping cattle and pigs. In this area, farms with greater numbers of livestock increased, while smaller populations were abandoned (Wissenschaftlicher Beirat Agrarpolitik beim BMEL, 2015). One example of this was the increase of 1 % in the number of cattle in the last year to 12.7 billion head, while a reduction of 2 % could be observed regarding the number of cattle farmers. The increase in the number of cattle can probably be traced to the end of the milk quota within the European Union (EU). Dairy farmers obviously reacted to the abolition of this regulation with an increase in herd sizes. Generally, the number of dairy farmers has been reduced by one third over the last ten years. Meanwhile, 45 % of the cattle kept in Germany live in farms each with more than 200 animals. An intensified structural change can also be observed in pig husbandry. Here again, the number of animals has increased (to 28.1 billion pigs), while the number of pig farmers decreased by 4 %. Today, 74 % of the pigs are kept in farms each with more than 1,000 animals (DBV, 2014).

It can be expected that this structural change will continue, especially for the work-intensive piglet and milk production. The work process advantages and the higher productivity are the driving forces of large or very large farms. However, large farms also have a great need for very good operational management and a sufficient number of animal handlers. The difficulty is that qualified workers are hard to find on the labor market today Entenmann, 2015; Wissenschaftlicher Beirat Agrarpolitik beim BMEL, 2015).

In addition to the structural change, a change in the social acceptance of today's animal husbandry has occurred (Petersen et al., 2002). Consumer requirements have become more important than ever before to modern animal husbandry. According to a survey of 1,000 German citizens in 2012, 46 % of participants stated a very high or high interest in agricultural issues. This was 11 % more than in 2002. The focus of the respondents was on questions of the product quality (95 %) and food safety (88 %), as well as the emotionally highly charged aspect of the treatment of livestock (87 %). A total of 85 % of the people questioned stated that the responsible treatment of livestock is the most desirable property of a farmer. Only 24 % of the respondents believed that farmers could keep their livestock in large numbers, appropriate to the species (i.m.a, 2012).

German agricultural policy responded with an adaptation and modification of legal requirements which should improve the animal welfare in German livestock husbandry (e.g. prohibition of conventional cages for laying hens, implementation of group-housing of pregnant sows; TierSchNutztV, 2014). A lot of different labels with various demands regarding animal husbandry, animal welfare and food traceability were also established, such as the "Tierschutzlabel," "Neuland," "Safe," and "Tierschutz, geprüft" (Verbraucher Initiative e.V., 2015).

Because of all the factors mentioned above, the farmer is arriving increasingly in a position where recording and improving the life of individual animals and increasing the efficiency of animal production simultaneously are of paramount importance. The collection of animal-related data and data from their environment using simple, innovative and low-cost techniques is a central part of so-called precision livestock farming (PLF) (Berckmans, 2008).

1.2 Precision livestock farming (PLF)

The major part of PLF is the real time, on-going and automatic monitoring of individual animal parameters and surrounding parameters in all husbandry areas by “smart” sensors to show and improve animal behavior, animal health and animal performance, as well as the housing conditions. However, the major aim of PLF is the automatic control of animal production systems analogous to industrial control mechanisms (Banhazi, 2012; Berckmans, 2008; Berckmans, 2014; Busse et al., 2015; Hartung, 2005). The basis of all applications are the diverse sensors mentioned above, which are attached directly to the animal or installed in the animal’s surroundings (Brehme et al., 2004). This includes acoustic and optical sensors, as well as sensors for temperature, pH value, and movement and pressure measurement (Banhazi, 2009). Figure 1.1 gives a schematic overview of the PLF process structure to control biological processes.

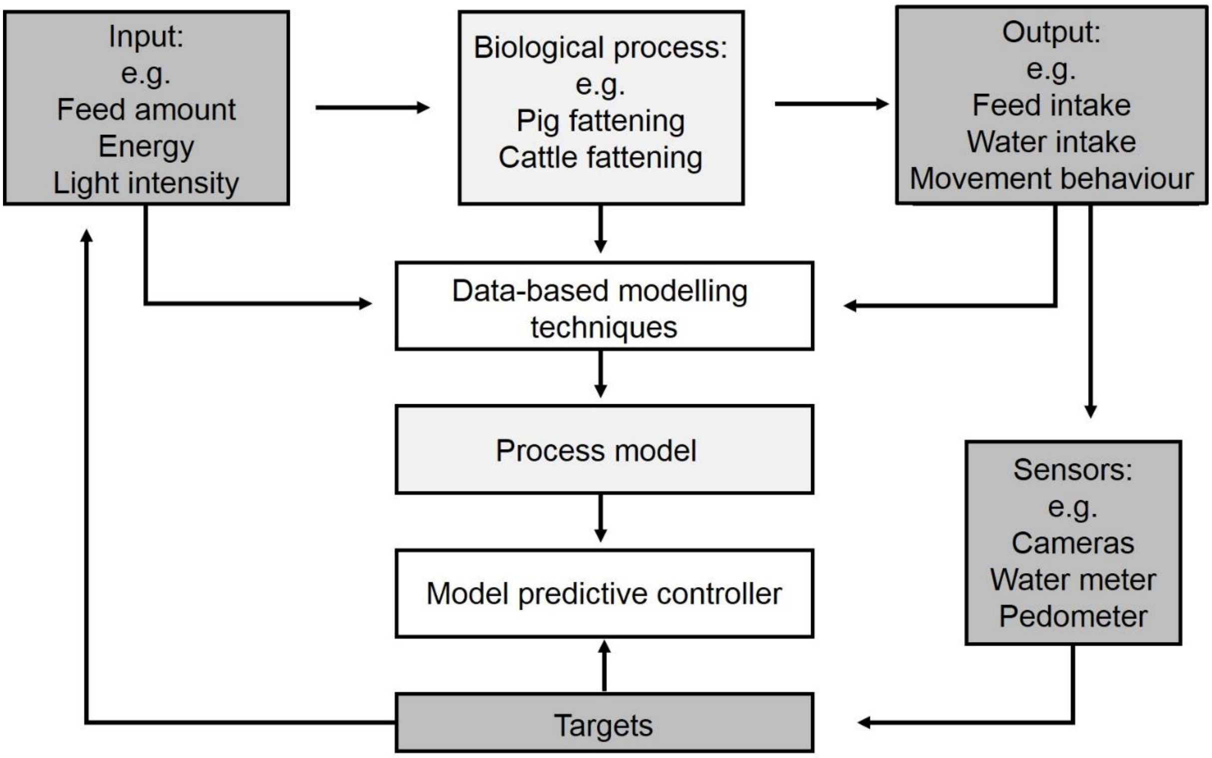

Figure 1.1: Schematic overview of PLF components and the process structure to control biological processes (changed and adapted from Berckmans, 2008 and Wathes et al., 2008).

The monitoring of sounds (frequencies) of animals, for example, can already provide information about the health status of the herd (Berckmans, 2014; Van Hirtum & Berckmans, 2004). With the aid of image analysis techniques, low-cost cameras can be used to assess animal behavior, size, weight, and shape (Chedad et al., 2003; De Wet et al., 2003; White et al., 2004; Whittemore & Schofield, 2000). Sensors to quantify the yield and/or the electric conductivity of milk are used to detect the poor welfare of individual dairy cows and, therefore, to improve productivity (de Mol & Ouweltjes, 2001; Köhler & Kaufmann, 2003). Telemetric sensors for measuring the heart rate, body temperature and/or activity were also developed, mainly for use in research (Lowe et al., 2007; Mitchell et al., 2004). Even though the main problems are the costs, robustness, reliability, and compatibility of the sensors, it is predicted that the sensors and sensing techniques will become readily available in the future (Wathes et al., 2008).

After the data acquisition, the data has to be processed by a computer-based background system. However, because livestock systems are dynamic processes, no standard mathematical model can be used as a basis for evaluation software. An adaptive approach is mostly needed (Berckmans, 2004; Berckmans, 2008). The complexity of a mathematical model depends on the PLF process. According to Banhazi (2012) and Wathes et al. (2008), the biggest challenge is to develop tools to determine the biological meaning of a model's structure, order and parameters. Consequently, the results of this analysis should be the basis of the farmer's decisions or optimizations in livestock husbandry.

1.3 Radio-frequency identification (RFID)

Individual animal identification is essential for complete traceability and monitoring of animals according to the PLF. This problem can be solved by a technology called radio-frequency identification (RFID). This method was invented in 1948, but has only been a proven technology since the 1970s. In the 1980s, it also became widespread in the agricultural sector for animal identification and the first applications in field trials were started. Later on, a fast development of this technology and the emergence and implementation of standards followed. Today, RFID has become part of our everyday life (e.g. in libraries, the logistic area, geriatric care) and is used in many applications in animal husbandry (Roberts, 2006; Sarma et al., 2001).

An RFID system typically consists of an RFID transponder, an RFID reader (containing an external or internal antenna) and a connection to a host or enterprise system (Finkenzeller, 2012; Roberts, 2006; Schoblick & Schoblick, 2005). Figure 1.2 shows the functioning principle of an RFID system schematically.

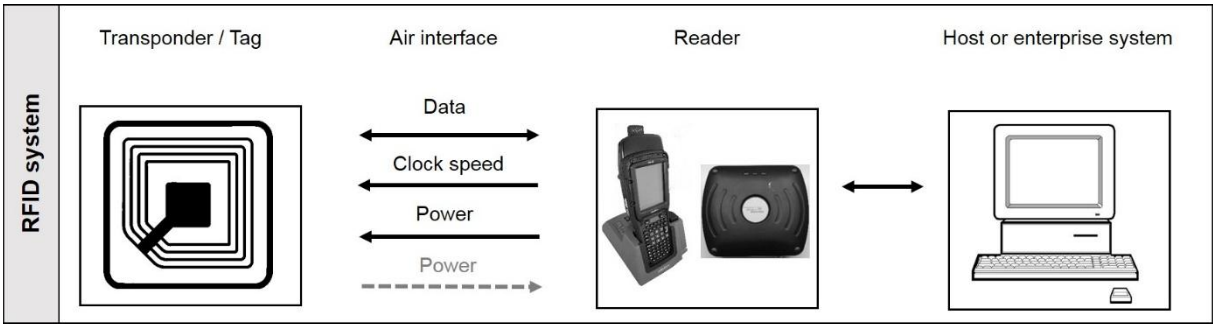

Figure 1.2: Schematic overview of the functional principle of an RFID system (own diagram).

Generally, RFID systems are very diverse. An overview of the different possible system properties can be seen in Figure 1.3. On the basis of this figure, the system properties will be described and explained.

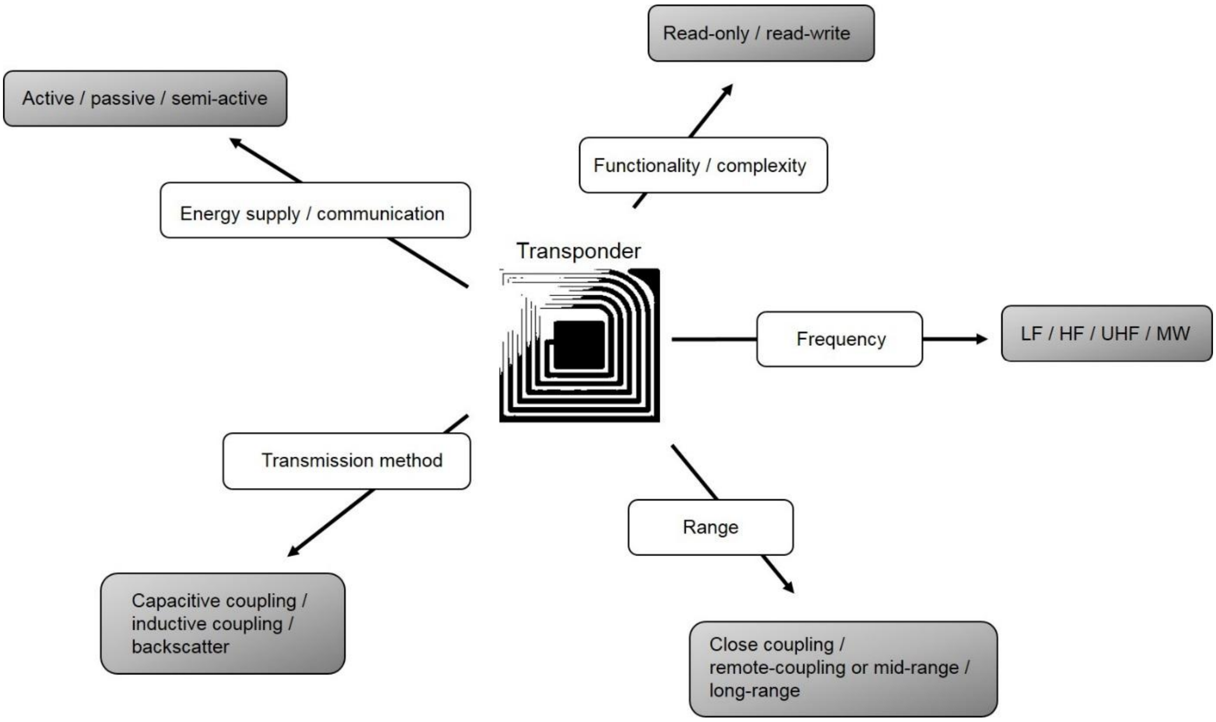

Figure 1.3: Overview of the most important RFID system properties (own diagram).

At first, the system should be distinguished according to the power supply of the transponder. There can be **active or passive transponders** within an RFID system.

In addition to a transmission and receiver unit, active transponders have their own power supply (battery), while passive transponders generate their energy from the radiation of the reader. Active transponders are generally larger and more expensive than passive transponders. The lifetime of active transponders is limited due to the use of a battery. Compared to active transponders, passive transponders have a theoretically unlimited life-span. They are smaller, lighter and cheaper due to their construction. A shorter read range and the requirement of a reader with higher output power are detrimental aspects of passive transponders. Additionally, they are influenced more easily by an electromagnetically “noisy” environment. There are also semi-passive transponders. In this case, the battery runs the chip’s circuitry, but the device communicates by drawing power from the reader. Transponders are generally available in a variety of shapes, sizes and protective housings, according to their field of application (Roberts, 2006; Sarma et al., 2001).

A distinction between chipless and chip-based transponders can also be made. Chipless transponders can be used as anti-theft or anti-counterfeiting devices. An individual identification number can be saved on the microchip using chip-based tags. There is also the possibility to store supplementary details on a user memory for some chip models. Chip-based tags are classified by two categories: read-only and read-write.

A **read-only transponder** receives a unique number (UID) prior to selling which cannot be changed. **Read-write transponders** contain a storage component where an individual number can be saved, read out and changed (Finkenzeller, 2012; Helmus et al., 2009). The latter are used, among other things, to track items through the supply chain (Li et al., 2006). The additional number may be an electronic product code (EPC), which is often used in ultrahigh frequency technology. Thus, when the so-called EPCglobal network is also incorporated, retailers have the possibility of tracking goods in real time throughout the whole world. The structure of an EPC is internationally determined and has a code length of 64 or 96 bits (GS1, -,-; Kern, 2006).

In addition to the power supply and chip category of the transponder, an important differentiator is the operating frequency of the RFID systems, which is regulated by national and international valid remote access guidelines. The performance (e.g. read range, reading and programming speed, size) of a transponder is predetermined by choosing the frequency range. The frequency range is one of the most important factors of a system which has to be decided (Kern, 2006).

The RFID systems are commonly divided into four characteristic frequency ranges (Jansen, 2005; Lampe et al., 2004; Overmeyer & Vogeler, 2005):

- Low-frequency (LF, 100 - 135 kHz),

- High-frequency (HF, 13.56 MHz),

- Ultrahigh frequency (UHF, 868 MHz (EU), 915 MHz (US))

- Microwave (MW, 2.45 GHz and 5.8 GHz).

The frequency ranges differ in the method of data transmission, read range, susceptibility against disturbances (water and metal), data transmission rates, anti-collision techniques and much more. Figure 1.4 shows application examples and characteristics of the different frequency ranges.

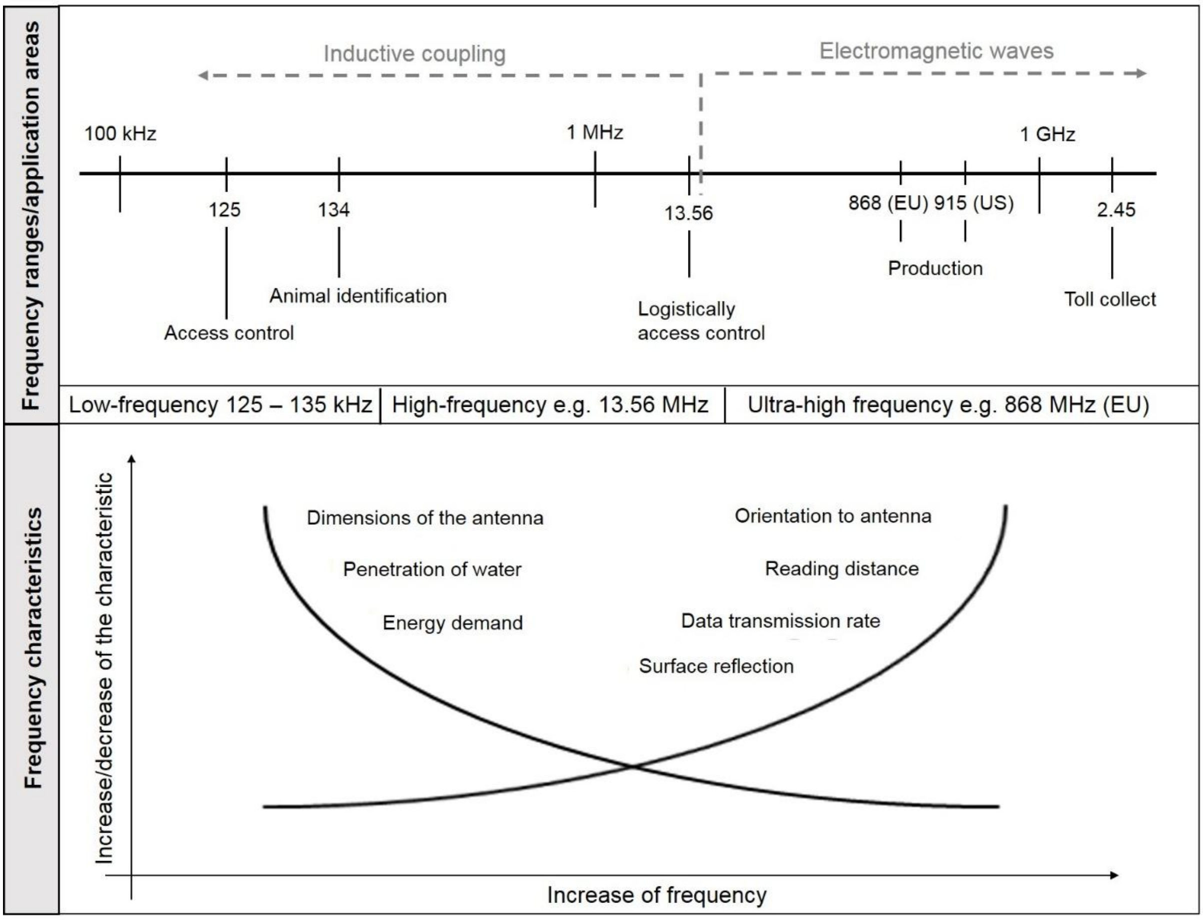

Figure 1.4: Application areas and characteristics of different RFID frequency ranges (following Finkenzeller, 2012 and Kern, 2006).

The application area of the **low-frequency (LF, 100 - 135 kHz)** range is limited to short distances because the read range of these systems is merely one meter. If many transponders are read in a given period of time, only a small amount of data can be stored on the transponder, because the data transmission rate is low. Because of this anti-collision technique and, thus, a simultaneous read-out of many transponders is hardly possible in this frequency range (Schoblick & Schoblick, 2005). Today, the LF range is mostly used for animal identification applications, production control and immobilizers in cars. This frequency can be used internationally (Dobkin, 2012; Lampe et al., 2004; Roberts, 2006).

The RFID systems working in the **high-frequency (HF, 13.56 MHz)** range are limited to applications where a maximum read range of three meters is needed. The transmission of a larger amount of data is possible due to higher data transmission rates. Because of these characteristics, HF systems rank among the most frequently requested RFID solutions. Application areas are article surveillance, cash register and mass access control systems. This frequency band can also be used internationally (Finkenzeller, 2012; Roberts, 2006; Schoblick & Schoblick, 2005).

The greatest benefit of the **ultrahigh frequency (UHF, 868 MHz (EU), 915 MHz (US))** range compared to LF systems is the high data transmission rate. So far, the main application area of these systems has been in the logistic area. The automatic quasi-simultaneous detection of pallets or containers can be realized well. Because there are a lot of application examples in other industrial areas, the development potential of this frequency band for use in agriculture is very high. However, problems arise when the system is surrounded by metal surfaces or fluid accumulations: the electromagnetic radiation is then reflected or absorbed and the read out of transponders is prevented (Finkenzeller, 2012; Kern, 2006; Wu et al., 2006).

Very high data transmission rates can be realized in the **microwave (MW, 2.45 GHz)** range. However, compared to UHF systems, the influence of metal or liquid in the surroundings of MW systems is of even greater importance. The functioning of MW systems is severely restricted near these disturbance variables (Schoblick & Schoblick, 2005).

Table 1.1 gives a summary of the frequency range characteristics, application areas and legal requirements which have been described previously.

Table 1.1: Overview of RFID frequency band characteristics (based on Bundesnetzagentur, -,-; Finkenzeller 2012; Kern, 2006; Roberts, 2006).

Characteristic	LF	HF	UHF	MW
Frequency	134.2 kHz	13.56 MHz	868 – 950 MHz	2.4 GHz
Read range (passive systems)	1 m	up to 3 m	up to 9 m	up to 12 m
Effects of metal / water surrounding	low	medium	high	high
Data transmission rate	low	medium	high	high
Method of data transmission	inductive coupling	inductive coupling	inductive coupling/ electromagnetic	electromagnetic
Anti-collision technique	hardly applicable	possible	possible	possible
Potential of development	low	medium	high	limited
Permitted transmission power of the reader			≤ 2 W ERP* (865 MHz)	≤ 4 W EIRP* (closed rooms) ≤ 500 mW EIRP (not closed rooms)
Application examples	animal identification	access control	logistics	car identification

* ERP = effective radiated power; EIRP = equivalent isotopically radiated power

The antenna of a transponder can be shaped totally differently depending on the frequency range and application area. It enables contactless data transmission between the transponder and reader as well as the transmission of clock pulse and energy (Finkenzeller, 2012; Lenzbauer, 2007). Antennas built for the LF range consist of a ferrite rod or a copper coil. Air coils are mostly used in the HF range, while dipole antennas are built for the UHF range. The benefits of the HF and UHF antennas are the flat and cheaper layout (Kern, 2006).

The systems can be classified in read ranges according to the frequency. There are close coupling, remote coupling, mid-range and long-range systems. Within these systems, read ranges from a few centimeters to several meters are conceivable.

Close coupling systems work with a maximum read range of one meter. They use an electrical field and so-called **capacitive coupling**. The electric field occurs between the capacitor plates of the transponder and the reader. The transponder encodes its signal by means of voltage changes in the electric field and, subsequently, the reader decodes these voltage changes. A direct contact or a special orientation between reader and transponder is needed for the reading process. A frequency range of ≤ 135 kHz or 13.56 MHz is mostly used for these systems. Application areas are electronic access controls or contactless chip-card systems with payment functions (Kern, 2006; Overmeyer & Vogeler, 2005).

Remote coupling or mid-range systems have a read and write range of about one meter. The LF (135 kHz) or HF (13.56 MHz) frequency band and the magnetic field (**inductive coupling**) are used for these systems. The transponder in these systems generates its energy from the magnetic field which is produced by the reader. The transponder chip is provided with energy through the rectified voltage of the transponder antenna. The data transmission takes place through the removal of energy from the magnetic field and the change of the impedance. If the transponder disappears out of the near field ($\lambda/2\pi$ around the reader), the energy supply of the transponder is not sufficient and the transponder cannot send a respond signal. These systems are normally used in the anti-theft or access control area. An additional thought is to use the systems for brand protection (Kern, 2006; Overmeyer & Vogeler, 2005; Schoblick & Schoblick, 2005).

Systems with a range of more than one meter are called **long-range systems**. Here the UHF or microwave band and the electromagnetic field (**backscatter coupling**) are used. Passive systems work in a range of about eight to ten meters, while systems with active transponders reach a distance of 15 meters. In contrast to the latter, in systems using the backscatter principle, the electromagnetic radiation is reflected and not sent back. The reflection properties of the transponder antenna have to be changed for data transmission. Therefore, a load resistance is turned on and off. The application area of these systems is the registration of pallets with goods and container shipment (Kern, 2006; Lenzbauer, 2007; Schoblick & Schoblick, 2005).

The simultaneous detection of several transponders is also possible in the HF, UHF and MW bands. Therefore, anti-collision techniques are used. A distinction between four methods can be made here. There is the spatial division multiple access **(SDMA)**, the time division multiple access **(TDMA)**, the frequency division multiple access **(FDMA)**, and the code division multiple access **(CDMA)**. Almost all RFID applications work with TDMA. The transponders are assigned timeslots by the reader for responding with the so-called ALOHA access method. The reader queries these timeslots and recognizes if none, one or many transponders are responding. Transponders which are only responding can be addressed as targeted, while transponders sharing one timeslot get a new chance to respond in the next query round when timeslots are assigned randomly again. They have the chance to respond in the next query round. The read range of the reader and the size of the antennas in the SDMA are adjusted to the object which needs to be identified. Simultaneously, several readers and antennas operate comprehensively in arrays. This technology is used at sport events (e.g. tartan mats). All other methods do not play a role in practice. The simultaneous detection in the LF band is only possible to a limited extent. No satisfactory results have been achieved with this method so far in animal husbandry (Burose et al., 2010).

Furthermore, RFID systems can be differentiated into two operating modes to read out and write on the data from the transponder chip: the duplex procedure and the sequential procedure. The duplex procedure is further divided into the half-duplex and full-duplex procedure. Figure 1.5 illustrates the differences between the operating methods.

Figure 1.5: Timescale of the energy and signal transmission with different operating methods (following Finkenzeller, 2012).

Using the duplex procedure, the data transmission is independent of the energy supply. Here, a permanent energy transmission is available. There are differences in the timing of the communication between the half-duplex and the full-duplex procedure. Using the full-duplex procedure, transponder and reader transmit and receive simultaneously (Finkenzeller, 2012; Lenzbauer, 2007). Compared to the full-duplex procedure, the transmitting and receiving of the half-duplex procedure takes place in a time-delayed manner. When the reader is sending and the transponder is receiving, there is no data transmission from the transponder to the reader, even if the transponder is located within the reading area of the reader. Compared to the duplex procedure, the sequential procedure has no permanent energy supply during the data transmission between transponder and reader. However, because the transponder and the reader send alternately, the sequential procedure can also be described as a special type of the half-duplex procedure (Kern, 2006; Schoblick & Schoblick, 2005, Zhang et al., 2007).

1.4 Benefits, possible potentials and problems of UHF RFID for animal identification

The UHF RFID is widespread in the logistic area. The system could also have high potential and benefits regarding animal identification. An overview of the possible potentials, benefits and problems of UHF RFID for animal identification will be given in the following.

1.4.1 Benefits and possible potentials of UHF RFID

The UHF RFID technology is an international standard and has a great potential for development. Because UHF RFID is prevalent in the logistics industry, reliable, cheap and innovative hardware for UHF transponders and their chips, as well as for UHF readers, will be available in the long-term, also for use in a stable environment (GS1, 2012; Umstätter et al., 2014). Due to the increased use of the technology in a variety of areas, a saving of costs can be expected and the technology could be affordable for the agricultural sector where the profits are low. The identification of animals, foods and other products of the grocery chain could be carried out with the same RFID technology (Barge et al., 2013; Barge et al., 2014; Wang, 2014). The hardware used would be compatible, which would result in a reduction of media discontinuities. The control and monitoring in the case of epizootic diseases, the traceability of animals and foods, and the quality assurance and documentation of production processes could be improved significantly. The implementation of an unchangeable worldwide unique animal ID (64 bit, ISO 11784) on a passive UHF transponder is possible, which would allow the accurate identification of an individual animal along the value chain. In addition to the unique number, a separate memory bank on the chip can be used to store further animal-related data. This data can be altered at will and may be used for further cost-saving management applications. For instance, the reduction of the amount of labour needed (Umstätter et al., 2014). Besides the good storage characteristics using passive UHF transponders, reading distances of more than three meters can be reached. This is especially beneficial for animal species which are difficult to handle or rather shy (e.g. steers or sheep). Furthermore, passive UHF transponders are extremely light, which is why they are particularly suitable for attachment to an animal. Thus, small or young animals (e.g. piglets) could also be tagged with an UHF ear tag. It is possible to track an animal's life from birth onwards by using this device. A further advantage is that the animals do not have to be separated, because high data transmission rates and the anti-collision techniques allow for a simultaneous detection of many transponders (Finkenzeller, 2012; Kern, 2006, Stekeler et al., 2011). Furthermore, UHF antennas can be adjusted to diverse applications. They can work in the near or far field and the reading field is modifiable in its expansion and orientation (Nikitin et al., 2007). The antenna technology in this area is well advanced, so that the antenna fields can be adjusted specifically (Nikitin & Rao, 2008).

1.4.2 Problems of UHF RFID

The UHF RFID systems are characterized by several properties. While all RFID technologies are sensitive to metal or metal surfaces, the sensitivity to water increases with the operating frequency (Nikitin & Rao, 2006). Metal surfaces or electrical conductive surfaces interfere with the transponder reader communication, because the electromagnetic radiation is reflected, whereas the presence of water interferes with the communication because the electromagnetic radiation is absorbed. Through the stable environment and the animal itself, metal surfaces (reflection) and water (absorption) are inherent parts of a transponder's surroundings and trouble-free communication seems infeasible. Nevertheless, studies have shown that UHF transponders can be modified to reduce the influence of these disturbance variables (Catarinucci et al., 2012; Dobkin, 2012; Finkenzeller, 2012, Stekeler et al., 2011). But it should be noted that through an adaption of the transponder not the reflection and absorption in the surrounding can be influenced, but a frequency shift through the permittivity of nearby materials ca be prevented. However, not only the frequency shift, but also a changing of the transponder's directional characteristics must be taken into account (Lorenzo et al., 2011; Nguyen et al., 2013).

1.5 Placing and description of the project

The electronic identification of animals in Germany is only currently mandatory for small ruminants (sheep and goats; EC, 2004) and pets (dogs, cats and ferrets; EC, 2013). But because of the increasing animal numbers per farm mentioned above, new and tightened statutory directives, and a strong consumer request for traceability of individual animals, individual electronic identification is now a highly relevant subject. The recording and documentation of the daily routine of an individual animal has also gained in importance to may draw conclusions about the individual animal welfare.

Present RFID systems in animal husbandry work mostly with LF technology. With these systems, the control and management of feed intake (feed on demand), activity (minimal walking distances) and access to special stable areas (milking robot, directed cow-traffic) is possible (Cornou et al., 2008; Junge, 2015). If a small distance between the transponder and reader is sufficient and the separation of animals is possible or wanted, LF systems are suitable. For a reading over longer distances and simultaneous animal detection, a higher frequency range has to be used (Dobkin, 2012).

With UHF systems, not only greater reading distances, but also the simultaneous detection of many transponders, hotspot monitoring and a localization of animals seem possible (Adrion et al., 2015a; Adrion et al., 2015c; Huhtala et al., 2007; Song et al., 2007; Stekeler et al., 2011; Zhou et al., 2015). Thus, UHF systems could cover the application areas of LF systems and trigger applications to further improve the traceability and management of individual animals (Dobkin, 2012). So far, systems working with UHF RFID are described in context with the grocery chain, but not with animal husbandry directly. The UHF RFID system has not yet been explored and implemented in this sector. Official and independent publications in this area can be found rarely. In the last few years, a small number of projects testing UHF systems in livestock farming have been carried out:

- Stekeler, T., 2015. Simultaneous detection of fattening pigs with RFID-technology. Dissertation. University of Hohenheim. Forschungsbericht Agrartechnik. VDI-MEG 547.
- ScotEID – Scottish EID Livestock Traceability Research (https://www.scoteid.com/)
- RFID Pathfinder Group – The use of EPC RFID Standards for Livestock and Meat Traceability (http://www.rfid-pathfinder.org.nz/wp-content/uploads/2012/08/EPCIS-Final-Report5.pdf)
- PigTracker – Using UHF RFID for Pig Traceability (http://rfididk.org/wp-content/uploads/2014/02/11.25-Pigtracker-Using-UHF-RFID-for-Pig-Traceability.pdf)
- Pig Affairs (http://www.purespekt.com/applications/rfid-pig-tagging)
- EZG Gut Streitdorf in cooperation with Fa. Sapro and ECMAS (VÖS Magazin – Verband Österreichischer Schweinebauern, Ausgabe Österreich 1/2014, 27-28 or http://www.voes-online.at/index.php/projekte/elektronische-ohrmarke)
- HANA Micron - Anitrace (http://www.anitrace.net/)

UHF RFID prototype ear tags were used to attach the transponder to the animal in all of these projects. The use of ear tags is reasonable in the UHF band, because the absorption of the electromagnetic radiation through body liquids and, thus, the influence of water is least. *A priori*, the use of boluses or encapsulation for implantation would be unsuitable to attach a UHF transponder to the animal. In the LF area, various studies have already shown that ear tags have major advantages compared to boluses, collars, encapsulations for implantation, and electronic hobbles (cattle: Klindworth, 1998; Klindworth et al., 2002; pigs: Caja et al., 2005; Zähner & Spiessl-Mayer, 2005).

However, either the reading rates in general, the functionality or durability and/or size of the ear tags, or the costs of the UHF RFID system used were unsatisfactory in these projects.

This dissertation is part of a project funded by the Federal Ministry of Food and Agriculture (BMEL). The project title is "Electronic animal identification based on ultrahigh frequency radio frequency identification – UTE (UHF animal identification)." Besides the University of Hohenheim four companies are part of this project. The deister electronic GmbH, Barsinghausen, Germany is mainly responsible for the UHF transponder pattern and stationary UHF reader development. The Agrident GmbH, Barsinghausen, Germany is commissioned with the construction of reader housings and antennas as well as a mobile UHF reader. They also provide assistance with the installation and supply the software for the first experiments. The transponder patterns are grouted into the pig and cattle ear tags by the Caisley International GmbH, Bocholt, Germany. The development of a database and further software for experimental procedure is done by the Phenobyte GmbH & Co. KG, Ludwigsburg, Germany.

The main aim of this project is the development, use and evaluation of innovative techniques for electronic animal identification with UHF RFID. Within the project, flexible UHF transponder ear tags for pigs and cattle, stationary and mobile UHF readers, and software for data management and evaluation will be developed and evaluated. The simultaneous detection of many animals in a group, the monitoring of animals at hotspots, and the indoor localization of animals should be realized with a UHF system at the end of the project. Figure 1.6 shows the three main stages and the sub-goals of the project.

Different self-developed UHF transponder types, the size of pig and cattle ear tags, were produced and tested (nine transponder types for cattle and nine transponder types for pigs) during stages 1 to 3. These transponder patterns were molded into a standard pig or cattle ear tag. Additionally, one purchased transponder type of each size (pig and cattle) and a transponder type used in industry for reference purposes were included in the tests.

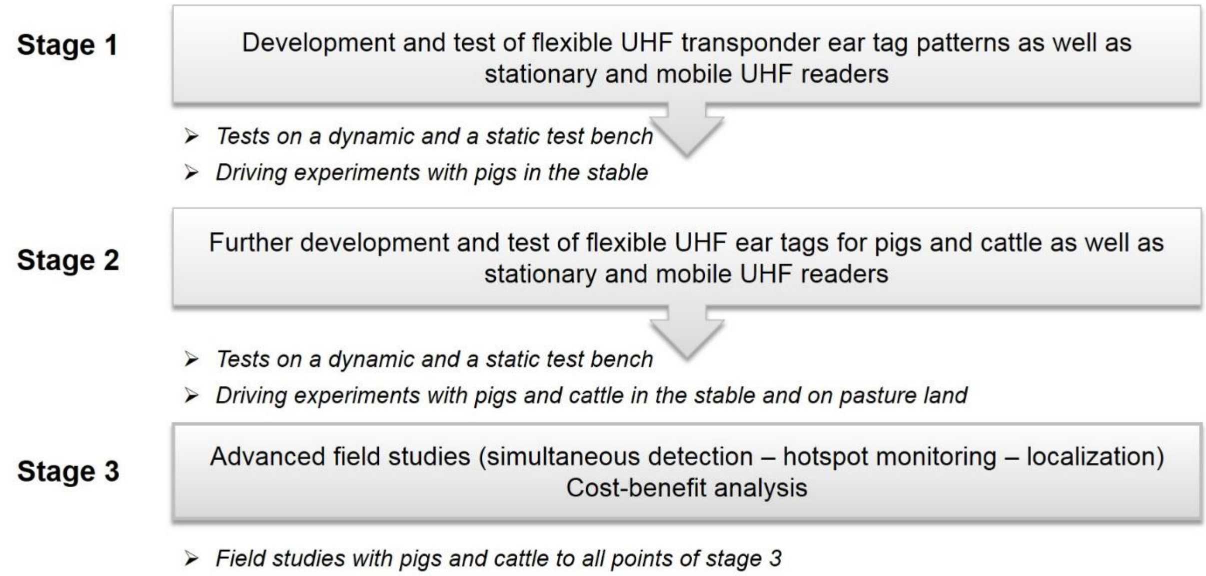

Figure 1.6: Project structure.

All of the transponder types were tested on a dynamic and a static test bench before use with animals. Afterwards, all suitable transponder types were tested in field studies (driving experiments with pigs and cattle). Furthermore, four static UHF readers (with internal or external antennas) and four different external UHF antennas were tested in several experiments. Additionally, a combined LF/UHF handheld was developed.

Part of this thesis are experiments of the dynamic test bench, the driving experiments and the cost-benefit analysis of the UHF system

On the **dynamic test bench**, the UHF transponders were attached to a V-belt, which was installed on a rectangular timber frame. The transponders were driven through a reader field a certain number of rounds. With this breadboard construction, the transponders could be tested at different speeds, with different holder materials, in different orientations, and with a varied reader output power. Their functioning and quality were evaluated with the number of readings per round one transponder exemplar achieved. The quality of one transponder type was determined through the average of all transponder exemplars. These tests reflect in model form the application of the system in practical driving trials (cf. chapter 2.1).

The transponder types could be tested under practical conditions in **driving experiments (simultaneous detection)** with pigs and cattle. The animals were driven through a gate of UHF readers for several rounds, the number of readings per round and the reading rates of one transponder type exemplar was calculated. The average of all transponder type exemplars again showed the quality of one transponder type. Additionally, the functioning and durability of the transponder types in the stable environment could be tested. The driving experiments with pigs were only performed inside, while the driving experiments with cattle were performed in the stable and on pasture land. The influence not only of the animals' ears themselves, but also the influence of metallic surfaces and water in the stable environment was examined (cf. chapter 2.2).

A **cost-benefit analysis** was calculated for different UHF RFID applications. On the basis of four different floor plans (2 x pig house: conventional and pig port; 2 x dairy cattle: small farm and big farm), different equipment scenarios were calculated. Not only the costs, but also the monetarily assessable and the non-monetarily assessable benefits were pointed out (cf. chapter 2.3).

Further research is done on a static test bench, the hotspot monitoring and localization of the UHF transponders by others.

On the **static test bench**, the size and form of the effective transponder ear tag reading area and the received signal strength indicator (RSSI) could be investigated. The RSSI provided information on the reception field strength and the reading area provides information on the directional pattern of the transponder. The transponders could be tested in different orientations, with different readers and various output powers of the readers. The transponder exemplars could be individually positioned in a polystyrene foam block on a 350 x 350 cm horizontal working area. With the aid of two linear drives, the polystyrene pillar could be positioned orderly or randomly at desired points in front of or underneath a UHF reader (Adrion et al., 2015a).

Additional experiments for the **hotspot monitoring** of pigs were implemented on an experimental station and on a private farm. Therefore, several UHF RFID reader antennas were attached to hotspots in the animals' surroundings (trough, drinker, device with playing material, and passage to the open-air area). With the aid of video cameras (video observation), the actual presence of the animal at an antenna (hotspot) was compared to the time stamp of the UHF RFID system. The sensitivity, specificity, accuracy, and preciseness of the UHF RFID system at different settings were calculated.

For the test of **localization**, a UHF RFID antenna grid was mounted to the ceiling of one pen on the experimental station. This pen was divided into even sections which were each allocated with one antenna. Again with the aid of video observation, the displayed presence of one animal of the UHF system could be proofed by the video data.

A database and special software applications were developed for the test benches, the driving experiments, the hotspot monitoring, and the localization of the pigs.

1.6 Structure of the work

The structure of the thesis presented is oriented towards the structure of cumulative dissertations. In the frame of this thesis, three main parts of the whole project are presented in the form of scientific research papers. Subsequently, there will be an overarching discussion and a conclusion of the thesis presented.

The following three research papers are published in or submitted to peer reviewed journals:

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

   Published in: Computers and Electronics in Agriculture 113 (2015) 81-92

   Authors: Nora Hammer, Felix Adrion, Dagmar Jezierny, Eva Gallmann, Thomas Jungbluth

2. Title: Comparison of different ultra-high-frequency transponder ear tags for simultaneous detection of cattle and pigs

   Published in: Livestock Science 187 (2016) 125-137

   Authors: Nora Hammer, Felix Adrion, Max Staiger, Eva Holland, Eva Gallmann, Thomas Jungbluth

3. Title: Cost-benefit analysis of an UHF-RFID system for animal identification, simultaneous detection and hotspot monitoring of fattening pigs and dairy cows in their production environment

   Published in: Landtechnik – Agricultural Engineering 72(3) (2017) 130-155

   Authors: Nora Hammer, Mareike Pfeifer, Max Staiger, Felix Adrion, Eva Gallmann, Thomas Jungbluth

2 Publications

2.1 First publication:

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

Authors: Nora Hammer, Felix Adrion, Dagmar Jezierny, Eva Gallmann, Thomas Jungbluth

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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

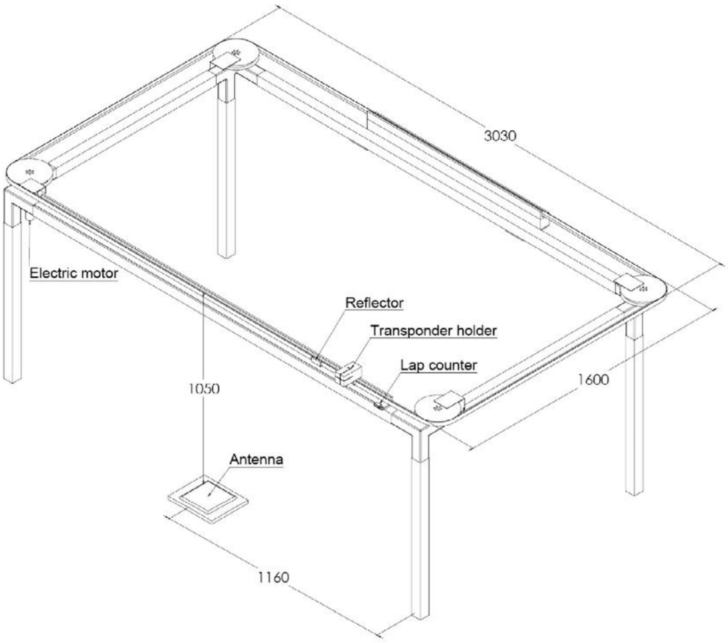

Fig. 1. Construction of the test bench (dimension in mm).

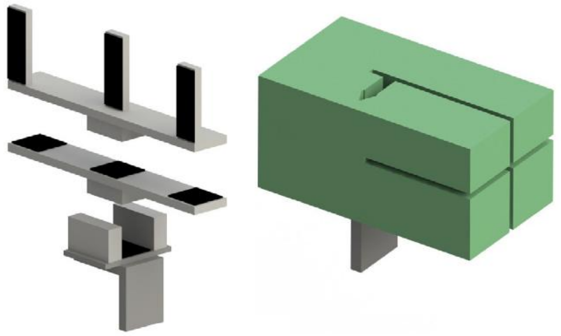

Fig. 2. Transponder holder. PVC holder (left), two attachments for six orientations. XPS holder (right), one holder for six orientations.

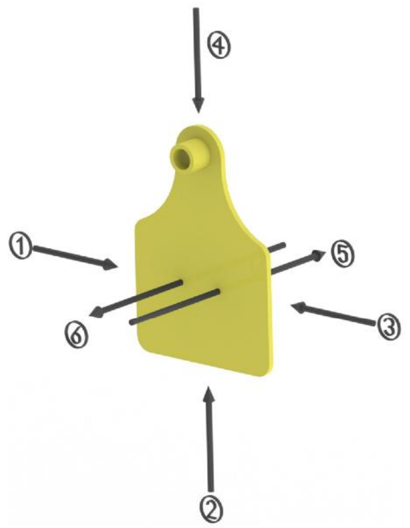

Fig. 3. The six possible transponder orientations. Reader radiates at the left narrow side (1), bottom side (2), right narrow side (3), top side (4), front side (5) and back side (6) of the ear tag.

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

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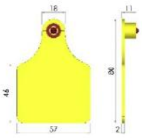
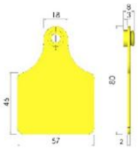
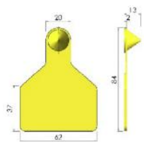
Table 1
Overview of the passive transponder patterns and their characteristics used for the experiments. Figures show the dimensions of the ear tags used with the transponders.

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

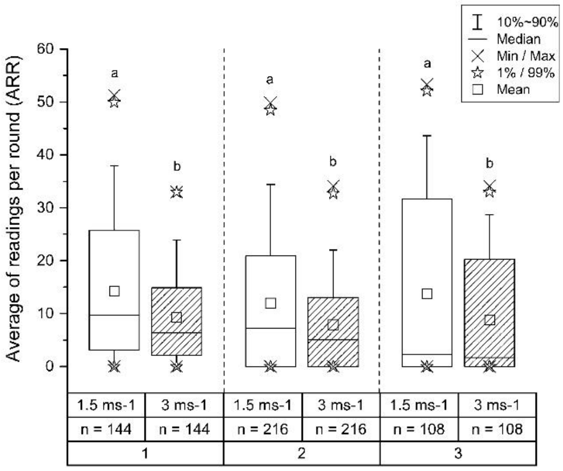


Fig. 4. Differences between the average of readings per round (ARR) in terms of speed (1.5 m s^{-1}, 3.0 m s^{-1}) analysed in three experiments. Experiment 1: transponder types A, B1, B2, B3, holder material PVC; Experiment 2: transponder types A, A1, B4, holder material PVC; Experiment 3: transponder 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 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.

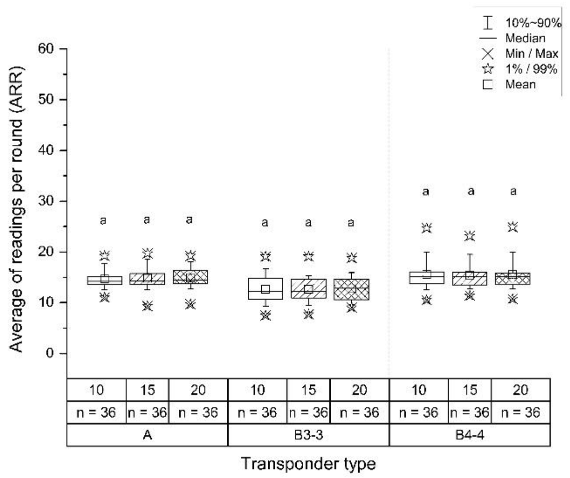


Fig. 5. Differences between the average of readings per round (ARR) in terms of varying the number of rounds (10 vs. 15 vs. 20) based on three transponder types. Holder material XPS and reader setting 'triggered read' with a speed of 3.0 m s^{-1} were used. *n*: repetitions, a, b: different letters within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

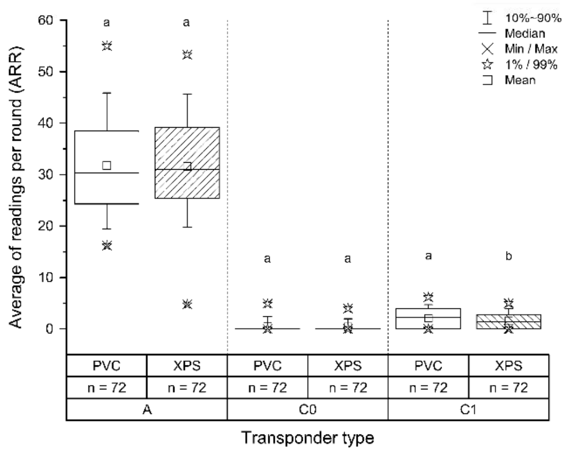


Fig. 6. Differences between the average of readings per round (ARR) in terms of two different transponder holders (PVC vs. XPS) based on three transponder types. Reader setting 'triggered read' and two speeds (1.5 m s^{-1}, 3.0 m s^{-1}) were used. *n*: repetitions, a, b: different letters within a transponder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

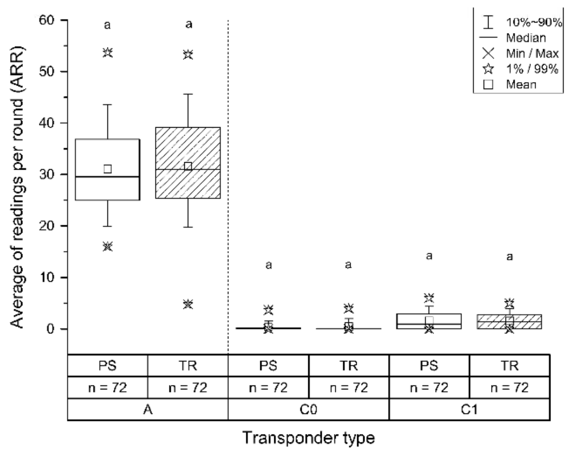


Fig. 7. Differences between the average of readings per round (ARR) in terms of two different reader settings ('presence sensing' (PS) vs. 'triggered read' (TR)) based on three transponder types. Holder material XPS. Two speeds were included (1.5 m s^{-1}, 3.0 m s^{-1}). *n*: repetitions, a, b: different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

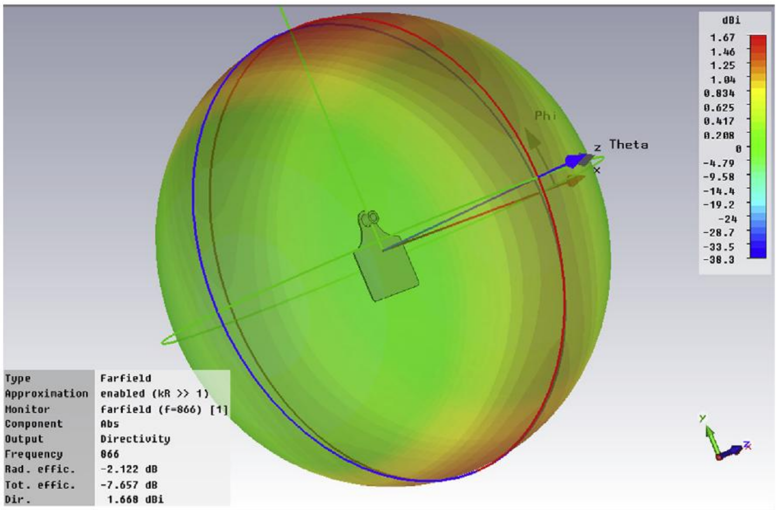


Fig. 8. Directivity of the folded dipole antenna of transponder type A (figure: deister electronic GmbH, CST Microwave Studio®).

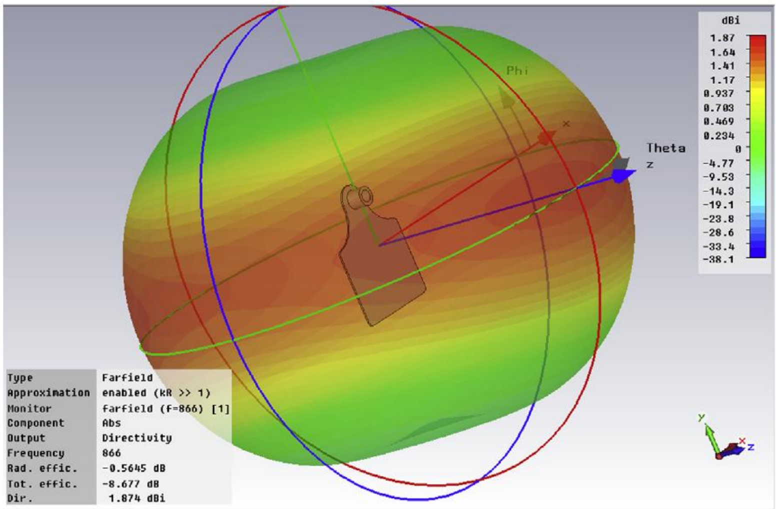


Fig. 9. Directivity of the PIF antenna of transponder types B3-4, B4-4 and B5 (figure: deister electronic GmbH, CST Microwave Studio®).

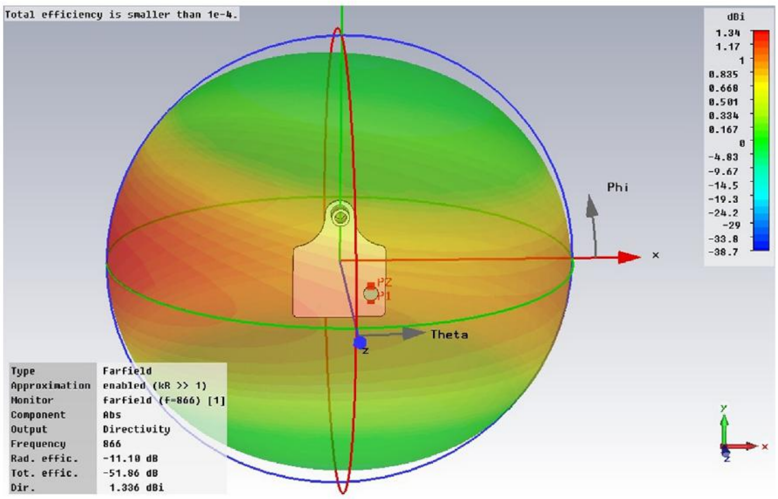


Fig. 10. Directivity of the PIF antenna of transponder type C2 (figure: deister electronic GmbH, CST Microwave Studio®).

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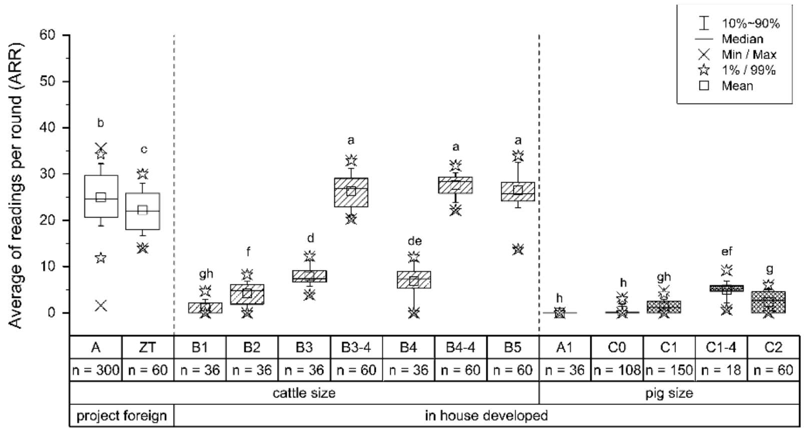

Fig. 11. Test of statistical significance of the average of readings per round (ARR) in terms of the different transponder types. Depending on the experiment, PVC or XPS as a transponder holder and 'triggered read' or 'presence sensing' as reader setting was used. All the experiments were performed at 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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2.2 Second publication:

Comparison of different ultra-high-frequency transponder ear tags for simultaneous detection of cattle and pigs

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Comparison of different ultra-high-frequency transponder ear tags for simultaneous detection of cattle and pigs

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Electronic animal identification is an important technology in modern animal husbandry providing great benefits. Low-frequency applications are state-of-the-art within the radio frequency identification of animals. Quasi-simultaneous detection of several animals and reading of the transponders over longer distances is impossible with low-frequency systems. Ultra-high-frequency (UHF) applications are suitable for this purpose. However, UHF systems have disadvantages through their susceptibility to metallic surfaces and liquids. Thus, the reflection and absorption of electromagnetic radiation in the animals' environment is often problematic. Consequently, an adjustment of the transponder ear tags regarding mechanical stability and functionality close to water (ear tissue) is necessary. In this project, targeted adjustments and a further development of UHF transponder ear tags concerning the resonance frequency were made. Three trials with cattle and two trials with pigs were performed in this study. Cattle were driven through a reader gate for ten rounds and six different types of transponder ear tags designed in-house were tested. The influence of the environment (indoor vs. outdoor), reader orientation at the gate (sideways vs. above) and output power of the readers (1.0 vs. 0.5 W) were tested in two experiments. The average number of readings per round and the reading rates of the transponder ear tag types were taken as target variables. In the trials with pigs, three transponder ear tag types were compared. The animals were driven through the gate for five rounds per repetition, but neither the reader output power nor the reader orientation were varied. The pig experiments were performed indoors.

The results of the cattle experiments showed that the average number of readings per round and the reading rates were significantly higher indoors compared to outdoors. The reader output power of 1.0 W achieved significantly better results compared to 0.5 W. The same applied to the reader orientation 'above' compared to 'sideways'. It could also be shown that an improvement of the transponder and, thus, an adjustment to the animal's ear could be achieved during transponder ear tag type development. A maximum reading rate of 100% was reached with the cattle transponder types finally developed (B3-4, B4-4 and B5).

In addition, an average reading rate of 100% was achieved for one pig transponder ear tag type (C2). However, these experiments have to be treated with caution due to a very low sample size.

1. Introduction

Electronic animal identification is an important technology in modern animal husbandry. It can provide great benefits regarding process control on farms, animal or disease monitoring, animal and meat traceability, and improvement in the entire farm management (Artmann, 1999; Babot et al., 2013; Geers, 1994).

Radio waves are one option for individual electronic animal identification (radio frequency identification, RFID). In addition to the standard low-frequency band (LF, 120–135 kHz) used, high-frequency (HF, 13.56 MHz) and ultra-high-frequency (UHF, 868 MHz, 915 MHz) bands have become more popular and have been tested increasingly in research (Hessel and Van den Weghe, 2013; Hogewerf et al., 2013; Maselyne et al., 2014; Reiners et al., 2009; Stekeler et al., 2011a; Umstatter et al., 2014). Low-frequency RFID systems cannot identify several animals simultaneously and a separation of the animals is unavoidable (Barge et al., 2013; Ribó et al., 2001; Stekeler et al., 2011b). Even when an anti-collision technique is used, the reading rates are not sufficient (Burose, 2010). Additionally, LF and HF systems have a reading range of 1.0 respectively 1.5 m, which requires a small distance between reader and animal (Bauer et al., 2011; Caja et al., 2005; Thurner and Wendl, 2007). However, UHF-RFID benefits from a greater

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read range, the possibility of quasi-simultaneous reading by using anti-collision systems and a higher data transfer rate (Chawla and Ha, 2007). Ultra-high-frequency systems achieve a read range above 3.0 m with passive transponders (Baadsgaard, 2012; Clasen, 2007; Finkenzeller, 2012; Ruiz-Garcia and Lunadei, 2011; Umstatter et al., 2012). This results in a good suitability of UHF systems for animal husbandry by allowing simultaneous detection of larger groups of animal and the possible greater distance between reader and animal. Ultra-high-frequency systems should also be in a position to assume the application areas of LF and HF systems with shorter read ranges by reducing the reader output power. Ultra-high-frequency systems were previously considered as unsuitable for animal identification because of the high absorption potential of water in the UHF band, however, there have been further developments in terms of performance and robustness over time which partly bypass this problem (Adrion et al., 2015; Catarinucci et al., 2012; Finkenzeller, 2012; Stekeler et al., 2011b).

The farmer generally has many choices where to attach a transponder on an animal for on-farm identification. Passive systems are predominantly used in animal husbandry because of size and costs. Due to the light weight of the transponders, they are compatible with all mounting options. A collar is often used with dairy cattle. However, the collar is not a realistic option for pigs and fattening cattle, mainly because of the high costs and the risk of ingrowth with quickly growing animals. The use here of either an encapsulation for implantation or a transponder attached to an ear tag is more reasonable (Caja et al., 2005).

Encapsulation for implantation would not be the method of choice because of the potential high water absorption in the UHF band and the issue of fast removal from the carcass at the slaughter line (Merks and Lambooij, 1990). Using this operating frequency, an electronic ear tag seems to be the best choice for pig and cattle identification.

The legal foundation for pig and cattle identification in the European Union 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). Combining the official identification via an ear tag permitted already with the on-farm identification seems to be an obvious development.

1.1. *Simultaneous individual animal identification with UHF-RFID*

There have only been a few projects testing UHF ear tags for animal identification directly on the animals in practice. Cooke et al. (2010) used a UHF ear tag in their experiments for the simultaneous registration of deer, sheep and cattle on different farms. In the deer experiments, they achieved a reading rate between 75% and 100% with a gangway width of just above 2.0 m, depending on the reader position. The reading rate of the sheep experiments was between 94% and 100%, depending on the reader type, reader position and race width. They only obtained a reading rate of 72% in their cattle experiments at a race width of 2.6 m. However, an adjustment of the test conditions could not be performed here (Cooke et al., 2010). Further experiments with sheep were performed within a project called Rosei. Here, the authors achieved reading rates of 100% with a UHF transponder ear tag and two antennas in a metal race. They completed 2800 individual passes without a failure (European Commission, 2015). Stekeler et al. (2011b) attached a rigid UHF transponder to a pig ear tag and drove fattening pigs through a gate with two readers. They achieved a reading rate between 71.2% and 77.5%, while comparing different reader positions at a race width of 1.1 m. A UHF ear tag was developed for use in pigs in a project called "PigTracker". A reading rate of $>95\%$ with a reading distance of 2.0 m was achieved in driving experiments with piglets (Baadsgaard, 2012; Swedberg, 2012). Hogewerf et al. (2013) carried out driving experiments with a button-type ear tag and five groups of pigs (10 or 11 pigs in each group) with a reader supplying four antennas. In a first trial in a 2.0 m broad hallway, they achieved a reading rate of 89.6% without a further adjustment of the experimental design. In conclusion, to the best of the authors' knowledge, the UHF technology has not been tested very often and a reading rate of 100% has seldom been reached.

1.2. *Ear tag technology*

There can be a general differentiation between rigid and flexible ear tags. The rigid ear tags are mostly button ear tags, and the transponder is inlaid into a round solid plastic ear tag. The surface available for the transponder antenna is very limited and the variability of the antenna structure of the transponder is restricted. Flexible ear tags, on the other hand, have a larger flat part where the transponder can be integrated. In general, the transponder has to be grouted into the ear tag to retain the size and not increase its weight. A professional grouting is very important to protect the transponder and to ensure durability.

The impedance of the transponder's antenna is changed depending on the material of the ear tag and its permittivity. This results in a shift of the transponder's resonance frequency. A reduction of the resonance frequency occurs usually (Rao et al., 2005). Consequently, the transponder must be adjusted to its surroundings (ear tag). The detuning of a transponder through the variation of its antenna length, label and antenna material, size and form are possibilities for a targeted adjustment and its successful use in animal husbandry (Adrion et al., 2015; Catarinucci et al., 2012; Lorenzo et al., 2011; Nikitin and Rao, 2006).

A few companies, for example, "definitive! business applications e.K., Münster, Germany", "MS Schippers GmbH, Kerken, Germany" and "Simplum GmbH, Berlin, Germany", currently sell rigid UHF ear tags for animals. Flexible UHF ear tags are also sold; "HANA micron Inc, Asan-si Chungnam, South Korea" can be mentioned here as an example.

1.3. *Objectives*

This study is part of a research project which is concerned with the development and testing of flexible UHF in-house developed ear tags for animal identification developed in-house. An optimal resonance frequency adjustment of the different transponder types developed to an animal's ear is the main aim. First systematic laboratory tests were carried out before testing the UHF ear tags in practice (Adrion et al., 2014, 2015; Hammer et al., 2013, 2014, 2015). According to the test bench results, different UHF ear tag types emerged as suitable for use in animal husbandry during the progress of the project.

Subsequently the test of these transponder ear tag types under practical conditions served the aim to identify the most suitable and durable one for simultaneous detection of cattle and pigs. Therefore, six different transponder ear tag types for cattle and three types for pigs were tested in driving experiments. The influence of the environment (indoors vs. outdoors), the reader orientation (sideways vs. above) and the reader output power (0.5 vs. 1.0 W) was also tested in the cattle experiments.

2. Materials and methods

2.1. *Animals, UHF transponder ear tag types and UHF readers*

All the experiments were conducted at the Agricultural Sciences Experimental Station of the University of Hohenheim. Unfortunately, it was not possible to test all transponder ear tag types

Table 1
Overview of transponder types (Hammer et al., 2015).

Transponder type	Number of ear tags	Characteristics	Species
B1 B2 B3	6 5 4	– Antenna sized for cattle ear tags – Antenna design: Pif antenna – Variation of antenna length and, thus, resonance frequency (higher from B1 to B3) – Label and antenna material: layers of adhesive aluminium foil – Grouted into a cattle ear tag	Cattle
B3-4 B4-4	8 8	– Further development of B3 – Different label and antenna material: polyimide foil with aluminium cover	Cattle
B5	15	– Further development of transponder type B4-4 – Variation of antenna length and, thus, resonance frequency (higher for B5) – Label and antenna material: polyimide foil with aluminium cover	Cattle
C1	7	– Antenna sized for pig ear tags – Antenna design: Pif antenna – Label material: layers of adhesive aluminium foil – Grouted into a cattle ear tag	Pigs
C1-4	3	– Second generation of C1 – Different label and antenna material: polyimide foil with aluminium cover	Pigs
C2	10	– Further development of C1-4 – Variation of antenna length and, thus, resonance frequency (higher for C2) – Label and antenna material: polyimide foil with aluminium cover	Pigs

at the same time because of the production process and their continued development during the project. This led to the implementation of a number of experiments per animal species. Three experiments were performed with cattle, incorporating 29 heifers of the Holstein-Frisian breed and two heifers of the Jersey breed. Two experiments also were performed with fattening pigs: 20 fattening pigs of the German Landrace × Pietrain breed and Swabian breed were used.

Six cattle-sized and three pig-sized transponder types were tested. Table 1 gives an overview of the transponder types and generations used per animal species. All of the transponder ear tag types presented here were transponder patterns developed and improved within the project period. The different transponder ear tag types and their characteristics are described in detail in Hammer et al. (2015), however, the transponder design is especially subject to patent protection and cannot be described in more detail. This is also the reason why more detailed information cannot be given for the resonance frequency.

All of these transponder types were two-dimensional Pif antennas with a similar antenna design. They differed basically in the length of the radiating part of the antenna. The cattle and the pig transponders resembled each other. Only the ground plane and the radiating part of the pig transponders were smaller and shorter compared to the cattle transponders. All of the transponder types had a relatively similar reading field. They were all equipped with an Impinj Monza 4® chip. The transponder samples were grouted into a traditional plastic cattle ear tag (Primaflex® 1/3, Caisley International GmbH, Bocholt). The transponders intended for use on pigs were also grouted into a cattle-sized ear tag because of technical restrictions at this stage of development. The dimensions of the ear tag are shown in Fig. 1. The transponder was grouted into the female part of the ear tag and, thus, lay on the inner side of the animal's ear for all experiments.

The animals were driven through a gate containing two UHF readers (TSU 200, deister electronics GmbH, Barsinghausen, Germany) to test the suitability of the transponder ear tags for simultaneous detection. Only a limited number of ear tags could be tested because of the time-consuming production process and its cost and the high rates of loss during the production.

The same UHF readers were used for all cattle and pig experiments. These readers were characterized by an internal antenna covered by a robust IP67 housing. They worked with an operating frequency of 868 MHz (EU), a circular polarised radiation and an opening angle of 90°. The readers adjusted themselves to their environment with an auto-tune function. An effective radiated power of a maximum of 1.0 W [W] was possible with these readers (antenna gain included). The antenna field was switched on and off manually or by software at the beginning and end of each repetition (cattle experiments: 1 repetition = 10 rounds; pig experiments: 1 repetition = 5 rounds). The transponder reset time (reset of the inventoried flag in the anti-collision procedure) was set at 100 ms. This implies that after a time of 100 ms, all

Fig. 1. Dimensions (mm) of the Primaflex® ear tag (left), pig with UHF transponder ear tag in its right ear (centre) and cattle ear with UHF transponder ear tag (ear tag 34) and standard visual ear tag (right).

transponders in the reading field can be read again. Because of the very short reading time (> 10 ms) of one transponder, all transponders present had the chance to be read in 100 ms. Thus, a number of readings per second are possible. The mounting of the readers depended on the experimental design and will be described in the following chapters.

2.2. Cattle experiments

The animals were tagged with an UHF ear tag at the beginning of the experiment. Each transponder ear tag was coded with an individual number. This number was linked to the individual number of the visual ear tag, and the animal's name, height and weight via a custom-built configuration software programme (Phenobyte GmbH und Co. KG, Ludwigsburg, Germany). The function of each transponder ear tag was checked on each test day before the driving experiments started. All animal- and test-related data were stored in a database (Phenobyte GmbH und Co. KG, Ludwigsburg).

The focus of experiment 1 was the comparison of the three different cattle transponder types, which differed strongly in their resonance frequency. Three transponder ear tag types (B1, B2, B3) were compared indoors with the reader orientation called 'sideways' in the first experiment (cf. Fig. 2). The different transponder types were assigned to an animal randomly. The UHF ear tag was tagged in the right or left ear of 15 animals (left=9; right=6) additional to and depending on the location of the visual ear tag in the ear.

The second experiment focused on the influence of the environment (indoors vs. outdoors), reader orientation (sideways vs. above) and reader output power (1.0 vs. 0.5 W) on the reading success of two transponder ear tag types developed further (B3-4, B4-4). Each of a group of 16 heifers was tagged with one of the two different types of UHF transponder ear tags randomly in the left ear in addition to the visual ear tag.

The third experiment was carried out after completion of the second experiment. In this experiment, each of 15 cattle was tagged with a UHF transponder ear tag of type B5 in their left ear next to the visual ear tag. All the parameters of the second experiment were tested for this transponder type except for the reader output power. Based on the results of cattle experiment 2, only a reader output power of 1.0 W was used in the third experiment. A comparative evaluation of the transponder types of experiment 1 and 2 was performed in this manuscript. In order not to falsify the comparison, the results of transponder types B3-4, B4-4 and B5 tested with 1.0 W were the basis of this evaluation.

The reader height and gate width were kept constant throughout all the cattle experiments. The cattle were driven through a gate containing two UHF readers for ten rounds per repetition in all trials. Several repetitions were performed on each test day. Table 2 gives an overview of all cattle experiments.

The experimental set-up indoors is shown in Fig. 2, while Fig. 3 shows the set-up for outdoors.

Only the reader orientation 'sideways' was tested in cattle experiment 1, while the reader orientation 'above' was added in experiment 2. Using the reader orientation 'sideways', one reader was located on the left side (in running direction, clockwise) of the gate, while the other was placed on the right side. When passing the gate, the right reader radiated from the front towards the animal's head and the left reader radiated from behind towards the back of the head. Both readers in all cattle experiments were mounted at a height of 230 cm. Thus, an undisturbed movement of the cows and the stuff in the barn was possible while the radiation angle of the readers radiated the whole width of the gateway. The inclination angle of both readers was 30°. Using the reader orientation 'above', both readers were installed horizontally and radiated towards the animal's head from above with an inclination angle of 90° (Figs. 2 and 3).

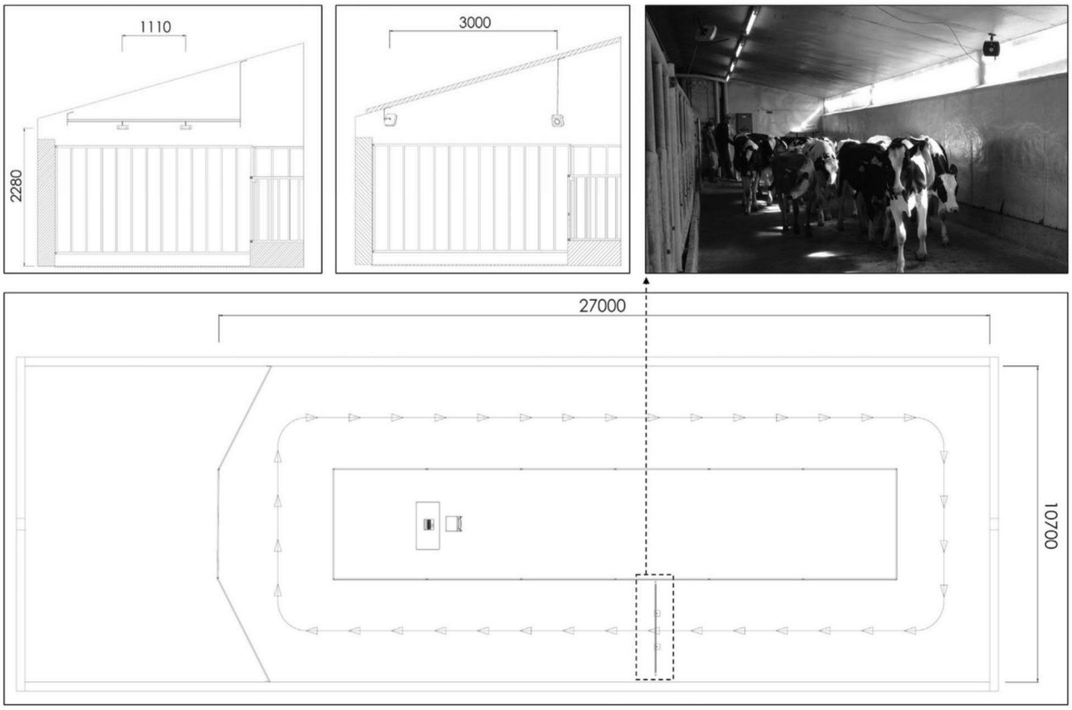

Fig. 2. Experimental set-up for the cattle experiments indoors (dimension in mm).

Table 2
Overview of cattle experiments.

Experiment	Transponder type	Number of animals	Repetitions
1	B1	6	8
	B2	5	8
	B3	4	8
2	B3-4	8	80
	B4-4	8	80
3	B5	15	40

2.3. *Pig experiments*

The experimental set-up of the pig experiments was similar to the cattle experiments and oriented towards Stekeler et al. (2011b).

After all the animal- and test-related data were collected, the pigs were driven through a gate with two UHF readers for five rounds (5 rounds=1 repetition). After a break of at least 45 min, the procedure was repeated. Two repetitions were performed on each test day and an effective radiated power of 1.0 W was used. Three transponder ear tag types were tested in two experiments.

In the first experiment, two transponder ear tag types (C1; C1-4) were randomly spread through three pig groups (10 pigs each). Only a very limited number of transponder ear tags could be tested here (C1=7 ear tags; C1-4=3 ear tags). The remaining animals were not part of this experiment. These two transponder types were tested over a period of about eight weeks.

In the second experiment, an improved transponder type (C2) was examined. One group (10 pigs) was tagged with this transponder type. These pigs were driven through the gate on two test days within two weeks.

All pigs of both experiments were tagged in the right ear. Because of the very low sample size of the two experiments, the results of the three pig transponder types will be presented in parallel within the frame of this manuscript. These results should be seen more as an outlook that a good simultaneous reading of the pig transponder types is also possible.

The experimental set-up and the exact dimensions of the pig experiments are shown in Fig. 4.

Both readers were mounted at a height of 167 cm. The gate width was 166 cm. One reader was located on the left side (direction of movement, clockwise) of the gate, while the other was placed on the right side. When passing the gate, the right reader radiated from the front towards the pig's head and the left reader

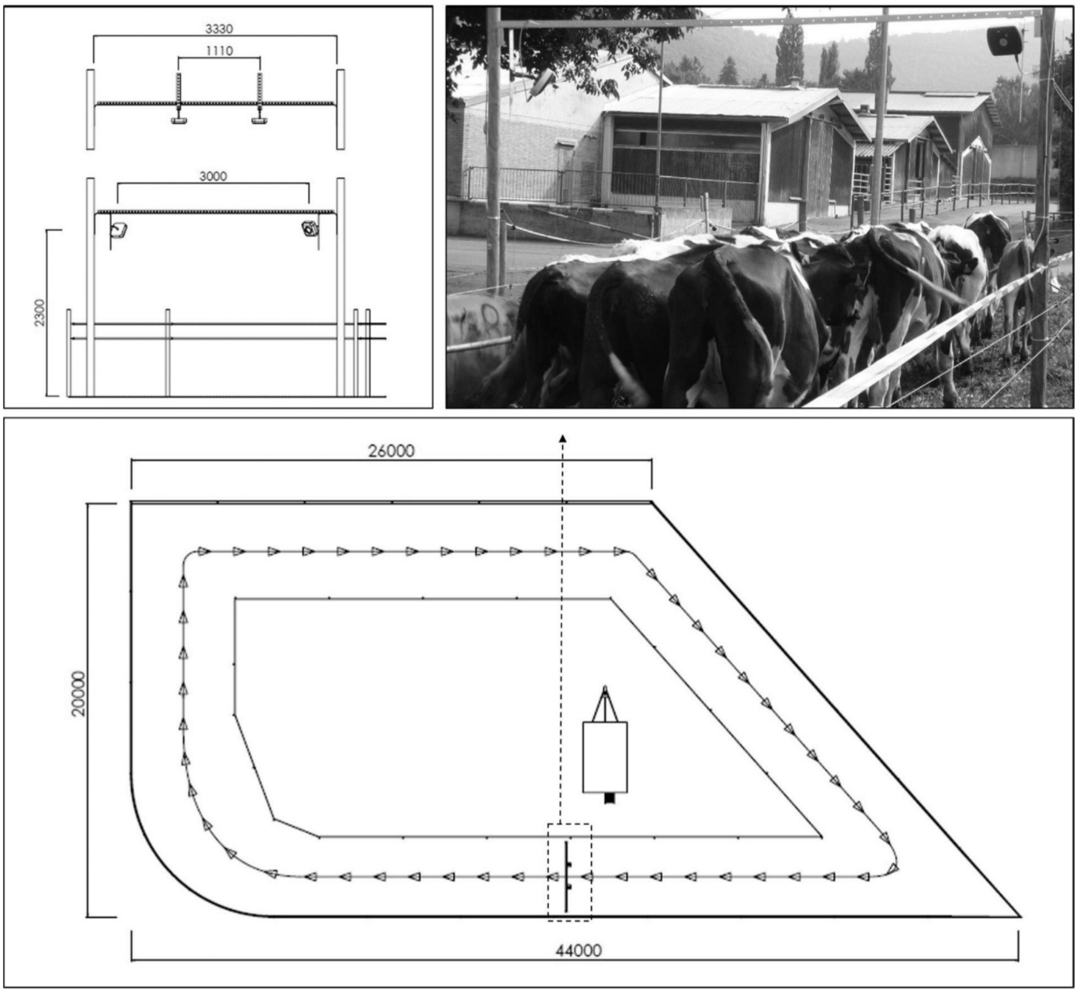

Fig. 3. Experimental set-up for the cattle experiments outdoors (dimensions in mm).

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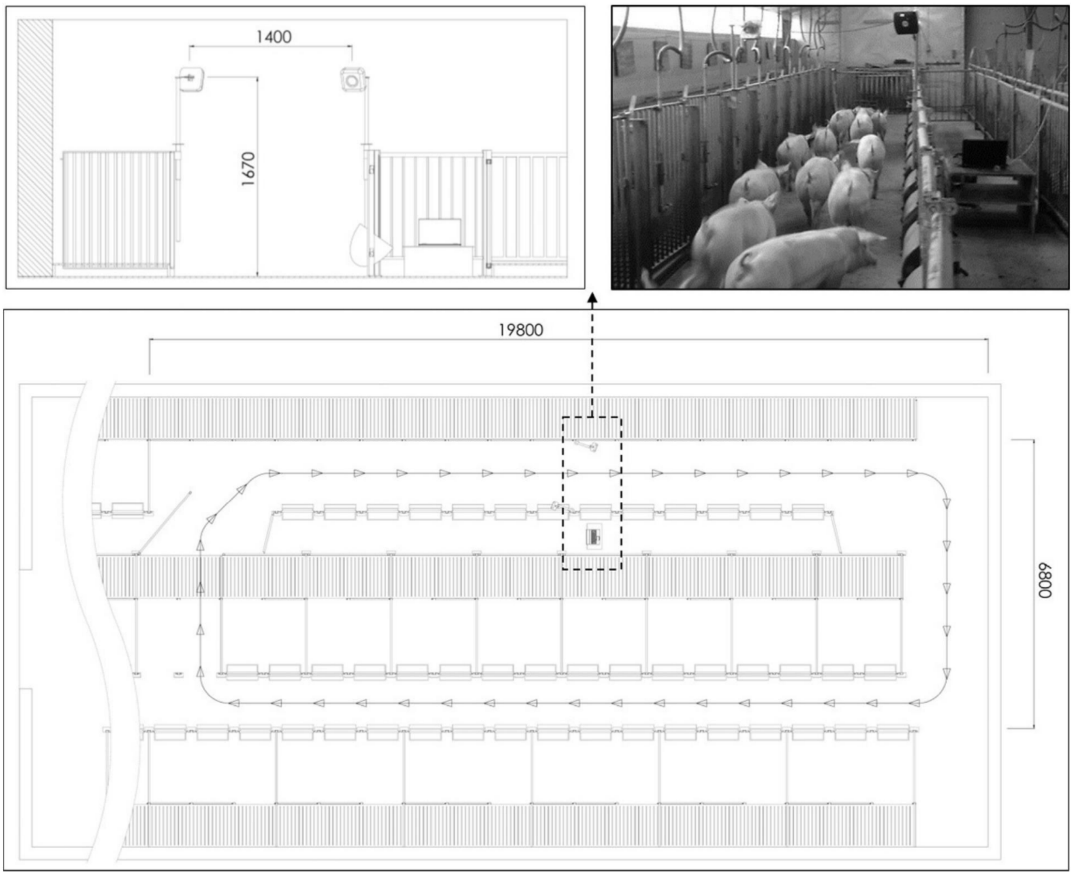

Fig. 4. Experimental set-up of the pig experiment (dimensions in mm).

radiated from behind, towards the back of the head. The inclination angle of both readers was 20°. Both readers were also rotated by 20° to the centre of the gateway.

2.4. Data preparation

Two parameters were taken into account to evaluate the quality of the different transponder types for all experiments performed. The 'number of readings per round' achieved by each transponder ear tag was recorded for each round. Consequently, an 'average number of readings per round' could be constructed for each transponder ear tag (Eq. (1)). This was carried out for every repetition.

$$\text{Average of readings per round} = \frac{\sum \text{Number of readings}}{\sum \text{Number of rounds}} \quad (1)$$

Furthermore, the reading rate of an individual transponder ear tag was calculated for every repetition. Therefore, a 'number of readings' equal to zero was listed as zero, and a 'number of readings' greater than zero was listed as one for one round. Subsequently, a proportional analysis was performed. The reading rate of an ear tag was calculated by the following formula (Eq. (2)):

$$\text{Reading rate [\%]} = \frac{\sum \text{rounds, where number of readings} \geq 1}{\sum \text{Number of rounds}} * 100 \quad (2)$$

A comparison of the transponder types was performed in cattle experiment 1 and a mixed model (SAS® 9.4 proc mixed) could be calculated. The model creation was started with the full model with all interactions (2-fold to 4-fold). The random effects for the 'number of readings' were the repetition and the ear tags. When calculating the mixed model for the 'reading rates', only the ear tag was used as the random effect. The normal distribution within the calculation was examined and the data was transformed. A $\text{Log}_{10}(y+1)$ transformation for the 'number of readings' and an arcsin $(\sqrt{y}/100)$ transformation for the 'reading rates' were used. The normal distribution was determined via Q–Q plots graphic analysis. Firstly, no variance homogeneity was given. Therefore, the transponder types were determined as a grouping variable in the analysis and the variance component per transponder type estimated. Comparisons of means were conducted with t-tests. A simulate adjustment for multiple comparisons of means followed. Unfortunately, no randomised implementation of the test procedure was possible because of operational processes on the experimental station for cattle experiment 2 and 3. A mixed model was also calculated for cattle experiment 2 because the data set met all other requirements of the model. The repetition and the ear tag were used here as random effects in both models. The same data transformations as those of cattle experiment 1 were used. Because transponder type B5 was tested in another experiment (experiment 3), this transponder ear tag type could not be integrated into the mixed model of cattle experiment 2.

Table 3 shows an overview of the fixed effects and the final

Table 3
Overview of fixed effects and final mixed model used in cattle experiments 1 and 2.

	Cattle 1	Cattle 2
Fixed effects	transponder type (T)	Transponder type (T), performance (P), reader orientation (O), place (PL), all interactions (AL)
Final model	Number of readings:	Number of readings:
	y=T+R+E+e	Y=T+P+O+PL + AL+ R+E+e
	reading rates:	Reading rates:
	y=T+E+e	y=T+P+O+PL + AL + R+E+e

R=repetition; E=ear tag; e=residual error.

model, after eventual withdrawal of non-significant effects or interactions.

A graphic representation with the types of experiment 2 was chosen to classify cattle transponder ear tag type B5. The same applied to the pig transponder types, because of the very low sample size.

3. Results

3.1. Cattle experiments

3.1.1. Experiment 1 (Comparison of transponder types B1, B2 and B3)

Fig. 5 shows the results of experiment 1 in cattle, where different transponder types (B1, B2 and B3) were compared. A different number of ear tags was available for every transponder type. Six ear tags of type B1, five of type B2 and four of type B3 were tested in this experiment. The three different transponder types showed distinct differences.

With regard to the overall mean of readings per round and the average reading rates for all test days, transponder type B1 performed worst (2.1; 30.4%), while transponder type B3 performed best (28.7; 94.4%). B2, with 16.5 readings per round and 78.8% average reading rate, lay in between the two other transponder types. The average number of readings per round and the reading rates showed a clear increase from B1 to B3. The statistical analysis of both parameters showed a significant difference between transponder type B1 and B2 and between B1 and B3. However, no significant difference was obtained between B2 and B3. It should also be mentioned that transponder type B3 showed the greatest variance in the average of readings per round, but the smallest variance in the reading rates. No lost or broken ear tags were recorded within this test period.

3.1.2. Experiment 2 (influence of environment, reader output power and reader orientation on the performance of transponder types B3-4 and B4-4)

With two transponder types developed further (B3-4, B4-4), the influence of a different environment (outdoors vs. indoors), reader output power (0.5 W vs. 1.0 W) and reader orientation (above vs. sideways) on the average of readings per round and the reading rates was tested. Fig. 6 shows the results of the different environments.

It can be seen in Fig. 6 that the overall mean of readings per round and the average reading rates were higher indoors (22.3; 77%) than outdoors (9.3; 66.1%). The statistical analysis also showed a significant difference between the two environments. Additionally, it can be seen that the variance in the average of readings per round indoors is higher than outdoors. This is the opposite of the situation regarding the reading rates.

Fig. 7 presents the results of the different reader output power (0.5 W, 1.0 W). It can be seen that a reader output power of 1.0 W achieved a greater mean of overall readings (21.5) and higher reading rates (81%) compared to the output power of 0.5 W (10.2; 62%). The statistical analysis again confirmed the graphic evaluation and a significant difference between the two output powers was observed.

Similar to the results for the environment, a higher variance for the better variant was seen in the reading rates in contrast to the average of readings per round. The results for the different reader orientations are presented in Fig. 8. A difference was made here between readers mounted on top of the gate ('above') and readers mounted on each side of the gate ('sideways').

It could be shown that significant differences in the average of readings per round and in the average reading rates also existed in terms of the reader orientation. The overall mean of readings per round and the average reading rates were significantly higher for the reader orientation 'above' (18.4; 78.7%) compared to 'sideways' (13.3; 64.3%). Similar to the other parameters, the variant with the

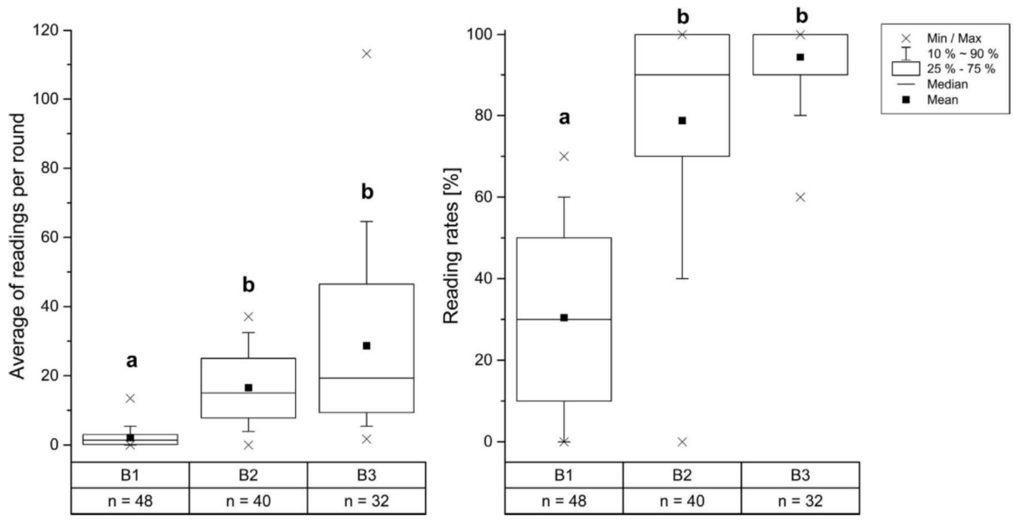

Fig. 5. Average of readings per round (left) and reading rates (right) of cattle transponder types B1, B2 and B3; n: sample size (number of ear tag * repetitions); a, b: different letters indicate that values diverge significantly ($P<0.05$).

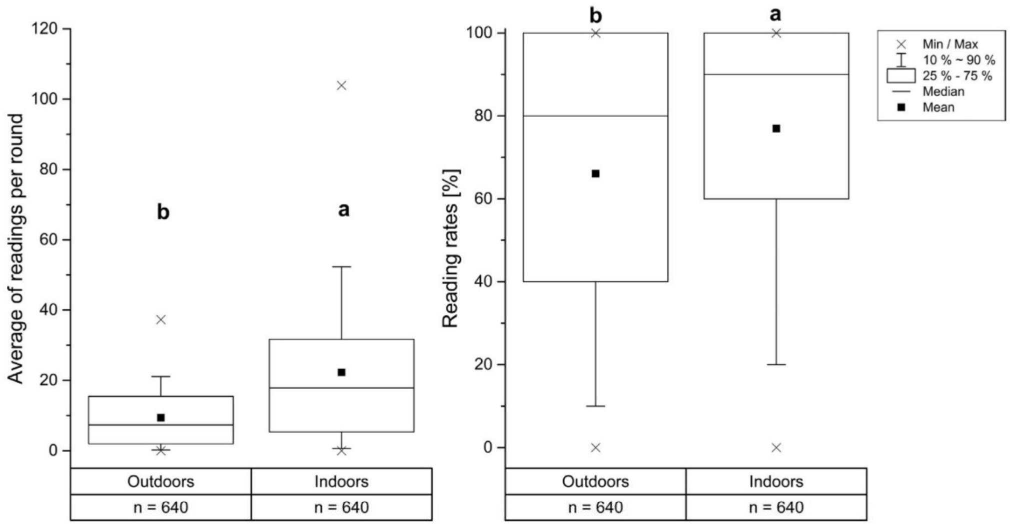

Fig. 6. Average of readings per round (left) and reading rates (right) of cattle transponder types B3-4 and B4-4 indoors and outdoors; n: sample size (number of ear tag * repetitions); a, b: different letters indicate that values diverge significantly ($P<0.05$).

lower variance of the average of readings per round again had a higher variance than the reading rates. Again in general the reading rates show greater variances for both variants.

All ear tags with these transponder types (B3-4, B4-4) stayed functional over the entire period of experiment, and no losses were recorded.

3.1.3. *Comparison of transponder types B3-4, B4-4 and B5*

The results of the statistical comparison of transponder types B3-4 and B4-4 are shown in Fig. 9. The results of transponder type B5 are also presented in this figure to show them in relation to the results of the two other transponder types.

The differences in the overall mean of readings per round (19.7; 23.2) and the average reading rates (73.8%; 88.3%) between transponder type B3-4 and B4-4 are small, as can be seen in Fig. 9. No significant difference was found for the average of readings per round or for the reading rates. In comparison to these transponder types, type B5 achieved a higher overall mean of readings (27.4), but lower average reading rates (86.8%).

No transponder ear tag broke or was lost on any test day. No decline of the transponder performance over time was observed.

Furthermore, it was remarkable that the reading rates of the individual ear tags differed so greatly. Fig. 10 shows the reading rates of the individual ear tags. Regardless of the environment, the ear tags of transponder type B3-4 varied between 20.3% and 99%, while the values of type B4-4 were between 74.6% and 100%. When considering the ear tags of transponder type B3-4 closer, it should be noted that two particular ear tags (17, 26) showed the poorest average reading rates. The ear tags of transponder type B4-4 ranged more homogeneous.

The average reading rates of the ear tags of transponder type B5 ranged between 28 and 100%. The reading rates of two ear tags

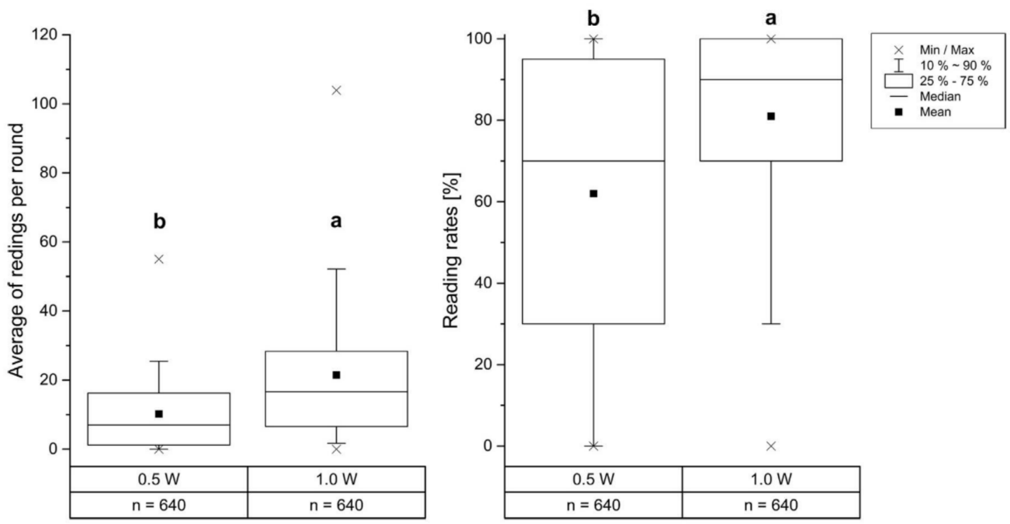

Fig. 7. Average of readings per round (left) and reading rates (right) of cattle transponder types B3-4 and B4-4 with a reader output power of 0.5 W and 1.0 W; n: sample size (number of ear tag * repetitions); a, b: different letters indicate that values diverge significantly ($P<0.05$).

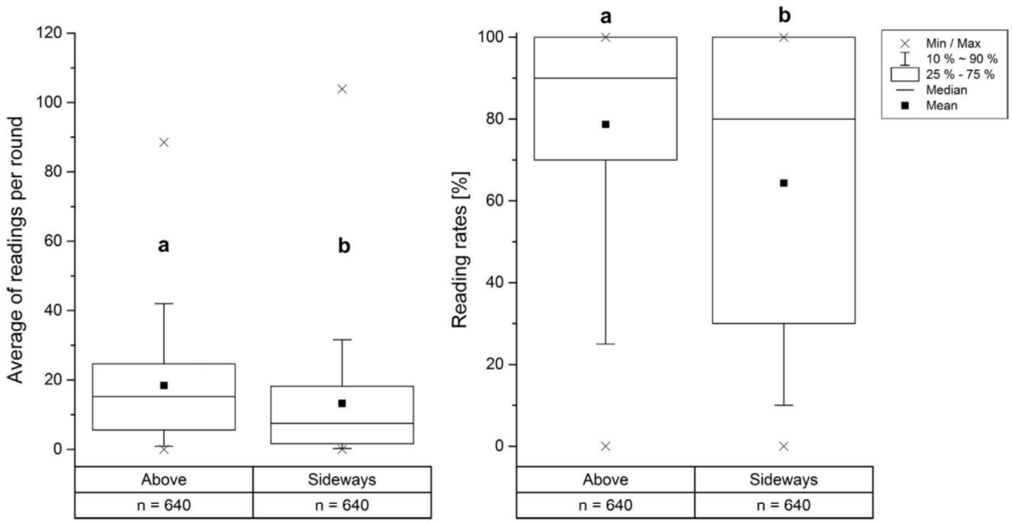

Fig. 8. Average of readings per round (left) and reading rates (right) of cattle transponder types B3-4 and B4-4 in reader orientation 'above' and 'sideways' n: sample size (number of ear tag * repetitions); a, b: different letters indicate that values diverge significantly ($P < 0.05$).

were again considerably worse (7; 17) than the others. The average reading rates without including these two ear tags were between 85 and 100% and, thus, even better and more homogeneous than B4-4.

3.2. Pig experiments

Three transponder types (C1, C1-4 and C2) provided for use on pigs were developed within the project. All ear tags of transponder type C1 were lost or broken in the sixth week of the experiment. Only two ear tags of transponder type C1-4 remained functional until the end of the testing period. Ten ear tags of a third transponder type (C2) were tested in a further experiment. All transponder ear tags were lost or broken within two weeks.

No statistical analysis could be performed for the pig experiments because of the very limited number of ear tags.

The results of performance of the different transponder types can be seen in Fig. 11.

Transponder type C1 performed worse (3.2; 68.5%) compared to type C1-4 (19; 96.5%) in terms of the overall mean of readings per round and the average reading rates. It is also noticeable that the variance of the reading rates for transponder type C1 was quite large. When looking at the averages of transponder type C2, it is conspicuous that the overall mean of readings per round is lower (14.1), but the average reading rate is higher (100%) compared to transponder type C1-4. Within the testing period of transponder type C2, every transponder ear tag was read in every round of the experiment. However, rounds with no readings existed for transponder types C1 and C1-4. Furthermore, it can be seen that the variance within the reading rates is much lower for C1-4 and C2 than for C1.

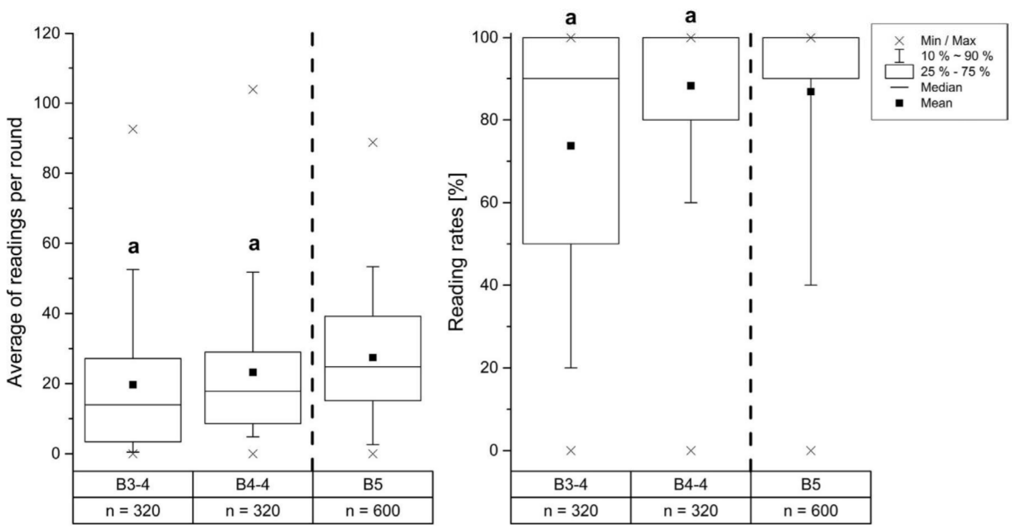

Fig. 9. Average of readings per round (left) and reading rates (right) of cattle transponder types B3-4, B4-4 and B5; n: sample size (number of ear tag * repetitions); a, b: different letters within a transponder type indicate that values diverge significantly ($P < 0.05$); no statistical evaluation for transponder type B5 was performed, as data belong to different experiments.

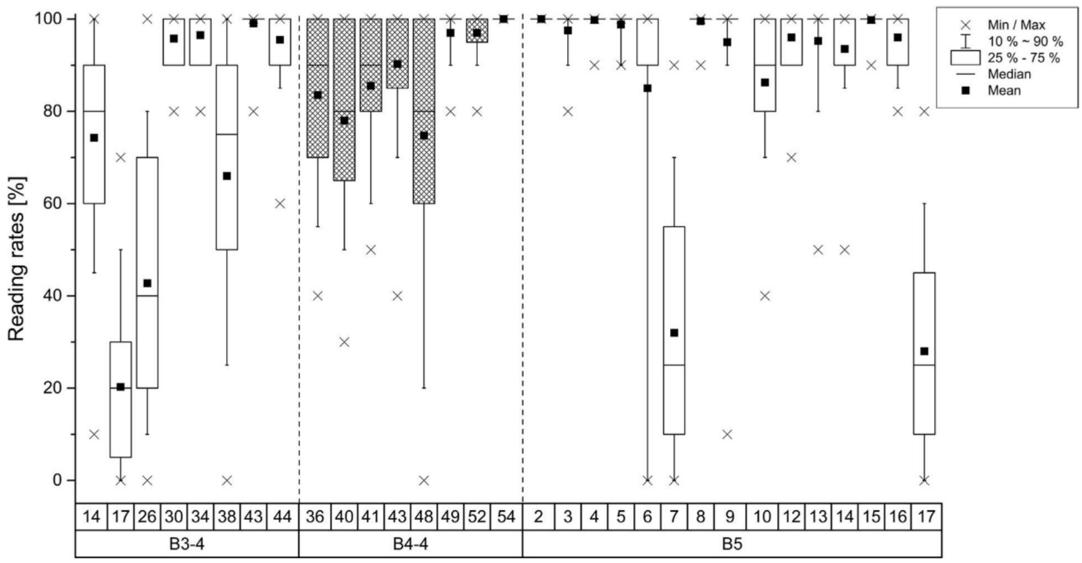

Fig. 10. Reading rates of the individual ear tags named by individual numerals of transponder types B3-4, B4-4 and B5; sample size=40 (repetitions with 1.0 W).

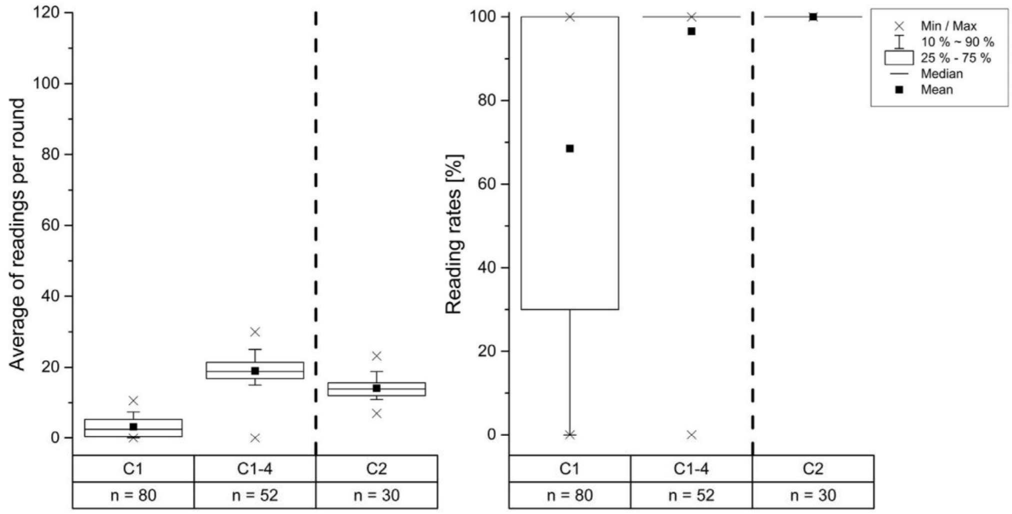

Fig. 11. Average of readings per round (left) and reading rates (right) of pig transponder types C1, C1-4 and C2; n: sample size (number of ear tag * repetitions).

4. Discussion

4.1. Cattle experiments

4.1.1. Cattle experiment 1

Three transponder types for cattle (B1, B2 and B3) developed within the project were compared in the first cattle experiment. Transponder type B3 achieved the highest average reading rate with 94.4%, which is a promising result for the simultaneous detection of cattle. The increasing number of readings per round and the reading rates from type B1 to type B3 can be explained by the adjustment of the resonance frequency. The latter was increased to compensate for the detrimental effects of surrounding materials (plastic ear tag and animal's ear (Table 1)). Transponder type B3 had the highest resonance frequency. The adjustment of the transponders for use in an ear tag seemed to work and an improvement from type B1 to type B3 could be recognised.

4.1.2. Cattle experiment 2

When comparing the two environments, indoors and outdoors, it was remarkable that the overall mean of readings per round and the average reading rates indoors were significantly higher (cf. Fig. 6). This is probably caused by reflections. Indoors, the electromagnetic radiation is reflected by the metallic surface of the barn equipment. In this way, the possibility of a transponder being read by at least one of the two readers is increased. Almost no reflections are present on pastureland (outdoors), thus, the reader–transponder communication has to work in a direct way. If organic material (such as a cow's head) absorbs the electromagnetic radiation, the possibility of reliable reading decreases. This circumstance is also probably the reason for the higher average of readings per round and average reading rate using the reader orientation above. Here again, a significant difference between the two orientations was obtained (cf. Fig. 8). Using reader orientation 'above', the readers radiated from above to the animal's head and the ear tag was covered less by organic material (such as the nose or back of the head of the animal) and could be read more reliably in contrast to the reader orientation 'sideways'. Additionally, with an opening angle of 90°, the distance from the reader to the transponder ear tag was, on average, shorter with this reader orientation. Thus, a higher radiative power of the reader was available for the transponder to send a response signal. A significant difference was found for the parameter 'reader output power'. The overall mean of readings per round and the average reading rates here were significantly higher using a reader output power of 1.0 W (cf. Fig. 7). Again, with 1.0 W, a higher radiative power of the reader is available for the transponder to send a response signal. This is the reason for the difference between the two output powers.

4.1.3. Comparison of transponder types B3-4, B4-4 and B5

An increased number of ear tags would also have assured more reliable results, but a higher number of ear tags was not feasible because of the development process in the project.

Transponder type B4-4 showed a higher average reading rate compared to transponder type B5, but a smaller overall mean of readings per round. Even though no statistical comparison with type B5 was performed, it can be inferred that a further improvement of the adjustment of the cattle transponder was achieved. The average of readings per round and the reading rates improved along the development chain (from experiment 1 to experiment 3). In conclusion, the average reading rates $> 86\%$ indoors and outdoors with a reader output power of 1.0 W and the reader orientation 'above' can be declared as a very good result (transponder types B4-4 and B5). These can be compared with the reading rate achieved by Cooke et al. (2010) of about 72% in cattle trials.

Regarding the comparison of the individual ear tags, it was noticeable that the variability between the single ear tags was not as great for B5 as for B3-4 and B4-4. The ear tags especially of type B3-4 showed great differences. The ear tags of type B5 were generally much more homogeneous, except for two ear tags. One reason for the variability in the reading rates could be the individual animals. The shape of the ear and, thus, the position of the ear tag in the animal's ear, the speed of the animal while passing the gate, the position of the animal in the herd and the head posture might have had an influence on the reading success. All of these parameters influence the absorption of the electromagnetic radiation and the power of the response signal of the transponder more or less. Unfortunately, these parameters were not examined in closer detail in this experiment. Small differences in the single transponders themselves could be another reason. Minimal variations in antenna length or structure at this stage of the project could not be excluded. This could also result in a slightly shifted resonance frequency.

4.2. Pig experiment

This experiment with three pig transponder types (C1, C1-4 and C2) can be better described as a first test with a perspective for further pig transponder development because of the very limited number of ear tags due to this early stage of development and a missing statistical analysis. With respect to the reading performance an improvement with the development of the transponder types could be graphically observed. Transponder type C1-4 achieved a good overall mean of readings per round, while type C2 achieved a very good average reading rate of 100%. Such a high reading rate has not been achieved by any other UHF project with pigs (Baadsgaard, 2012; Hogewerf et al., 2013; Stekeler et al., 2011b).

The durability of the pig ear tags has not turned out satisfactory. All ear tags of transponder type C1 were lost or broken within a relatively short time (42 days with already 30% of this type non-functional after 24 days). However, two out of three ear tags of transponder type C1-4 remained functional until the end of the experiment. The ear tags of type C2 again only stayed functional for approximately two weeks.

It was shown that the label material of C1-4 (polyimide foil with aluminium cover) contributes to a better durability of the ear tags through a more effective grouting process. Unfortunately, a better durability of type C1-4 through the polyimide foil, which was clearly visible, could not be proved by the results of transponder type C2.

4.3. Readings per round vs. reading rate

It should be pointed out again that a higher number of readings per round is not synonymous with a higher reading rate. One reading per round is sufficient to be classified as a 100% reading rate. Calculating the reading rates, it makes no difference if an animal stops right under the readers and is read many times or if it runs through the gate fast and is read only once. The reading rate is the decisive factor for the application in practice. A reading rate of 100% should always be the aim for a practical use of the transponder ear tags.

The number of readings per round is suitable to indicate quality differences between the several transponder types. The more readings per round a transponder type achieves, the better its performance potential is and the higher the probability of being actually read in practical applications is. A better performing transponder is also read at a greater distance in front of and behind the gate. This is why the readings per round is more important than the reading rates for the further development with fine tuning of the transponder types.

4.4. Improvement of gate and reader settings

Even though transponder types B4-4 and B5 constitute suitable transponders for simultaneous cattle detection, a further adjustment of the gate should be carried out to ensure an average reading rate of 100%. One possibility would be a further adjustment of the transponder-reader communication by using the so-called 'inventoried flags'. During the anti-collision process, these inventoried flags can be changed by a reader after a successful reading. Afterwards, the transponder is insensitive to further commands from the reader for a certain time period. Consequently, multiple readings of transponders passing the gate could be prevented, resulting in a reduction of data traffic on the air interface. After a predefined time, the inventoried flag of the transponder is reset and the transponder can again be read. This setting is sensible to ensure a high reading rate in practical applications because a single reading per transponder is sufficient to register an animal.

Another adjustment could be made by modifying the reader orientations. The reader orientation 'above' (inclination angle 90°) in the cattle experiments generally achieved better reading rates than the reader orientation 'sideways'. However, the readers could be slightly tipped in the direction of the gateway (change of inclination angle) to further improve this reader orientation and to improve the reading success of the individual transponders. The expected advantage of this adjustment would be the radiance of a greater area in front of and behind the gate. Additionally, an overlap of the reading fields of the two readers (opening angle 90°) would be completely prevented, which would also prevent the simultaneous accessing of a transponder by two readers. In the worst case, a multi-accessed transponder does not get the chance to send a response signal back to the reader and will not be read.

A further option would be the use of more than two antennas. These other antennas could be installed at ground level. Animals walking with hanging heads could be detected more easily. Ultra-high-frequency gates with more than two antennas have already been used for pigs in the project called "PigTracker" (Swedberg, 2012) and for cattle by the company "Hana micron Inc." (Anonymous, 2015).

The ear tag losses in the pig experiment can also be declared as too high.

4.5. Durability and size of the pig transponder ear tags

An improvement in the durability of the pig transponder ear tags is essential for their further use in practice. Reducing the size of the ear tag to a real pig-sized ear tag is the first step to diminish the chewing of the ear tag by other pigs, because the ear tag is more difficult to access. A change in the chip location within the transponder design more in the top-centre of the ear tag is a possibility to optimise the durability of the transponder ear tag. If the transponder chip is bitten, the transponder loses its function immediately, while the transponder antenna can keep its function after being deformed. In the meantime ongoing tests with such modified and smaller pig ear tags show promising results with improved transponder performance and durability (unpublished results).

5. Conclusions

It was demonstrated in several driving experiments with cattle and pigs that flexible UHF transponder ear tags are generally suitable for use in simultaneous detection of transponders in cattle and pigs. Furthermore, it could be proved that driving experiments are suitable and necessary to test UHF transponder ear tags in practice. Suitable and durable UHF transponder ear tags were found in the cattle experiments. Regarding the further development of the transponder ear tag types, it was shown that the correct detuning of a transponder results in a clear improvement in the results and an improvement in the detection reliability. A reading rate of 100% could be reached in the pig experiments, but the transponder ear tags need to be reduced in size and improved in robustness and durability to keep their functionality during the whole lifetime of the pigs. The label and antenna material is a decisive factor for the success of the grouting process of the ear tag. Since the grouting directly influences the protection of the transponder by the ear tag material, the durability of the ear tag also depends on the foil material which has to be chosen carefully. In the present experiments, polyimide foil seems promising.

However, a poor reading performance of individual transponder ear tags, caused by absorption of the electromagnetic radiation by animal body tissue, can occur frequently. This makes it all the more important to optimise the reader gate in different environments to guarantee reliable animal detection, and for administrative purposes. In general, an adjustment of the reader settings and the reader orientation seems sensible to further improve the reading rates.

This study has provided an outlook on the potential of UHF transponder ear tags and shows that a development of special transponders for this scope of application is necessary and promising.

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2.3 Third publication:

Cost-benefit analysis of an UHF-RFID system for animal identification, simultaneous detection and hotspot monitoring of fattening pigs and dairy cows in their production environment

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Cost-benefit analysis of an UHF-RFID system for animal identification, simultaneous detection and hotspot monitoring of fattening pigs and dairy cows

Nora Hammer, Mareike Pfeifer, Max Staiger, Felix Adrion, Eva Gallmann, Thomas Jungbluth

Increasing legal requirements regarding animal welfare on livestock production units that are simultaneously increasing in size require an optimisation of housing conditions with high demands on the management of such farms. Within an innovation project, a UHF-RFID system for simultaneous detection and monitoring of fattening pigs and dairy cows at particular hotspots within the respective housing environments was developed in order to simplify management of farms with larger numbers of livestock. Following many technical advances, there still remains lack of clarity regarding opportunities for UHF systems on the market. To help clarify matters, a cost-benefit analysis was carried out based on four fictive example farms (2 x fattening pigs and 2 x dairy cattle). The results show that the UHF-RFID system applied under the assumptions made offered an economic advantage under the best possible conditions for only one of the dairy farms. Rentability of the system for the other farms could only be achieved if an enormous cost reduction was assumed.

Keywords
Cost-benefit analysis, UHF-RFID, hotspot monitoring, fattening pigs, dairy cows

RFID technology uses different frequency ranges characterised by various attributes. These differ not only in their susceptibility to interference and their data transmission systems, but also in respective transmission distances (Kern 2006).

With the current lower frequency range applied as standard (LF range, ISO 11785 compliant) an error-free simultaneous reading of several transponders by the reader cannot be relied upon. Even when using the so-called anti-collision system, this problem has not so far been solved (Burose et al. 2010). Thus, singling animals is still necessary for reliable identification performance. This means stress for the animals concerned and can mean additional constructional, financial and time investments for farmers (Stekeler et al. 2011).

With systems operating in high frequency (HF) and ultra-high frequency (UHF) ranges, simultaneous reading of transponders is possible (Adrion et al. 2015a, Hammer et al. 2015, Hammer et al. 2016, Maselyne et al. 2014). Additionally, such systems offer advantages of greater transmission distances and higher data transmission rates (Kern 2006). Disadvantageous, especially with UHF, is, however, higher susceptibility to interference factors, such as water and metal, that are unavoidably present through the animals themselves and their housing environment.

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However, there are measures that can be taken, at least in part, against such susceptibilities, through specific further development of transponders (antennae design, support material, etc.) (Adrion et al. 2015b, Catarinucci et al. 2012, Finkenzeller 2012, Hammer et al. 2015). Through the great reading distance capability of passive UHF transponders (> 3 metres) there occurs multiple possibilities for application in livestock production. Not only is simultaneous detection within large groups of animals (e. g. during the loading or transfer into new accommodation of livestock) (Hammer et al. 2016) already possible, but so too is continuous monitoring of certain areas of the housing environment (e. g. troughs, drinking points or environment enrichment devices), at least under trial conditions in test stands and barns (Adrion et al. 2015a).

Cost-benefit analysis (CBA)

Alongside cost-efficiency analysis (CEA) and cost-utility analysis (CUA), cost-benefit analysis (CBA) represents an economic instrument for evaluation of objects, action alternatives and projects (Mühlenkamp 1994). In comparison to CEA and CUA, with CNA the costs, but also the benefits of a project or an action alternative, are evaluated on a monetary basis. In the case of both other systems, monetary evaluation of benefits is not carried out (Musshoff and Hirschauer 2013).

Aim of CBA is monetary evaluation of present and future costs and benefits of a project or an action alternative as well as the discounting and the comparison at a uniform point in time (Müller-Stewens et al. 2015). Hereby, either different action alternatives, or the absolute sustainability of advantage or disadvantage of individual projects, can be assessed (Musshoff and Hirschauer, 2013). The difference between the benefits and the costs given by a CBA result, gives in the first place, information on the action alternative that can be rationally selected as well as information on the meaningfulness of investment in a project.

Especially with information technologies, there often exists lack of clarity over profitability (Verstegen et al. 1995). The once-only costs of such technologies are comparatively simple to calculate based on the market price for purchase and implementation plus operational costs as well as depreciation period, interest charges, applicability of consumption parameters and maintenance aspects. There exist, however, multiple problems in the evaluation of the benefits.

According to Verstegen et al. (1995), the benefit of information technologies is defined as ”the difference between the benefits of the best alternative decision under availability of certain information and the benefits of the best alternative without availability of this information (.....)”. Pietsch (2003) standardised the benefits of information technologies through two useful effects. To these belong savings when compared with the process applied beforehand for producing the information, and earnings/advantages produced by the application of the information technology. Additionally, the benefits can be subdivided into the descriptive elements quantifiable and non-quantifiable, as well as direct and indirect, benefits.

One reason for the evaluation problems of information technology benefits can lie in the very great range of the information, the multiple performance parameters and decisions, as well as direct and also indirect influences (King et al. 1990, quoted from Verstegen et al. 1995). The person as user has, for example, an important influence on the method of information technology application and, with that, on the resultant benefits (Verstegen et al. 1995). Many authors have, therefore, the point of view that the classic cost-benefit analysis is not sufficient for evaluation of information technology benefits in agriculture (Lincoln and Shorrock 1990, Kleijnen 1980, quoted from Verstegen et al. 1995). These authors propose an addition to the classic cost-benefit analysis with a second step for evaluation of the non-monetary benefit categories.

In the literature, a difference is made between two extended approaches adjusted to suit agricultural requirements. Whereas the benefits of information technology within the framework of the normative approach is theoretically assessed, the positive approach procedure applies empirical studies (field experiments or those in test stations) for assessing the benefits (Verstegen et al. 1995).

Objective

After many technical advances able to be achieved within the framework of the innovation project for development of the electronic UHF ear tag for animal identification (Adrion et al. 2015a, Adrion et al. 2015b, Hammer et al. 2016), there still remained, however, unclarity over market opportunities for the UHF system. For this reason, the costs and the benefits of UHF-RFID system applications are here calculated with the help of application examples (example farms) featuring fattening pig and dairy cattle farms.

Material and methods

Applied UHF-RFID system components

Every UHF-RFID system comprises the fundamental components transponder, reader and computer-supported data processing system. Within this project, function examples for a practically functioning and durable ear tag for cattle and pigs was developed (Figure 1) and used in the case studies.

Figure 1: Ultra-high frequency pig and cattle transponder ear tags (© N. Hammer)

Along with the UHF transponder ear tags, two different UHF readers from deister electronic, Barsinghausen were used in the fictively installed system. With the first reader (TSU 200, deister electronic 2012) all the electronics including antennas are part of the housing with no possibility of attaching additional external antennas. Two of these readers were used for recording animals in groups moving within passages whilst changing housing area or loading for transport (gate usage). The second reader (TSU 200 Mux) permitted attachment of up to four external antennas. The advantage of these four external antennas lies in the possibility of applying them flexibly within the animal management system with the ability of scanning a number of places within the building. This reader was used for hotspot monitoring of animals in the example cases. The TSU 200 Mux is built by Agrident GmbH with casing suitable for the demands of livestock production (temperature fluctuations, dust, dirt, water splashing). Both readers have a maximum output performance of 1 W.

Different external antennas could be attached to the TSU 200 Mux. Within the example farms presented here, an antenna from the company Kathrein RFID, Stephanskirchen, Mira 52010082‘ and an external antenna from MTI Wireless Edge Ltd., Rosh-Ha'Ayin, Israel, Antu Patch 63‘ were used. The antennas differed mainly in their respective reception opening angles. Depending on the application location, a larger or a smaller opening angle can be practical. Figure 2 shows both readers used, as well as comparing both antenna types.

Figure 2: Reader TSU 200 with integrated antenna, TSU 200 Mux with four external antennae connections, external antenna from Kathrein-RFID, “Mira 52010082” and external antenna from MTI, “Antu-Patch 63” (l to r) (© F. Adrion)

Also required for application of the UHF system were a few cables and other electrical components. Within the system described here, coaxial cables provided connections between readers and antennas. The coaxial cables were attached to the antennas via type N coaxial connections. The reader and the computer-supported data processing system were connected by 4-pole control cable with RS-485 BUS system and 24 V power supply. This cable led to a control cabinet within which the control cabling of all readers mounted in the respective barns ran together. The cabinet also included the central power supply for the readers. The data from the readers were collected from the serial interfaces onto an ethernet interface with help of “serial device servers”. The computer features an ethernet switch upstream in order to provide sufficient ethernet cable connections. Figure 3 shows a diagram of the applied UHF-RFID system hardware components within a barn.

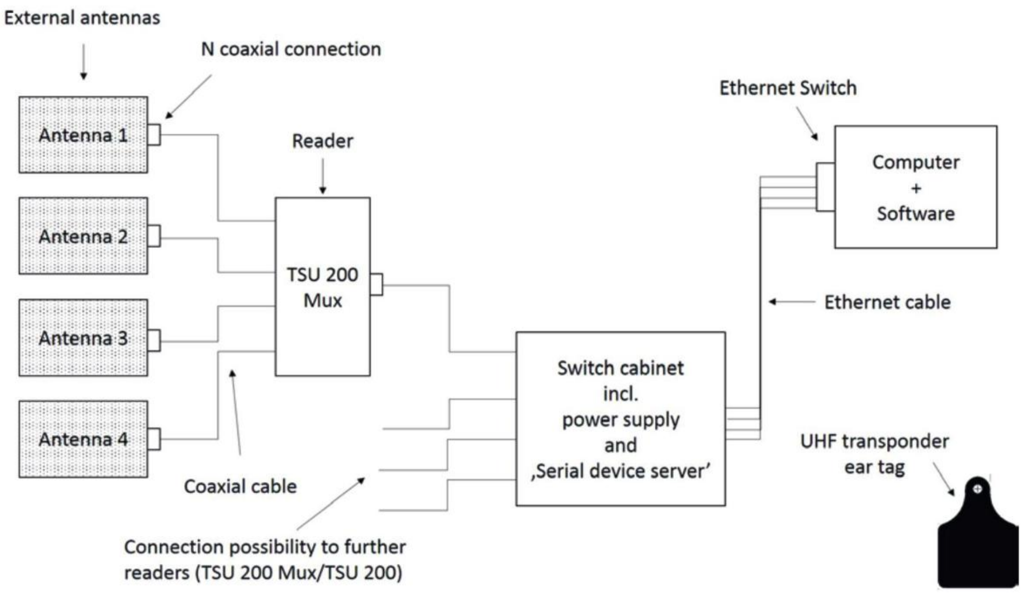

Figure 3: Diagram depicting layout of the applied UHF-RFID system

Within the computer, the recorded data of the UHF-RFID system is further processed by software from Phenobyte GmbH and Co. KG, Ludwigsburg which was specially developed for this purpose. This software accomplished various different tasks according to the situation and respective application field. Involved was the processing of data from simultaneous reading of animal groups, or reading of animals in different hotspots within their housing environment. Also undertaken by the software was depiction of visit incidents, or length of time of visits, at the previously determined hotspots, and the production of 'alarm lists'.

Case studies

The calculations of costs and benefits of the described UHF-RFID system for electronic animal identification were carried out for example farms. For this, were selected two differently sized fattening pig barns (an alternative management form with Pig Port 3 vs. conventionally managed farm) and two dairy cow barns (typical family farm vs. larger farm with hired labour).

Barn A – natural ventilation barn for fattening pigs (Pig Port 3) (400 fattening pigs):

Natural ventilation barns for fattening pig production according to Fritzsche und Van den Weghe (2009) provide an alternative to fully-enclosed insulated and forced ventilation housing and are mainly used in ecological/organic livestock management systems and in production systems serving welfare-based labels.

The Pig Port 3 system (Figure 4) selected for the cost benefit analysis had 400 fattening pig places. The barn featured a partly roofed outrun available to the pigs as activity space (Zimmer and Brede 2014). Each of the planned 20 pens could hold 20 animals.

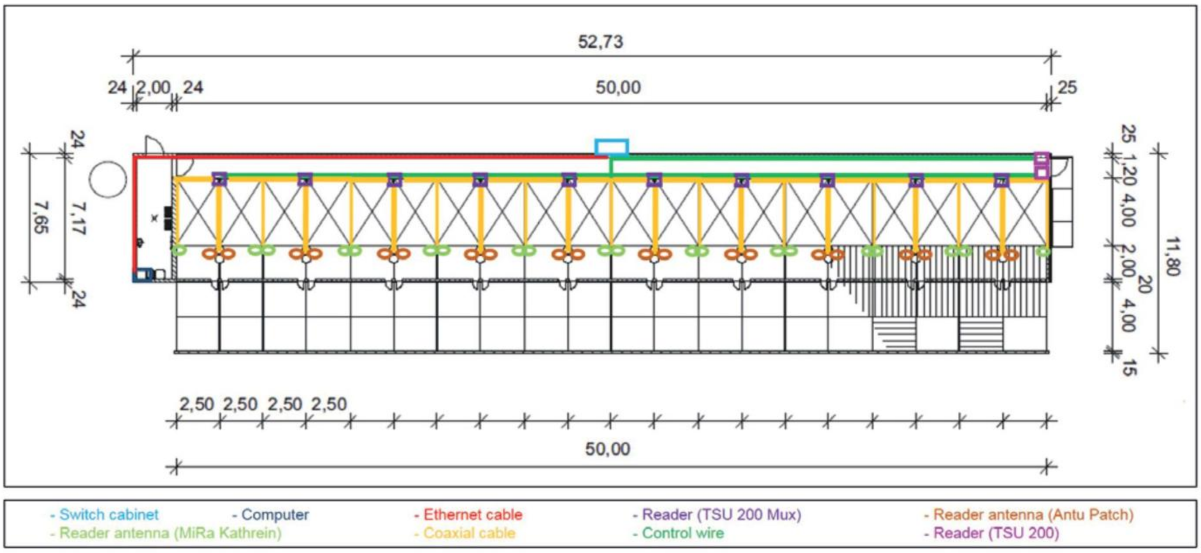

Figure 4: Plan elevation of example barn A for 400 fattening pigs with schematic illustration of the inbuilt RFID system hardware components (© KTBL 2015a, adjusted)

As shown in Figure 4, the naturally ventilated barn was equipped fictively with a UHT-RFID system. Used in total were ten TSU 200 Mux readers, each connected to four antennas. One reader antenna (Kathrein MiRa) was inserted per pen, in each case attached to nipple drinkers on the pen walls and above each mash tube feeder was an MTI Antu Patch antenna. At the end of the feeding passage at the loading ramp, two TSU 200 were installed as readers. The switch cabinet was planned in the middle of the feeding passage. The computer was situated in the barn office. In total, 266 m of antennas cable, 187 m of control wiring and 38 m of ethernet cable were laid.

Barn B – enclosed, force ventilated fattening pig barn with large groups (1600 fattening pigs): "The closed and force ventilated barn without litter and with insulated lining and heating is standard in fattening pig production" (Fritzsche and Van den Weghe 2007) and because of this was selected as one of the examples for the following cost benefit analysis. Shown here in detail is example barn B (Figure 5) with a total 1600 fattening pig places. Incorporated are 40 pens, each holding 40 animals.

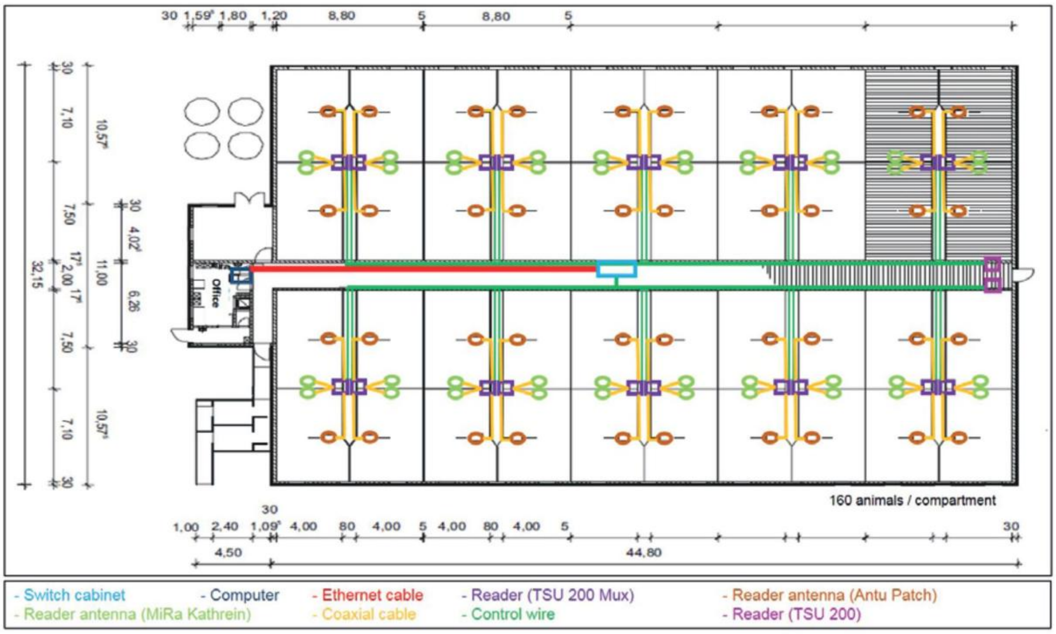

Figure 5: Plan elevation of example barn B for 1600 fattening pigs with illustration of fitted RIFD system hardware components (© KTBL 2015b, altered)

Also in the plan of the example barn B, all drinkers are fitted with a reader antenna Kathrein MiRa and all tube mash feeders with the antenna MIT Antu Patch. In total, 20 TSU 200 Mux, 40 Kathrein MiRa and 40 MIT Antu Patch antennas were fitted. Once again, a reader was planned at the end of the feeding passage by the loading ramp with the help of two TSU 200 antennas. In total, 450 m antennas cable, 417 m control wiring and 26 m ethernet cable were calculated.

Barn C – cubicle barn with outdoor run for 71 dairy cows (71 cows):
As example C (Figure 6), a double-row cubicle barn with 71 cow places was selected as representative of a family-run dairy farm in Germany. A special aspect of the example barn C was the solid-floored outdoor run. Barn C featured a 2 x 8 herringbone parlour preceded by a waiting area.

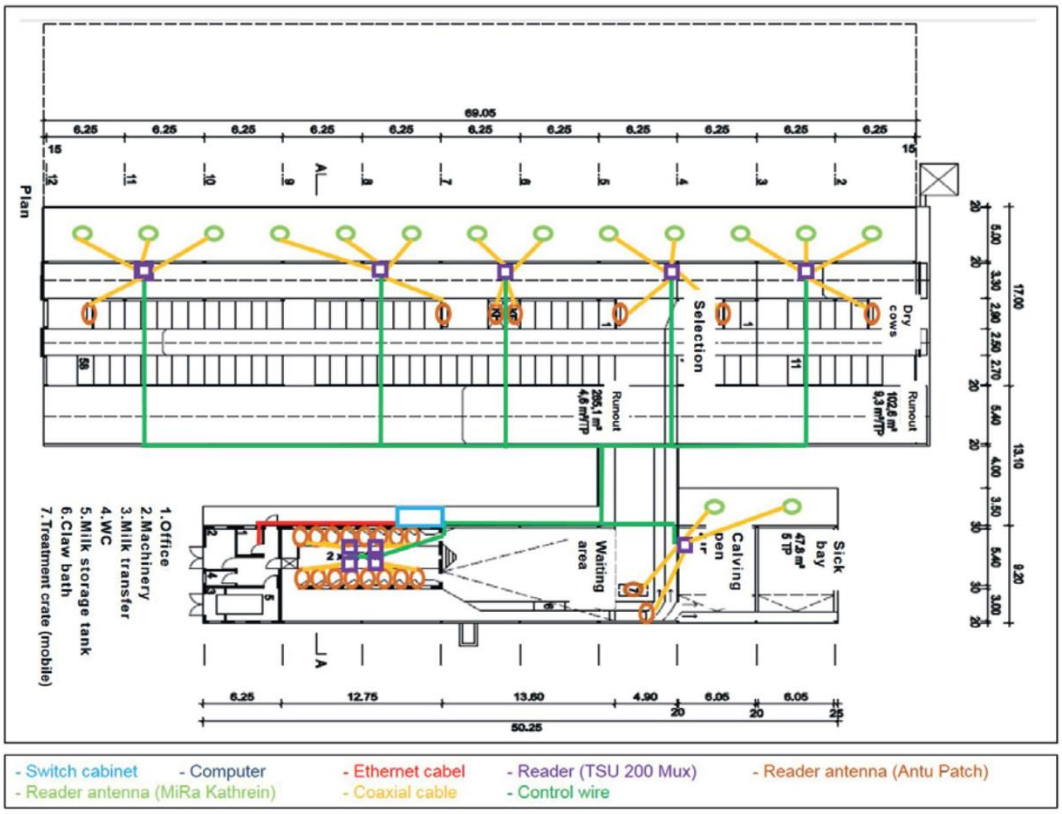

Figure 6: Plan elevation of example barn C with diagram of fitted RFID system hardware components (© KTBL 2015c, adjusted)

In the example barn C plan, the feeding table is in each case fitted with the Kathrein MiRa reader antennas, because these have a larger opening reception angle than that demonstrated by the MIT Antu Patch antennas. The number of antennas was calculated in such a way that the reader cones just overlapped on the feeding table surface and so the entire feeding table was effectively radiated. The cow positions in the parlour and each drinking point and two concentrate dispensers were each fitted with an MIT Antu Patch antenna. In total, the barn was planned to be fitted with ten TSU 200 Mux, 25 Antu Patch and 15 MiRa Kathrein antennas with 215 m antennas cable, 332 m control wiring and 16 m ethernet cable.

Barn D – cubicle barn for 624 dairy cows (624 cows):

Example barn D (Figure 7) is laid out as a as a double three-row cubicle barn with solid floored passages and scraper mucking for 624 dairy cows to represent larger dairy farms with hired labour.

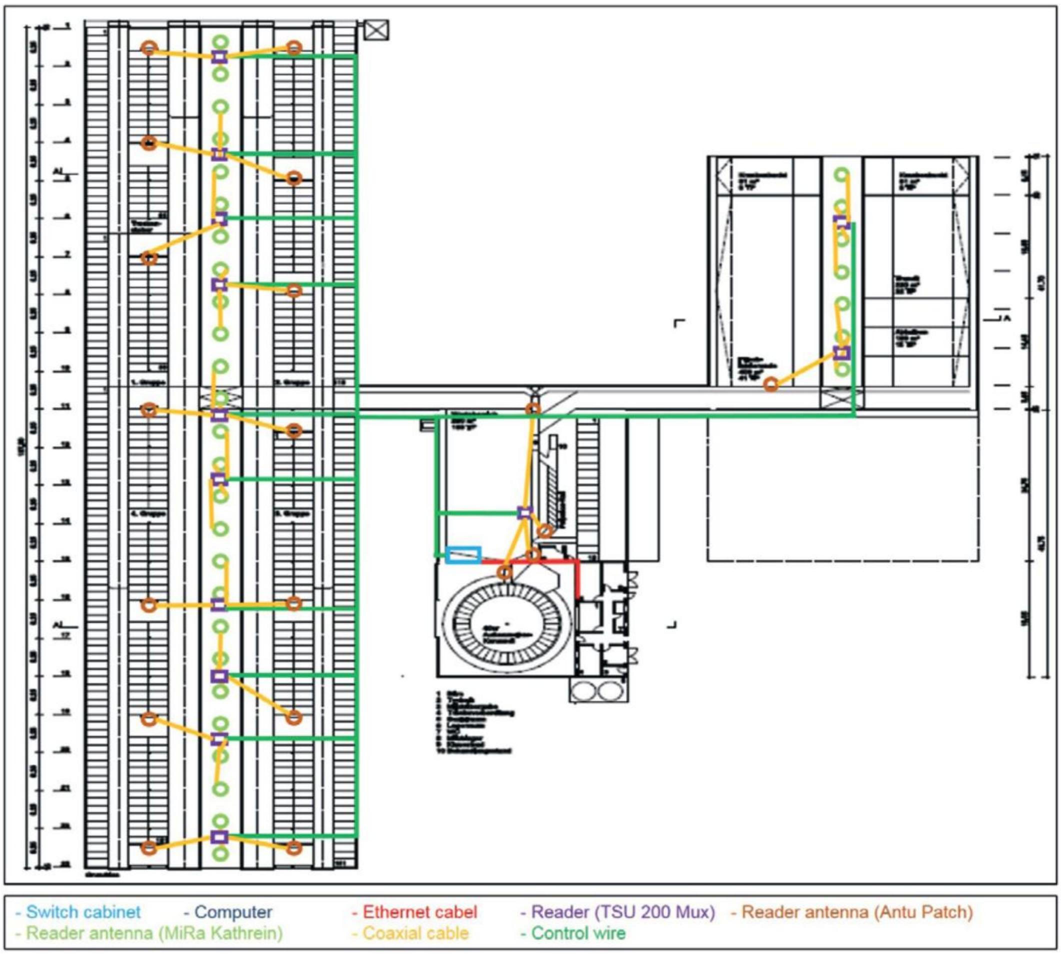

Figure 7: Plan elevation of example barn D for with diagram of fitted RFID system hardware components (© KTBL 2015d, adjusted)

The cows in example barn D were milked in an outer milking system, a 40-point carousel parlour with waiting area for around 160 cows. Planned for the barn were once again MiRa Kathrein antennas for the feeding table and Antu Patch antennas for drinking troughs as well as for carousel parlour entrance. This plan did not include concentrate feeders. Planned were in total 13 TSU 200 Mux, 19 Antu Patch and 33 MiRa Kathrein antennas with 382 m antennas cable, 1131 m control wiring and 24 m ethernet cable.

Calculating the costs

The costs of the described UHF-RFID system were calculated under the following assumptions:

- All farms selected the complete equipping of barns with the UHF-RFID system (fattening pigs: fitting of all troughs and drinking points (hotspot application) as well as loading ramp (gate application); dairy cows: fitting of feeding table, all watering points and concentrate feeders (hotspot application), as well as parlours (individual animal identification). In the dairy farms, the examples here had no readers at loading ramps. For more detailed information, see Figures 4 to 7.

- All the farms already use a farm computer which can also be available for processing the data from the systems described here.

Total costs of the system comprise material costs (hard and software as well as initial fitting with UHF ear tags for dairy cows), fitting and installation costs, costs occurring on an annual basis for new UHF transponder ear tags, energy costs and costs for depreciation and interest (according to information from Potthof 1998, Pietsch 2003) (Table 1). On the basis of the barn layout were calculated the required number of components and the necessary lengths of cable for the UHF-RFID system. Any costs for infrastructure alterations in form of new constructions or rebuilding measures were, however, not considered.

Under these preconditions the costs of the UHF-RFID systems were additionally worked out for two different situations:

1. Maximum costs of the UHF-RFID system (current costs, cost situation CS 1).
2. Reduced costs of the UHF-RFID system (costs assessed by the manufacturer after market establishment, cost situation CS 2).

Table 1: Cost blocks and appropriate procedure in cost calculations and also basic assumptions for calculations

Cost item	Appropriate procedure for calculation	Basis of calculations/assumptions
Fixed costs		
Material costs	Requested information from manufacturer or project partner/ online research	Hardware costs differ, depending on product, software costs: 50,000 €; CS 1: 50 licences; CS 2: 100 licences; Incl. 8.0 % of total software costs for annual updates as from second year. Costs for original UHF ear tags (dairy cattle only)
Fitting and installation costs	Calculation	Installation time: 0.5 labour hours per antenna plus 8.0 labour hours additional work; hourly rate: 40 € (own experience)
Variable costs		
Costs of UHF transponder ear tags	Requested information from manufacturer or project partner/ calculations	Number of required transponder ear tags based on average values from KTBL. Pigs: 2.85 production cycles/year multiplied with assessed ear tag price (CS1 1.5 €; CS2 1.05 €); Dairy cows: replacement rate 37 % (Frisch et al. 2014) multiplied by supplied ear tag price (dairy cows: CS1 2.50 €; CS2 2.10 €)
Energy costs	Calculation	Considers only energy consumption of readers 24 h/365 d per year. Additional calculation for 70 % and 50 % working time. Assumption: power requirement per reader = 0.024 kW (Deister Elecetronic 2012); Electricity price 27 ct/kWh (RWE 2015)
Calculation		
Purchase costs	Literature/calculations	Sum of material costs, fitting and installation costs
Depreciation	Literature/calculations	Assumption: Five year working lifetime (Verstegen et al. 1995). Depreciation: purchase cost per 5 years
Interest costs	Literature/calculations	Interest at 4.0 % applied as compound interest rate for own and foreign capital (Omelko and Schneeberger, 2005). Interest costs: purchase costs/2 · 0.04 (KTBL 2012)
Total annual costs	Literature/calculations	Sum of fixed (depreciation + interest) and variable (energy + ear tag) costs per year

Cost item	Appropriate procedure for calculation	Basis of calculations/assumptions
Cost per animal place	Literature/calculations	Annual total costs/number of animal places per management system (Pigs: 400 and 1,600; dairy cows: 71 and 624) (KTBL 2015e-h)
Costs per product unit	Literature/calculations	Annual total costs/kg of product (pigs: barn A = 94,548 kg meat; barn B: 420,336 kg meat (KTBL 2015e, f); dairy cows: barn C: 514,750 kg milk; barn D: 5,304,000 kg milk) (KTBL 2015g, h)

CS = Cost situation

Determining the benefits

The determination of the benefits is limited to benefit categories from the farmer's point of view, all further possible perspectives (law maker, authorities, livestock, etc.) being ignored. Otherwise, determination of benefits followed recommendations from Verstegen et al. (1995), so that monetarily assessable values as well as non-monetary assessable benefit categories are taken account of (Table 2). The quantification of the monetarily assessable benefit categories was undertaken through application of differing scenarios. Based on the scenarios (potential savings from 2, 5 or 10 % of production costs in various benefit categories) the benefits, representing the sum of the gross benefits of the UHF-RFID system, are monetarily evaluated. The system net benefits are calculated by subtraction of the costs from the gross benefits. Applied for all benefit categories are KTBL cost efficiency calculations for the appropriate management procedure, production system and housing size (www.ktbl.de/online-anwendungen). Hereby in each case an average production level is accepted.

Table 2: Observed benefit categories, the assumptions and scenarios (reduction of production costs by 2, 5 and 10 %) as well as evaluation possibility.

Benefit category	Assumptions applied for starting situation and non-monetary effects	Evaluation
Early identification of disease (Veterinary treatment and medicine cost savings)	Costs for vets and medicine: • Pigs: ø 2.60 € per animal place and year under tendential organic management (barn A) and 4.30 € for conventional management (barn B) (KTBL 2015e, KTBL 2015f). • Dairy cattle: 50 € per cow and year (KTBL 2015g, KTBL 2015h)	monetary
Efficient livestock controls (Cost savings on ø labour time for livestock control)	Labour time: • Tendentially organic pig production (barn A): 0.5 work hours per animal place and year (KTBL 2016) Large-scale conventional fattening pig unit (barn B): approx. 0.3 work hours per year and animal place (KTBL 2016) • Smaller and larger-scale dairy units with herringbone parlour (barn C) and carousel parlour (barn D) approx. 3 work hours per animal place and year (KTBL 2016); assumed hourly pay rate: 17.50 € (KTBL 2015e)	monetary
Combination of interfarm and individual farm livestock ID (Only for dairy cows. Cost savings through discontinuation of current ID, e. g. collar).	Annual animal ID costs 5 € per animal place (KTBL 2015e, KTBL 2015f, KTBL 2015g, KTBL 2015h).	monetary
Fertility management (For dairy cows only: reduced inseminations, semen)	Insemination, semen and service fees 25 € per animal place and year (KTBL 2015g, KTBL 2015h).	monetary
Simultaneous detection of animal groups	Improvement of animal welfare, increased work safety (greater scanning distance, no singling out).	non-monetary
Data and information pertaining to individual animals	Strategic (selection according to genetics, disease susceptibility, performance data, i. e. control instrument as basis for single animal based management)	non-monetary

Within the following survey, the costs and benefits of the information system are theoretically assessed, in other words, the normative approach is applied. But because the information system to be used had already been tested on experimental farms, some results from field experiments could be brought into the calculations.

Results and discussion

Costs

The resultant costs of the UHF-RFID system as described in Table 1 were calculated for the fattening pig barns as well as the dairy barns, under both cost situations. The determined annual total costs, costs per animal place and per production unit of the example farms are presented for both cost situations in Tables 3 and 4. Additionally, the saving potentials of CS 1 to CS 2 are given as percentages. In the case of fitting and installation costs, as well as annual running costs, the costs of CS 1 and CS 2 were not altered for the fattening pig or dairy farms.

Table 3: Details of all costs (in €) of the UHF-RFID systems for fattening pig barn A (stocking: 400) and B (stocking: 1600) in cost situations 1 and 2, as well as percentage cost reduction (rounded up)

Pigs	**Cost situation 1 in €**		**Cost situation 2 in €**		**Cost reduction in %**	
Cost block	**Barn A**	**Barn B**	**Barn A**	**Barn B**	**Barn A**	**Barn B**
Material costs in total	27,764	46,413	16,264	26,033	41	44
of which hardware costs	26,444	45,093	15,604	25,373	41	44
of which software costs	1,320	1,320	660	660	50	50
Fitting and installation costs	1,120	1,920	1,120	1,920	0	0
Annual running costs	681	1,249	681	1,249	0	0
Annual ear tag costs	1,710	6,840	1,197	4,788	30	30
Purchase costs in total	**28,884**	**48,333**	**17,384**	**27,953**	**40**	**42**
Interest costs	**578**	**967**	**348**	**559**	**40**	**42**
Depreciation 5 years	**5,777**	**9,667**	**3,477**	**5,591**	**40**	**42**
Annual total costs	**8,746**	**18,722**	**5,703**	**12,187**	**35**	**35**
Costs per animal place	**21.90**	**11.70**	**14.30**	**7.60**	**35**	**35**
Costs per kg meat	**0.092**	**0.045**	**0.060**	**0.029**	**35**	**35**

Table 4: Detailing of all costs (€) of the UHF-RFID system for dairy farm C (71 cows) and dairy farm D (624 cows) in cost situations 1 and 2, as well as percentage cost reduction (rounded up).

Dairy cows	**Cost situation 1 in €**		**Cost situation 2 in €**		**Cost reduction in %**	
Cost block	**Barn C**	**Barn D**	**Barn C**	**Barn D**	**Barn C**	**Barn D**
Material costs in total	26,803	33,693	15,894	20,370	41	40
of which hardware costs	25,305	30,813	15,085	18,400	40	40
of which software costs	1,320	1,320	660	660	50	50
of which initial equipment Ear tags	178	1,560	149	1,310	16	16
Fitting and installation costs	1,120	1,360	1,120	1,360	0	0
Annual operating costs	568	738	568	738	0	0
Annual ear tag costs	66	577	55	485	16	16
Purchase costs in total	**27,923**	**35,053**	**17,014**	**21,730**	**39**	**38**
Interest costs	**558**	**701**	**340**	**435**	**39**	**38**
Depreciation 5 years	**5,585**	**7,011**	**3,403**	**4,346**	**39**	**38**
Annual total costs	**6,776**	**9,027**	**4,366**	**6,003**	**36**	**33**
Costs per animal place	**95.40**	**14.50**	**61.50**	**9.60**	**36**	**33**
Costs per kg milk	**0.013**	**0.002**	**0.008**	**0.001**	**36**	**33**

As can be seen from Table 3, material costs (≈ 96 %) and particularly hardware costs (> 88 %) make up the largest part of purchase costs in all four example farms. Also in CS 2 (Table 4) where the assumed material costs are reduced by approx. 40 %, these still represent the largest proportion. However, the hardware costs represent not only the largest proportion of material costs but also the largest proportion of annual total costs. The high percentage proportion of material costs when all costs are considered for all the farms observed here tends to be unusual for an information system. For instance, with Andres (2009) only 20 % of total hardware costs were caused by hardware. There, with a total of approx. 75 %, wage and licence costs represented by far the highest proportion of total costs (Andres 2009). This UHF-RFID system is not yet established in practice. For this reason, the costs of system components not greatly in demand so far are substantial. This especially applies to the reader costs. UHF readers and the required connections and cables for use in the challenging open farm environment have to be especially protected (splash proof, dust and ammonia proof, where required protected against biting), all of which increases manufacturing costs.

Perspectives for cost reduction:

Hardware

The reader devices featured here are still in the development stage. An estimated reduction of up to 50 % in reader costs through these systems coming onto the market (CS 2) can be assumed (own assumptions, reached through discussions with experts). Additionally, there is offered through the application examples presented here (hotspot monitoring) UHF readers that enable the attachment of a number of (>4) external antennas. An example is the Impinj Speedway (Impinj Inc., Seattle, WA, USA), which, via an antenna hub, enables the connection of 32 external antennas (Impinj Inc. 2015). With this, the number of readers in the featured example barns would be reduced by a large factor and the costs thus substantially lowered (barn A: − 8 readers; barn B: − 17 readers; barns C: − 8 readers; barn D: − 11 readers). This would correspond in the case of barn B and CS 1 to a saving for the entire system of up to 17,000 €, in other words − 30 % of hardware costs. However it can be seen that this optimistic assessment does not take into account additional costs for probably more expensive coaxial cables and for the required antenna hub. Also, the price of the Impinj Speedway 32 port as possible reader could not be exactly established. Its suitability for application in a barn environment is questionable and a modification of the reader for usage in a barn environment would probably be associated with further costs.

Costs for external antennas in the example application used here are calculated as fairly high. The high starting performance of the antennas selected and used in this case would probably be only necessary on the feed tables of a dairy unit. For calculation of the UHF-RFID system as presented here, only antennas which could be tested beforehand in self-conducted trials for their basic suitability were applied. On the drinking points and feed troughs of the fattening pig barns, as well as in the milking parlour of barn C, smaller- dimensioned antennas with reduced performance would very probably be suitable. These antennas would be somewhat cheaper and also already established on the market (see metraTec® Echo-N UHF-Antenne, metraTec GmbH, Magdeburg). However, such antennas, also have the problem of limited suitability for in-barn use at this stage.

The number of antennas can also be optimised. In barn C (71 cows, 2 x 8 milking parlour) attachment of an antenna for every milking point could be done without, for example. With software to sequence the order of animals entering the parlour, only two antennas are required: one on each side of the parlour. A reduction of 14 external antennas (- 8.5 % of hardware costs) is thus possible in CS 1. In any case, such an application would be practical with larger dairy units, e. g. those using a milking carousel and was planned as example in barn D (624 cows).

Software

The software costs lie substantially under those of hardware in all units under both cost situations and thus represent a markedly lesser proportion of purchase costs (between 2 and 5 %, depending on type of livestock, housing system and CS) and therefore of annual total costs. For CS 1 and 2, software costs were reduced by around 50 % through allocation of an increased number of licences (from 50 to 100 licences). Through allocation of further licences on more than 100 farms, the costs for software could once again be reduced.

The software costs as reported by Verstegen et al. (1995) showed a different reaction. When only a computer, printer and software were required, the cost of software (incl. annual updates) exceeded markedly those for hardware (software costs = 68 %), although, here too, software update costs of approx. 8 % were calculated-in.

Fitting and installation costs

Fitting and installation costs also proved to represent a very small proportion of purchase costs compared with hardware costs in both farms, representing between 4 and 7 %, depending on livestock type, housing system and CS. Thus, their share and that for the software costs, represent a limited proportion of annual total costs. However, these costs are also difficult to estimate. Here exists, alongside regional differences, also uncertainties over practicability and flexibility of the final developed systems. “Plug and play” solutions were aimed for. However, because of the many different livestock housing forms, these are difficult to realise.

Energy costs

Not to be neglected are also reader variable energy costs. In CS 1, these have a share of between ≈ 7 and 8 % and, in CS 2, a share of between ≈ 10 and 13 % of annual total costs, depending on livestock type and management system.

As with the hardware costs, there exists with the example farms and their respective energy costs optimisation requirement. For the above presented example farms, reader running times of 24 hours and 365 days in year were assumed in order to simplify calculation of total costs. These have to be readjusted. For instance, correctly adjusted readers could switch-on only when a transponder comes into range (Hammer et al. 2015) thus offering a substantial reduction in energy costs in practical application. This approach also applies in barn B. With an assumed running time of 70 % of total time, energy costs in CS1 could be reduced by an annual ≈ 874 € (30 %). The total costs from CS 1 would be reduced through this alone by an approx. further 2 %. With a reduction of 50 %, a further reduction in annual total costs of > 3 % could be achieved. In barn D, and a reduction of 50 % in energy costs, the annual total costs in CS 1 could be reduced by as much as >4 %.

Ear tags

The costs for ear tags have, especially in the fattening pig barns (A and B) a not insignificant proportion (between≈ 20 and 40 %, according to housing system and CS) of the annual total costs. In barn C the proportion of costs for ear tags compared to total annual costs was only approx. 1 % and in barn D between ≈ 6 and 8 %.

The proportionally high costs for the pig transponder ear tags is through the large number of ear tags required. With 1,600 pig places (barn B) and an assumed 2.85 batches per year (KTBL 2015f), this already means a requirement of 4,560 ear tags, in that all tags leave the farm with the pigs when they go to slaughter. Through hygienic and labour cost grounds, re-using the ear tags is not practical. Additionally, the aim is to achieve a combination of transponder ear tag and farm ear tag for identifying each animal so that, on leaving the unit, the ear tag must remain with the animal.

With dairy cattle, a milking herd animal replacement rate of 37 % was assumed (Frisch et al. 2014). In that a good durability of the transponder ear tags is assumed, and the cows remain longer than one year in the unit, every cow does not require one or more ear tags each year (UHF ear tag requirements per year being therefore only 37 % of the herd). The first equipping of dairy cows with UHF ear tags was integrated into the material costs in order to separate these better from the annual costs. Through this, the proportion of ear tag costs within the annual total costs of dairy production was substantially smaller.

Costs per animal place and product unit

Furthermore, large differences can be identified between the individual costs per animal place depending on type of animal or management system and production unit. Behind this situation is the markedly different livestock stocking per farm unit and, with that, the different levels of production. The UHF-RFID system on farm C is not especially lower cost than that of farm D although fewer animal places mean total costs are divided between fewer production units. Additionally, it can be said that a central feeding table as in barn D, where the animals can feed from both sides, represents a good suitability for the UHF-RFID system. Through the central positioning of the antennas, two feeding gates can be radiated and thus antennas saved.

Benefits that can be evaluated monetarily

Listed in Tables 5 and 6 are benefit categories that can be evaluated monetarily. Because the benefits that occur in a barn are unable to be precisely forecasted because of the many-layered differences in farm businesses, calculations are made here based on scenarios of a 2, 5 and 10 % reduction in applied costs for the benefit categories “Early identification of disease” “Efficient livestock control”, “Combination of inter and individual farm animal ID” (only dairy cattle) as well as “Fertility management” (only dairy cattle).

Table 5: Gross benefits and saving potentials of the UHF-RFID system in fattening pig management under different scenarios (rounded up)

	Barn A (400 fattening pigs)			Barn B (1600 fattening pigs)		
Benefit category in € per barn and year	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**
Early disease identification[1)]	21	51	103	137	342	685
Efficient animal control[2)]	70	175	350	168	420	840
Annual savings potential in €	**91**	**226**	**453**	**305**	**420**	**1,525**
Annual saving potential in € per animal place	**0.20**	**0.60**	**1.10**	**0.20**	**0.50**	**1.00**
Annual saving potential in € per kg	**0.001**	**0.002**	**0.005**	**0.001**	**0.002**	**0.004**

Assumptions:
1) Vet and medicine (€ per animal place and year) barn A = 4.30 €, barn B = 2.60 €.
2) Labour time requirement for animal control (hourly labour input per animal place and year) barn A = 0.3 h, barn B = 0.5 h; 2.85 batches per year.

Table 6: Gross benefits and saving potentials of the UHF-RFID system in dairy cattle management under different scenarios (rounded up)

	Barn C (71 dairy cows)			Barn D (624 dairy cows)		
Benefit category in € per barn and year	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**
Early disease identification[1)]	71	178	355	624	1,560	3,120
Efficient animal control[2)]	75	186	373	655	1,638	3,276
Combination of inter and individual farm animal control[3)]	7	18	36	63	157	315
Fertility management[4)]	36	89	178	312	780	1,560
Annual saving potential in €	**188**	**471**	**941**	**1,654**	**4,135**	**8,271**
Annual saving potential in € per animal place	**2.70**	**6.60**	**13.30**	**2.70**	**6.60**	**13.30**
Annual saving potential in € per kg	**0.000**	**0.001**	**0.002**	**0.000**	**0.001**	**0.002**

Assumptions:
1) Vet and medicines (€ per animal place and year) barn B + C = 50 €.
2) Hourly labour input for animal control (hourly labour input per animal place and year) barn C = 3 h, barn D = 3 h.
3) Animal identification (€ per animal place and year) barn C + D = 5 €.
4) Insemination, semen, service fees (€ per animal place and year) barns C + D = 25 €; replacement rate 37 %.

It can be seen that, even with a 2 % reduction in costs in every benefit category, an annual saving potential in fattening pig management of ≈ 91 € in barn A and 305 € in barn B is possible, which must then be calculated against the existing costs of the system (Table 5). With a very optimistic reduction of costs of 10 % for all benefit categories, there could be saved through the system up to ≈ 453 € in barn A and 1,525 € in barn B.

With the dairy cow barns, the saving potential is respectively higher (Table 6). If only 2 % of the costs of all benefit categories in barn C is saved, in this way a total ≈ 188 € of the total costs could be saved. With an optimistic saving of 10 %, ≈ 941 € could be saved. In barn D a saving potential of ≈ 8,271 € could be calculated for the 10 % scenario.

Annual savings potential

As with the cost calculations, the yearly savings potential per unit is greatly dependent on type and size of farm unit. Thus, the larger units have a substantially greater annual saving potential compared with smaller ones. With regard to savings potential per animal place and product unit, the situation is, however, completely the other way around because the saving potentials with the smaller farms are distributed over less animal places and product units, and are therefore larger.

Early identification of disease

Especially with fattening pigs managed in larger groups, the timely recognition of diseased individual animals is important. Under the assumptions in table 2 there is in barn A (400 feeding places), according to KTBL (2015e), an assumed better animal health than in barn B (KTBL 2015f). In the former, there are costs of approx. 1,028 € for vet and medicines. In barn B (1,600 feeding places) yearly costs are 6,848 € in this respect. Also with dairy animals, farm C with 71 cows requires 3,550 € for annual total vet and medicine costs and for barn D with 624 cows 31,200 € (KTBL 2015g, KTBL 2015h).

Through the application of the system and software presented here, disease could be identified on an animal individual basis through drinking, feeding and movement behaviour and thus treated early. According to many authors, especially with fattening pigs attention to drinking behaviour can support decisions regarding individual intestinal diseases (Kashiha et al. 2013, Madsen et al. 2005, Madsen and Kristensen 2005). Cornou et al. (2008) already use the feeding behaviour for recognition of lameness and health problems with sows managed in groups. Feeding behaviour of fattening pigs can also be used to determine optimum feed rations (Nielsen et al. 1996). In this way, additional savings may be realised in the area of feed costs. Optimum feeding of fattening pigs can, according to Niemi et al. (2010), bring an annual saving of 1.35 € to 1.88 € per animal place. Jensen et al. (2012) investigated the economic effects from lame fattening pigs based on nine different cases. Here, a reduction in the profit range from on average 0.80 € for hoof problems up to 55 € with fractures could be determined (Jensen et al. 2012).

With calves, too, animal individual and precise feeding techniques can lead to the amount of liquid consumed being managed through attention to individual concentrate rations intake. In that the concentrate consumption of calves represents a more sensitive parameter than the amount of liquid consumed, there results not only savings in expensive milk replacement but also advantages within the framework of early disease recognition (Deininger and Käck 1999). González et al. (2008) identified, through automatic animal controls, short-term alterations in average feeding times of dairy cows, initiated through diseases such as ketosis or lameness. Even at that time, the authors suspected improved animal welfare, as well as economic advantages on the farm, through early recognition and treatment of diseases (González et al. 2008). Ettema and Østergaard (2006) investigated different causes of lameness with dairy cows and calculated, with the help of a model, the resultant costs in each case. Depending on lameness cause, costs between 178 € and 278 € per case were determined (Ettema and Østergaard 2006).

In general, sick animals could be isolated earlier through the system, some diseases identified and treated earlier, and the treatment period shortened. This could lead to a reduced number of vet visits, reduced application of medicine, a more rapid recovery of animals and, with that, less performance penalties. Additionally, earlier identification of infectious diseases can prevent, or at least reduce, infection spread to other animals (Madsen and Kristensen 2005, Cornou and Kristensen 2013, Geers 1994). With many diseases, early identification of altered animal behaviour is especially important in that the animal is passing on infection even before the clinical symptoms are apparent (Charleston et al. 2011). Saatkamp et al. (1997) investigated different identification systems with and without behavioural observation with pigs in relation to pig fever and the related economic effects. The annual financial loss could be reduced from 155 € to 38 € with the help of identification system with behavioural observation (Saatkamp et al. 1997). Through application of the system, or automatic recording of individual behaviour and deviations from this, not only costs could be saved but also animal welfare improved (Kashiha et al. 2013). However, not only diseases could be identified earlier, but also stress for animals could be reduced with the help of the technique (simultaneous recording of numerous transponder ear tags) for animals in the process of loading or driving, in that the animals in the group could be moved with no necessity of separating out individuals (Hammer et al. 2016, Stekeler et al. 2011).

However, to watch out for here on a farm where animal health is very good, is the probability that the benefit of the UHF system, and therefore also the saving potential, is substantially less than with a farm where the animal health status is poor. Where no, or hardly any, sick animals are identified in the herd, even a UHF system offers no additional benefit. For this reason, too, the so-called scenario technique was applied, in that the possibility of single results, with regard to cost savings (benefits) is unknown (Dabbert and Braun 2009). As a rule, a negative and a positive trend scenario is created, representing the most unfavourable and the most favourable development case. The 2, 5 and 10 % selected here seem to be practical and represent a relatively wide trend range, even if a benefit through the UHF system at the present time is unable to be guaranteed.

Efficient animal control

The daily control of every individual animal, especially with large farms, is particularly difficult and time consuming for the farmer to apply, although legally required (TierSchNutztV, 2014).

The wage rate for farmers (stockpersons) is approx. 17.50 € per hour (KTBL 2015e). For barn A this represents ≈ 3,500 €, for barn B ≈ 8,400 €, for barn C ≈ 3,728 € and for barn D ≈ 32,760 €, to be earned or paid for by the farmer, his family or hired labour.

Through the UHF-RFID system and appropriate software it would be possible to reduce the farm work time requirement in this respect. Imaginable would be a reduction in work time through faster identification of animal position in the barn. Animals appearing on an alarm list, e. g., those showing markedly altered drinking, feeding or movement behaviour, would be entered into the system with pen number or last-known position (e. g. antenna number) with present position in the barn able, therefore, to be found more quickly. The additional assistance of a handheld mobile reader would be practical here for large groups of pigs in that the electronic ear tags are difficult to read because of their small size, or have not an individual number but only a farm number printed. Through using a handheld reader, individual animals in a larger group can be easier to find. Also digital herd management, compared with written herd management, can be assumed to offer time savings in that the animals in question are permanently identified through the software and the actual "condition" of every animal in the herd can be called-up with a simple mouse click. Andres (2009) for example, described the manual documentation, data collection and input of data in Russian agricultural farms as especially time-consuming and open to doubt. Mainau et al. (2009) also described the value of an information system as time saving for staff. Time can be saved through such a system which otherwise would be required for data evaluation and behavioural studies.

Spreng and Auernhammer (2008) reported that a complex computer-supported feeding system for calves offers economic advantages for the farmer. As advantages of such a system, the authors identify reduced feed requirement, shortened rearing times, higher weight gain, less vet costs and savings in labour input and time.

In such benefit categories there also exists the problem of the great variation in farms and the ways in which they are managed. Additionally, the farmer in question has a conclusive influence on the possibilities for time saving. Hereby, own working speeds, technical affinity, technical understanding and motivation all play a decisive role, to mention only a few parameters. Because of these, it is difficult to determine exact information on time savings or labour cost savings. Thus, calculation of benefits regarding labour efficiency under different scenarios, as here, is more practical (Dabbert and Braun 2009). A farmer who already spends a lot of time in animal observation and control has possibly a lesser direct benefit through the UHF system compared with one that so far spends very little time even thinking about it.

Combination of inter and individual farm animal identification

The identification of fattening pigs with the farm number as well as visual, animal individual identification for dairy cattle with two ear tags, is mandatory (EC 2000, ViehVerkV 2015). This makes practical the connection of inter and individual animal identification for management reasons via ear tags.

Individual animal identification in fattening pig production is currently not yet standard. However, because of the current discussion on antibiotic application and animal welfare it is certainly possible that there will be a change in law in the direction of strengthened documentation of medicine application and animal welfare, as well as appropriate farm controls, in the coming years. In sow or dairy cattle management, there are already helpful applications such as pedometers, collars and/or electronic ear tags in the lower frequency range for determining walking behaviour, as access controls for concentrate feed dispensers, or in handling systems for movement of animals.

With the background of the system being fitted in a fattening pig farm, transponder ear tags with the farm number also printed would be practical, taking over the role of the mandatory farm number ear tag and thus reducing costs. But there is still no information available on loss rates for UHF ear tags with pigs, so required replacement expenses are not known. For this reason, monetary evaluation of ear tags with fattening pigs is omitted.

For dairy cattle, too, at least one of the two required visual ear tags could be replaced by an electronic ear tag. The costs for the electronic ear tag in this way are reduced by the costs for the visual ones and the purchase of further management aids (e.g. pedometers or collars) might also be avoided. In that the application, as well as the price, between these products vary greatly, a percentage reduction is calculated here too (Table 6).

Fertility management

With dairy cattle husbandry, in addition to the other benefit categories, there exists a further benefit in the area of fertility management. The economic efficiency of a dairy cattle farm is strongly influenced, as well as by feeding and a good herd health status, by good reproduction performance (Brehme et al. 2003). If the heat period of a cow is not identified, or noticed too late, this has a negative effect on milk production and the lifetime performance of the herd and, with that, a direct influence on the economic performance of the unit (Brehme et al. 2003). In larger dairy farms there exists often the problem of determining the optimal time for insemination of a cow, in that the precise observation of each cow is often impossible, as well as taking up a lot of time (Kohler et al. 2010). Investigations show that even experienced staff only recognise between 40 and 60 % of heat periods (Liu and Spahr 1993, Firk et al. 2002). Additionally, the movement, feeding and drinking behaviour of cows in heat and before calving, all change (Brehme et al. 2003, Raya 2011). All these parameters can be determined per cow with the help of UHF-RFID systems and therefore deviations from the standard recognised in good time. The optimum insemination period and calving date is in this way easier to determine and plan for. Compared with other systems of heat identification, such as heat ID plasters on cow backs, or a good visual behavioural monitoring of the animal by the farmer, the UHF technique identifies more rapidly any increased activity or alterations in animal behaviour.

In that the other, already mentioned, methods for heat identification are cheaper, the purchase of a UHF system for heat identification only should be avoided. In order to exploit synergy effects, UHF system purchase should be done where other uses, as mentioned above, can also be taken advantage of.

Non-monetarily assessable benefits

Alongside monetarily assessable benefit categories, non-monetary ones should also be observed. These can include increased work safety for stockpersons and improved animal welfare through simultaneous detection of animal groups. In German agriculture, the number of recorded accidents is much greater than those for all other sectors covered by the mandatory health and safety reporting system (Elsner von der Malsburg 2007). From the accidents registered in agriculture every eighth is through direct contact with cattle. From those, 12000 accidents occur, approx. 78 % through cows, 8 % through bulls and 6.9 % through calves (SVLFG 2014). The expected benefits in this relationship is based on the advantages of the UHF system compared with the so-far standardly applied LF-RFID animal identification systems. Through the greater reach and data transfer rates of UHF systems, animals can be identified from a greater distance (Kern 2006). Additionally, because of the greater data transfer rates, more transponders can be contacted and read at the same time (Kern 2006). Also under this system, there is no requirement for animals to be precisely run alongside the antennas of the reader. Singling of animals is no longer required, which means less stress for the animals, less danger for working personnel (Stekeler et al. 2011).

A further, non-monetarily evaluated benefit category involves advantages from the possibility of accessing data and information from individual animals. With the help of UHF transponder ear tags, animal individual data from all possible management areas, as well as additional parameters, can be read, documented and analysed. Additionally, movement behaviour, length of time spent in certain management areas, performance data and, with flow meter fitted drinkers, also animal individual water consumption are among the aspects that can be included (Junge 2015). Furthermore, individual animal based peculiarities, e.g. regarding disease susceptibility or genetics, can be stored on an animal individual basis and evaluated. Such recorded data and information can be used as observation and controlling instrument within the management of barns or farms. Such information can also serve as the basis for strategic individual animal based management and have a substantially positive effect on the farm business results.

Costs vs. benefits

The advantageousness of an information system can be assessed when the absolute benefits minus the costs give the net benefits presented per production unit (Table 7). The fundamental data come from the KTBL cost efficiency calculations for the appropriate production sector, management conditions and barn sizes (KTBL 2015e, KTBL 2015f, KTBL 2015g, KTBL 2015h, KTBL 2016). From the table, it is clear that only in dairy cow production in barn D with an assumed maximum net benefit could a slight positive result be achieved.

Table 7: Net benefits per production unit (kg slaughter weight or kg milk)

	Production unit in kg per animal place and year	Net benefits in € per animal place and year		Net benefits in €/kg	
		min.	max.	min.	max.
Barn A (400 pigs)	236.4	-21.6	-13.1	-0.09	-0.06
Barn B (1600 pigs)	262.7	-11.5	-6.6	-0.04	-0.03
Barn C (71 cows)	7,250	-92.8	-48.2	-0.013	-0.007
Barn D (624 cows)	8,500	-11.8	3.6	-0.0014	0.000

Because of the system, the farmer in fattening pig farm A and B has to, in the best case, do without 0.06 € and 0.03 € per kg slaughter weight. At a current price of 1.40 €/kg slaughter weight (LEL Schwäbisch Gmünd 2015), and with conventional production this, after all, represents a good 4 % (barn A) or 2 % (barn B) of total income per pig. Because of barn A's EC organic conformity (KTBL 2005e) the farmer here is able to sell the meat at a higher price. With a current price of 3.50 €/kg slaughter weight (LEL Schwäbisch-Gmünd 2015), the percentage proportion then is ≈ 1.7 %.

Only in barn D, in the best case, could costs per kg milk be balanced by benefits.

Once more it can be seen, however, that the material costs (in particular the costs for readers) as well as energy costs for the UHF system on the example farm described here are calculated as very high. Where the system is acceptable for practical conditions, substantial savings are to be expected, especially in this area so that rentability of the system, for all barns if required, can result. To achieve this rentability in all barns would have required, however, a cost reduction of 92 % in barn A, 87 % in barn B and 97 % in barn C. Only under these conditions would the monetary net benefits (in the benefit scenario 10 %) balance the resultant costs of the system.

Additionally, it has to be mentioned that the benefit categories such as work safety, simplified data management, reliability and flexibility are difficult, if not impossible, to assess – although these parameters can be of great importance for the farmer. In this way the benefits could already, even in the case of limited cost reduction of the system, be increased and a rentability of the system achieved.

Conclusions

Through comparing costs and benefits, advantageousness of the system could in conclusion be shown only for barn D under the highest benefit scenario. In that, however, the system is not yet in practical application, the calculation of costs was difficult with added costs created through the orientation on component development costs. Through the early stage of development, these lay in all probability higher than the costs for later end usage. Additionally, installation of the system in practical farming conditions would be different than described here in many individual cases. In particular, the number of UHF readers required could be reduced because, in practical application, readers with several antennas attached could be used. The readers represent a high percentage proportion of total costs. Thus, an overestimate of system costs can be assumed.

In that the benefits of the system are also hard to estimate, calculations incorporated percentage graduations of potential savings per benefit category which also appeared practical in retrospect because the very different parameters (farm structure, farmer, individual animals) could mean a benefit category having an especially positive, or a slightly positive, influence. Under the assumption that the system costs under practical application would possibly lie markedly under the costs calculated here, an advantageousness could also be expected for the other farms. Developments in the dairy cattle sector show that, despite higher costs, farmers are happy to invest in such systems (offering labour savings). In particular, installation of all animal identification systems with UHF (milking, feeding, heat identification, health) could represent a perspective for technologically-affinitive farms. In fattening pig production, rentability of such a system would be difficult to be achieved, even in the future. However, there can be an additional benefit within the framework of traceability programs and documentation of animal welfare indicators supporting quality marketing. For realising a first estimation of the system's costs and benefits, this work is logical and necessary. A renewed cost benefit analysis of market-ready UHF-RFID systems is to be encouraged in order to achieve conclusive and more precise results.

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3 General discussion

The main aim of the work presented was the development of a UHF transponder ear tag for pigs and cattle and the laboratory and practical tests. Figure 3.1 shows the process sequence of the UHF transponder ear tag development and evaluation, as well as the parts of the project presented on which work has been done.

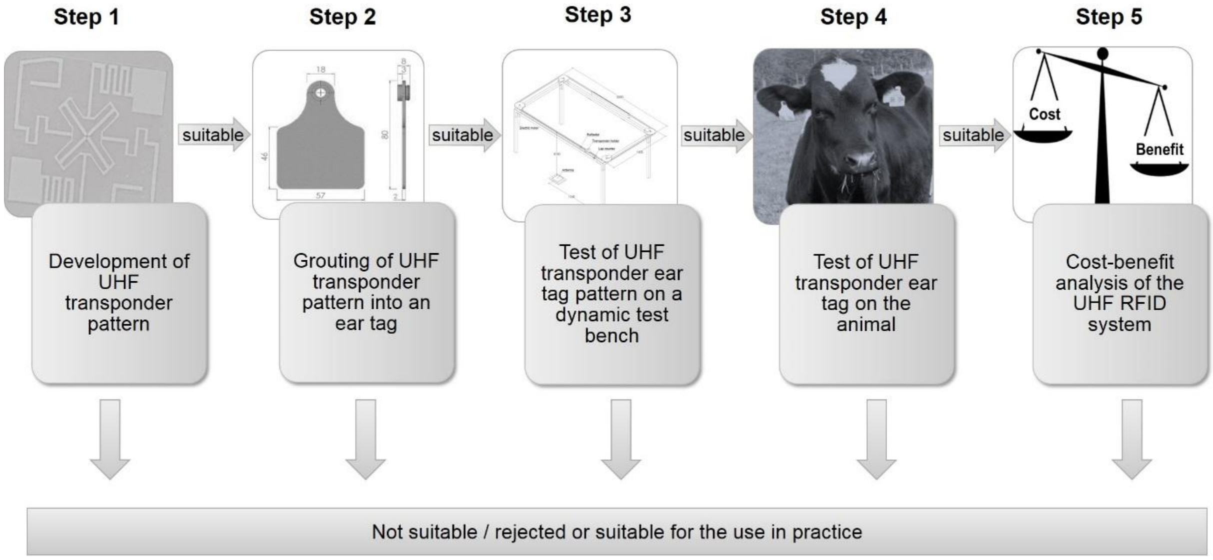

Figure 3.1: Process sequence of UHF transponder ear tag development and evaluation (own diagram).

The following discussion is oriented towards Figure 3.1. Firstly, the UHF transponder pattern development and the grouting into the ear tag will be discussed. Afterwards, the experimental procedure and the suitability of the dynamic test bench and the driving experiments will be argued. Finally the cost-benefit-analysis of the system will be discussed and conclusions regarding the whole work will be drawn.

3.1 UHF transponder development and grouting

At the beginning of the project there were different considerations about the right identification medium for pigs and cattle regarding the UHF technology. There were many reasons for the use of ear tags as an encapsulation medium of the UHF transponder:

1. An ear tag is easy to apply to both animal species and is already used in practice (Kern, 2006).
2. The identification of cattle with two visual ear tags and the application of an ear tag to pigs with the farm individual number at weaning is obligatory in the European Union (EC, 2000; Kern, 2006). Electronic ear tags (LF) in sow keeping and dairy farming systems are already often used as a management tool (Blair et al., 1994; Chapinal et al., 2008; Junge, 2015).
3. An electronic ear tag can be used for internal and external management purposes (Kern, 2006).
4. No other medium could be found which was suitable for attachment to both animal species which constituted a suitable encapsulation medium for the UHF transponder itself. Encapsulation for implantation, bolus or collar seemed unsuitable for at least one of the two species involved (Bergqvist et al., 2015; Caja et al., 2005; Kern, 2006; Merks & Lambooij, 1990).

Ear tags have proven their worth for many years e though there have been discussions about high loss rates (Bergqvist et al., 2015) and insufficient counterfeit protection. These problems can be faced with an adequate housing system (Baadsgaard, 2012) and a well-maintained database (Adam, 2011; Bütfering, 2011).

The UHF transponder ear tags to be developed should not differ fundamentally in size and shape from the current visual pig and cattle ear tag. Consequently, the structure of the transponder itself should be two-dimensional in order not to change the thickness of the ear tag totally. A passive transponder should be used to keep the costs and the weight of the ear tag low and to maintain its size and durability (Mitchell, 2013; Rao et al., 2005).

Additionally, two more aspects had to be taken into account during the transponder production process. On the one hand, it is important to know what material the radio frequency signal has to traverse while communicating with the reader. On the other hand, the material the transponder is applied to is of vital importance (Mitchell, 2013; Rao et al., 2005). Substances which disturb the environment, such as water and metal are all-present in animal husbandry and influence the communication between transponder and reader. A thoughtful transponder antenna design and an adjustment of the transponder antenna to use in an animal ear tag was unavoidable. This included particularly the variation of the structure of the transponder antenna (antenna length) and the label material. The transponder antenna plays a key role in the whole RFID system and influences read range, size and compatibility with the objects tagged (Marrocco, 2008). Ng et al. (2005) also varied the antenna length of a loop antenna to optimise the resonant frequency of the transponder for use in livestock identification and for the adoption to an animal’s ear.

A plurality of UHF transponder types were developed and tested with the collaboration of the project partners within the project period (cf. Chapter 1.5). Some of these transponder types were developed and sized for use in pig ear tags and some for use in cattle ear tags. Due to cost-saving, the pig-sized transponders were first grouted in a cattle ear tag. Therefore, the mould of the cattle ear tags had only to be changed a bit and there was no need to build a completely new one. The last four pig transponder types were grouted into a pig-sized ear tag only at the end of the project. Additionally, foreign and conventionally available transponder types were included in the tests for reference and comparison purposes. Tables 3.1a and 3.1b give an overview of all transponder types developed and evaluated during the project period. These tables show the transponder types, main characteristics, final evaluation and suitability for use in practice of each type.

Table. 3.1a: Overview of the passive transponder patterns and their characteristics developed and evaluated within the project (commercially available and cattle-sized).

Transponder type	Characteristics		Evaluation	Suitability for the use in practice
	Commercially available			
A	- UPM Web antenna - Reference transponder - Part of every laboratory experiment	- Folded dipole - Glued onto a cattle ear tag	- High reading rates - Not grouted/inlaid into ear tag - Adjusted to logistic applications	-
ZT	- SMARTRAC® Web - Embedded in an air-filled pocket between two plastic tabs	- Folded dipole antenna		0
MS Tag	- Schippers MS Tag UHF round - H-field antenna - Small button ear tag	- Loop antenna - Size fits pig ear tag	- Low reading rates - Strongly directed	-
	Sized for cattle ear tags			
Improvement (↓)				
I	- Developed in-house - Label material: layers of adhesive aluminium foil	- Flat dipole antenna	- Low reading rates - Insufficient frequency adjustment - Low durability/badly grouted	-
B0	- Developed in-house - Label material: layers of adhesive aluminium foil	- Pif antenna (PIFA)	- High reading rates - Low durability/badly grouted	-
B1, B2, B3, B4	- Developed in-house - Grouted into a cattle ear tag - Label material: layers of adhesive aluminium foil	- Pif antenna (PIFA) - Variation of antenna length (shorter from B1 to B4)	- B4 acceptable reading rates - Frequency adjustment better with B4 - Durability needs improvement	-
B3-4, B4-4	- Second generation of B3 and B4 - Label material: polyimide foil		- Frequency adjustment improved - Durability sufficient	0
B5	- Further development of transponder type B4-4 - Label material: polyimide foil	- Variation of antenna length	- Frequency adjustment completed - Durability sufficient	+

Table 3.1b: Overview of the passive transponder patterns and their characteristics developed and evaluated within the project (pig-sized).

Transponder type	Characteristics		Evaluation	Suitability for the use in practice
		Sized for pig ear tags		
A1	- Developed in-house - Label material: layers of adhesive aluminium foil	- Grouted into a cattle ear tag - Antenna design inspired by type A	- Low reading distance - Insufficient frequency adjustment - Low durability/badly grouted	-
C0, C1	- Developed in-house - Variation of antenna length (shorter from C0 to C1) and design - Label material: layers of adhesive aluminium foil	- Grouted into a cattle ear tag - Antenna design: Pif antenna	- Very low reading distance - Frequency adjustment better with C1 - Badly grouted	-
C1-4	- Second generation of C1	- Different label material: polyimide foil	- High reading distance - Good frequency adjustment - Low durability/badly grouted	-
C2	- Further development of C1-4 - Label material: polyimide foil	- Grouted into cattle ear tag - Variation of antenna length and design	- Lower reading rates than C1-4 - Insufficient frequency adjustment	-
C3-0, C3-1	- Further development of C2 - Chip position at the bottom of the ear tag	- Grouted into pig ear tag - Variation of antenna length (shorter with C3-1)	- Sufficient ear tag size for fattening pigs - C3-0 and C4-0 work best in test bench experiments - C3-1 and C4-0 work best in practice - Frequency adjustment sufficient - Durability sufficient/good grouting	+
C4-0, C4-1	- Further development of C2 - Chip position further up the ear tag	- Grouted into pig ear tag - Variation of antenna length (shorter with C4-1)		

- = unsuitable; **0** = medium; **+** = suitable; all in-house developed transponder types were equipped with an Impinj Monza 4® Chip

The structure and, thus, the size of the transponder type is influenced mainly by the targeted application area (pig or cattle ear tag). While all transponder types were tested on pigs, transponder types B1 to B3 and B3-4 to B5 were also tested on cattle. The antenna design (frequency adjustment), label material, size and chip position were all varied and adjusted during the development process. The grouting process was also improved with each transponder type. While the antenna design is responsible for the proper power-up of the transponder and, thus, the power supply of the chip, the label material can act as a spacer to other influencing materials (Mitchell, 2013; Sweeney, 2005). The position of the chip was varied in the last types of pig transponder ear tags (see transponder types C3-0, C3-1, C4-0 and C4-1). The reasons for this were durability and prior experiences with bite damage, which was also described by Baadsgaard (2012).

Most of the transponder antennas used in the UHF field are folded dipoles (Marrocco, 2008). In addition, the loop antennas designed for the application on the animal often behave like dipole antennas (Ng et al., 2005). Therefore, a transponder from the logistic area with a folded dipole antenna was used in the project (A = UPM Web) for reference purposes. However, our own initial tests failed to reduce this antenna design in size (A1) with the purpose of integrating it into a pig ear tag. Thus, further antenna designs within this project were oriented towards planar inverted F-shaped antennas (PIFA). A complex antenna design enables the use of different frequency bands here (Marrocco, 2008).

Transponder type B0 (first generation) showed good results in the laboratory tests and good reading rates (up to 100 %) under practical conditions with pigs. However, the grouting and durability was not sufficient. The variation of the antenna length and, thus, the detuning of the transponder of transponder types B0 to B5 was successful. The change from adhesive aluminium foil to polyimide foil has also been positive regarding the further development of the ear tags. An adjustment of the transponder to the animal’s ear could be achieved. A suitable, correctly dimensioned and durable UHF ear tag for simultaneous cattle detection could be developed with transponder type B5, even though transponder type B4-4 reached a better average reading rate, up to 99 %, compared to type B5 (90 %). The reading rates always depended on reader output power, environment and reader orientation (Hammer et al., 2015b; Hammer et al., 2015c).

Regarding the transponder ear tag for pigs, transponder type C4-0 seemed to be the best one for simultaneous pig detection. A reading rate of 100 % could be reached with this transponder type and a good durability could be observed. Compared to transponder type C3-1, which also showed good results, the chip position of this ear tag is better suited. The durability of the transponder can probably be ensured for a longer period of time because of the higher position of the chip on the ear tag. All transponder ear tags tested before C3-0 were of the wrong size for pigs and their durability was low. Notwithstanding the size of the ear tags, types C1-4 and C2 also reached good reading rates up to 100 % (cf. Chapter 2.2).

In conclusion, it can be stated that a suitable UHF transponder ear tag pattern for pigs and cattle could be developed. Compared to other projects, the UHF transponder patterns of this project are moulded and not just inlaid into the ear tag, which reduces the problem of corrosion of the transponder materials through humidity (Baadsgaard, 2012). Additionally, they have the right size for each species and proved a good functionality. In terms of the durability, the UHF transponder ear tags for cattle performed well (full functionality after eight months), while there is more improvement needed for the UHF transponder ear tags for pigs. Unfortunately, the durability of the ear tags could not be tested over a long period, because the fattening pigs were tagged with the ear tag within the fattening period. Because of a poor durability, the transponder type patterns developed first quickly lost their functionality by being bitten through or ear tag decomposition. After the improvement of the grouting process and the use of the small ear tag size, the interest of the pigs in biting on the ear tag was reduced and the number of non-functional transponder ear tags decreased. More tests, perhaps with sows (longer lifetime) or from the beginning of the piglet rearing, should be carried out to test the transponder ear tags over a longer period.

3.2 Dynamic test bench

3.2.1 Comprehensive overview and additional results of the experiments with the dynamic test bench

In this chapter, an overview of all experiments performed on the dynamic test bench within the project period is given. The results of Chapter 2.1 were also expanded by the results of four more self-developed UHF transponder types (C3-0, C3-1, C4-0 and C4-1) for use in pig husbandry.

Transponder ear tag types C3-0, C3-1, C4-0 and C4-1 differed in their chip position (top and bottom of the ear tag) and antenna length (detuning) and were grouted in a pig-sized ear tag. The functionality and durability of the transponder ear tag types were clearly improved (cf. Table 3.1b).

A detailed description of the breadboard construction and experiments which were performed was presented in Hammer et al. (2015). Table 3.2 gives an overview of all experiments performed within the project period.

Following the experimental procedure of all other experiments performed on the dynamic test bench (Chapter 2.1), the four latter transponder types mentioned were tested in six orientations, with the holder material XPS and a speed of 3 m/s. An average of ten rounds was also built and the reader TSU 200 with the reader setting TR was used. However, in contrast to the experiments described in Chapter 2.1, the reader output power was reduced to 0.5 W. Consequently, a reading of the transponders in undesired points of the test bench should be prevented because of the improved performance of the transponder types.

Table 3.2: Tests performed on the dynamic test bench within the project period

Test	Transponder generation	Transponder type	Number of exemplars	Reader Type	Test description, Additional comments	
1	C.a.	A	6	TSU 200	- Reader output power 1 W - Reader mode TR - Transponder orientation 1-6	- Holder material PVC - Speed 1.5 m/s and 3.0 m/s - 1 exemplar on holder
	2	B1	6			
		B2	6			
		B3	6			
2	C.a.	A	6	TSU 200	- Reader output power 1 W - Reader mode TR - Transponder orientation 1-6 - Also tested with water (10 gm)	- Holder material PVC - Speed 1.5 m/s and 3.0 m/s - 1 exemplar on holder
	2	B4	6			
		A1	6			
4	C.a.	A	6	TSU 200	- Reader output power 1 W - Reader mode (PS/TR) - Transponder orientation 1-6	- Holder material (PVC/XPS) - Speed 1.5 m/s and 3.0 m/s - 1 exemplar on holder
	3	C0	6			
		C1	6			
5	C.a.	A	6	TSU 200	- Reader output power 1 W - Reader mode TR - Transponder orientation 1-6 - Influence of ear tag material (ZT vs. ZT_{ng})	- Holder material XPS - Speed 3.0 m/s - 1 exemplar on holder
		ZT	6			
		ZT_{ng}	6			
6	C.a.	A	10	TSU 200	- Reader output power 1 W - Reader mode TR - Transponder orientations 1-6	- Holder material XPS - Speed 3.0 m/s - 1 exemplar on holder
		ZT	10			
	3	C1	7			
	4	C1-4	3			
		B3-4	10			
		B4-4	10			
7	C.a.	A	6	TSU 200	- Reader output power 0.5 W - Reader mode TR - Transponder orientations 1-6 - Different number of rounds was tested	- Holder material XPS - Speed 3.0 m/s - 1 exemplar on holder
	4	B3-4	6			
		B4-4	6			

C.a. = commercially available; PS = presence sensing; TR = triggered read; PVC = polyvinyl chloride; XPS = extruded polystyrene;
ng = not grouted

Test	Transponder generation	Transponder type	Number of exemplars	Reader Type	Test description, Additional comments	
8	C.a.	A	6	TSU 200	- Reader output power 1 W - Reader mode TR - Transponder orientations 1-6	- Holder material XPS - Speed 3.0 m/s - 1 exemplar on holder
	5	B5	6			
		C2	6			
9	C.a.	A	6	TSU 200	- Reader output power 0.5 W - Reader mode TR - Transponder orientations 1-6	- Holder material XPS - Speed 3.0 m/s - 1 exemplar on holder
	6	C3-0	6			
		C3-1	6			
		C4-0	6			
		C4-1	6			

C.a. = commercially available; PS = presence sensing; TR = triggered read; PVC = polyvinyl chloride; XPS = extruded polystyrene; ng = not grouted
Note: Tests 1 to 8, cf. Hammer et al. (2015) chapter 2.1; test 9 additional results not published

This automatically resulted in a lower average of readings per round (Figure 3.2). When looking at the results, attention needs to be paid to that circumstance. On the basis of Figure 3.2, it could be shown that transponder types C3-0 and C4-0 achieved good results. With averages of readings per round of 2.6 (C3-0) and 4.5 (C4-0), these two transponder types reached almost as many readings as transponder type C2 of the last transponder type generation developed at a higher reader output power of 1.0 W. Compared with this, transponder types C3-1 and C4-1 performed worse (≈ 0.1).

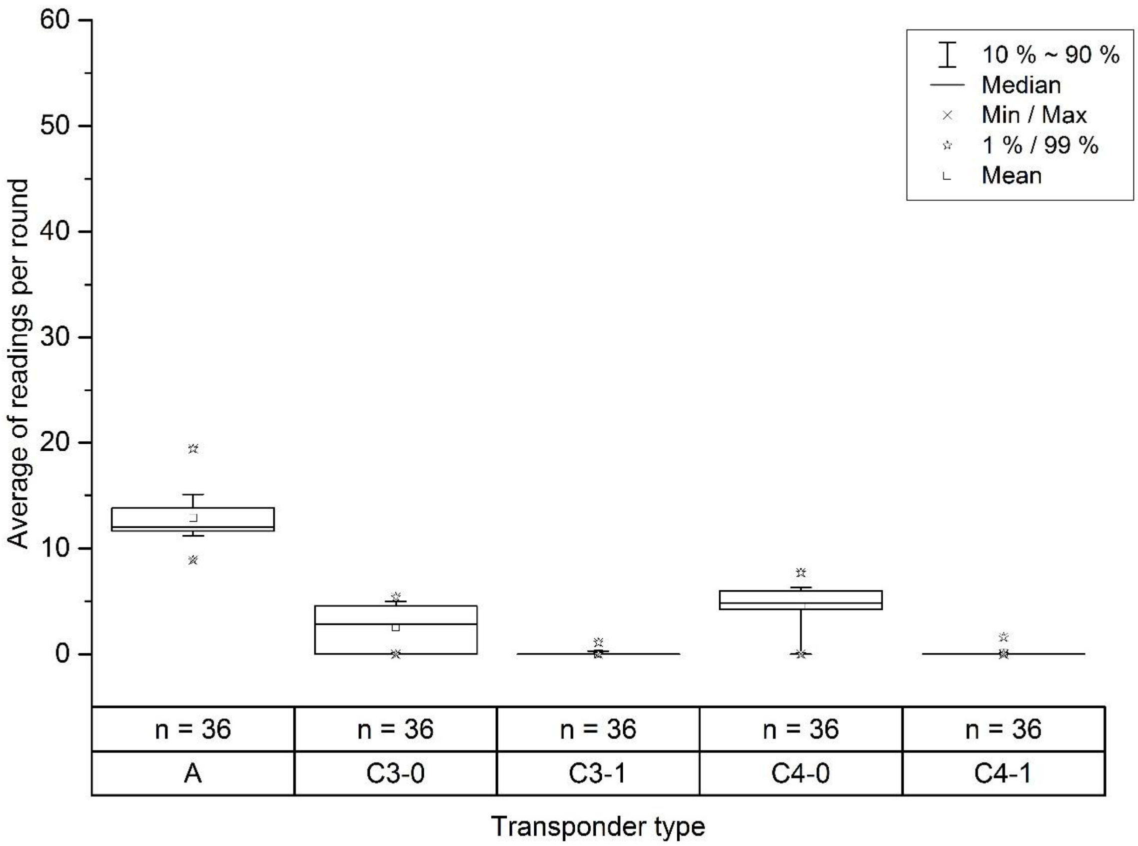

Figure 3.2: Average of readings per round in terms of four pig-sized transponder types (C3-0, C3-1, C4-0, C4-1) in comparison with a commercially available transponder type (A) on the dynamic test bench using a reader output power of 0.5 W.

3.2.2 Opportunities and limits of the dynamic test bench

With the aid of the dynamic test bench, all transponder type patterns developed in-house should be compared with commercially available, foreign and other transponder types developed in-house. The suitability of a transponder type for use on a moving animal should also be tested. The idea of that breadboard construction originated from Traunecker et al. (2012), while Kern (1998) had already built a similar test bench. Kern

(1998) tested the reading speed of a transponder when passing the reading field of a reader antenna. The time frame and the size of the detection area are of fundamental importance for the reading success. A constant speed, orientation and distance to the reader should be given during the test (Kern, 2006).

A modified version of the test bench described by Traunecker et al. (2012) was used to test the transponder types of this study. The detailed description of the test bench is represented in Hammer et al. (2015a) (cf. Chapter 2.1).

A comparison of two holder materials, two different speeds, two reader settings and a different number of rounds was tested to estimate their influence on the reading success (number of readings per round). The results of the different tests are published and presented in Hammer et al. (2015a) and Chapter 3.2.1.

Benefits of the dynamic test bench:

1. The dynamic test bench was a relatively easy application to get a first impression of the performance of different transponder types.

   Kern (2006) also described that kind of test bench as a good application to estimate a RFID system for its suitability in a special application area.

2. The dynamic test bench offered the possibility to test the transponder types in movement, different orientations, various speeds, and with different readers and reader settings.

   The influence of the parameters mentioned could be shown and evaluated statistically on the basis of targeted experiments, which are presented in Hammer et al. (2015a). Different orientations, speeds and distances between HF transponders and readers on a self-developed test bench were also tested by Fröhlich et al. (2007) and Thurner and Wendl (2007). However, in contrast to Thurner and Wendl (2007), with the test bench used here, the UHF transponder ear tags could be detected reliably at a speed up to 3 m/s depending on the transponder type.

3. The dynamic test bench was suitable to compare and test the different transponder types before testing them directly on the animal.

   During the project period, it could be shown that the transponder types which had good results on the dynamic test bench also showed a good performance in the driving experiments. McCarthy et al. (2009) also compared different UHF transponder types on a test bench to evaluate their suitability on different test samples. Wehking et al. (2007) did experiments with transponders located differently on small load carriers. Both authors detected differences between transponder types with the aid of the test benches.

4. The value `number of readings per round´ was appropriate to estimate the quality of a transponder type and to compare it with others.

   Other authors, such as McCarthy et al. (2009), Thurner and Wendl (2007) and Wehking et al. (2007), presented the reading rates instead of the number of readings per time unit or repetition of the transponders in their studies. In this project, the number of readings per round seemed to be better suited to find out subtle differences between the individual transponder types and transponder type exemplars. A conversion of the number of readings per round to reading rates is easy to realise.

5. The results of the test bench can be described as reliable and reproducible because the surroundings of the test bench were not altered and the reference transponder type showed reproducible results.

Drawbacks of the dynamic test bench:

1. There was no possibility to test the transponder ear tags under practical conditions and their behaviour on an animal's ear using the dynamic test bench. Even though there were some tests with water behind the transponder ear tag to simulate body tissue (see Tab. 3.2), the results were not comparable with a transponder ear tag tagged into an animal ear.

   Cooke et al. (2010) tested their UHF ear tags in an anechoic chamber in free space and on 30 mm of skin. They determined a reduction of the read range (typically around 3 m) and an increased variability on skin. Additionally McCarty et al. (2009) examined the influence of different meat-filled boxes and determined an influence on the readability of the UHF transponder. The tag detection rate was always highest with the empty reference boxes (McCarthy, 2009). Experiments performed by Adrion et al. (2015b) also showed the influence of different materials on the reading field of UHF transponders.

However, no experiments with animal ears were performed because of a fast spoilage of the ears and, thus, a poor repeatability of the experiments. The practicability of the transponder types was tested in driving experiments in the following. The results of the dynamic test bench by itself were insufficient to evaluate the suitability of a transponder type for the use in practice.

2. The dynamic test bench was not located in an anechoic chamber, which is why reflections and absorption through the test bench surroundings cannot be excluded (Kern, 2006).
3. No reliable statement about the reading field and orientation of the transponder types could be made using the dynamic test bench, because the transponder exemplar was moving and partly read from many sides depending on its reading field and the output power of the reader.

   The UHF transponder needs to be in a static position to test its reading field and orientation. This test bench was not intended to test these transponder characteristics. A static test bench was built to cover that area within the project (cf. Adrion et al., 2015a).

   In addition, it was difficult to test transponder types with a different performance on this test bench. Depending on the reader output power, the transponder types were either read on many sides of the test bench or not at all.

   The test bench should be modified or the reader output power should be reduced for further experiments with transponders which have a higher reading distance (> 1 m). Thus, the reading distance would be shortened for transponder types performing well.
4. It was also not possible to simulate a group of animals passing a reader field and to test many transponder exemplars at the same time. The durability of the transponder holder and the construction of the test bench was insufficient for this purpose.

In conclusion, it can be determined that the dynamic test bench was a good application to get an initial assessment of a transponder type with relatively little effort. All results were reproducible even though no anechoic chamber was used. The precise reading field of the transponder and its behaviour on an animal’s ear could not be proved. In addition, the driving of larger animal groups could not, unfortunately, be simulated using this application. Other experiments had to be performed to examine these parameters.

3.3 Driving experiments

3.3.1 Comprehensive overview and additional results of the driving experiments

An overview of all driving experiments within the project is shown in Tables 3.3a (pig) and 3.3b (cattle). Contrary to the detailed description of the results of the cattle transponder types in Chapter 2.2, a short summary of the results of the pig transponder types and some additional results will be presented in this chapter.

Summarizing the results of the pig driving experiments, the transponder types C1-4 and C2 performed very well and reached reading rates up to 100 %. However, these transponder types were still grouted into a cattle-sized ear tag and the number of exemplars was very limited. These results were expanded by the results of transponder types C3-0, C3-1, C4-0 and C4-1.

These four transponder types were grouted into a pig ear tag and had the right size for use with fattening pigs. The experimental set-up was the same as in the previous pig experiments (cf. Chapter 2.2).

Figure 3.3 shows the average number of readings per round and the reading rates of transponder types C3-0, C3-1, C4-0 and C4-1. It could be shown that transponder type C4-0 performed best and reached the highest overall mean of readings per round (11.6). Transponder type C4-0 is followed by C3-1 with an overall mean of 10.1 readings per round. Transponder types C3-0 and C4-1 performed worse (ø 7.2 and 6.6 readings per round, respectively). Transponder type C4-0 also reached the highest average reading rates with 98 %, followed by C3-0 (93.7 %), C3-1 (92.6 %) and C4-1 (91.6 %). A total of 5.1 % lost or broken ear tags were observed in the whole experimental period.

Table 3.3a: Overview of all driving experiments performed with pigs.

Test	Transponder generation	Transponder type	Number exemplars	Reader type	Test description, additional comments		Test period
1	C.a.	MS Tag	30	2 x UDL 800	- Reader output power 2 W - 3 groups of animals (10 each) - Running direction clockwise - Variation of reader position (left/right in running direction)	- Reader mode TR - Reader height 167 cm - Gangway width 157 cm	29.01.13 - 07.05.13
2	2	B2	12	2 x UDL 800	- Reader output power 2 W - 3 groups of animals - Running direction clockwise	- Reader mode TR - Reader height 167 cm - Gangway width 157 cm	26.07.13 - 08.08.13
		B3	6				
		B4	9				
		A1	6				
3	3	C1	7	2 x TSU 200	- Reader output power 1 W - 3 groups of animals (10 each) - Running direction clockwise	- Reader mode TR - Reader height 167 cm - Gangway width 157 cm	25.02.14 - 05.06.14
	4	B3-4	10				
		B4-4	10				
		C1-4	3				
4	5	B5	10	2 x TSU 200	- Reader output power 1 W - 2 groups of animals (10 each) - Running direction clockwise	- Reader mode TR - Reader height 167 cm - Gangway width 157 cm	21.10.14 - 25.11.14
		C2	10				
5	6	C3-0	10	2 x TSU 200	- Reader output power 1 W - 4 groups of animals (10 each) - Running direction clockwise	- Reader mode TR - Reader height 167 cm - Gangway width 157 cm	06.07.15 - 15.09.15
		C3-1	10				
		C4-0	10				
		C4-1	10				

c.a. = commercially available; PS = presence sensing; TR = triggered read; Note: Tests 1 to 4 cf. Chapter 2.2; test 5 additional results

Table 3.3b: Overview of all driving experiments performed with cattle.

Test	Transponder generation	Transponder type	Number exemplars	Reader type	Test description, additional comments		Test period
1	2	B1	6	2 x TSU 200	- Reader output power 1 W - 1 group of animals (15 animals) - Running direction clockwise - Stall environment	- Reader mode TR - Reader height 233 cm - Gangway width 345 cm	11.07.13 - 19.09.13
		B2	5				
		B3	4				
2	4	B3-4	8	2 x TSU 200	- Reader output power 0.5/1 W - 1 group of animals (16 animals) - Running direction clockwise - Variation of reader orientation (sideways vs. from above)	- Reader mode TR - Reader height 230 cm - Gangway width 345 cm	11.06.14 - 08.10.14
		B4-4	8				
3	5	B5	15	2 x TSU 200	- Reader output power 1 W - 1 group of animals (15 animals) - Running direction clockwise - Variation of reader orientation (sideways vs. from above)	- Reader mode TR - Reader height 230 cm - Gangway width 345 cm - Stall and pastureland environment	08.10.14 - 30.06.15

TR = triggered read

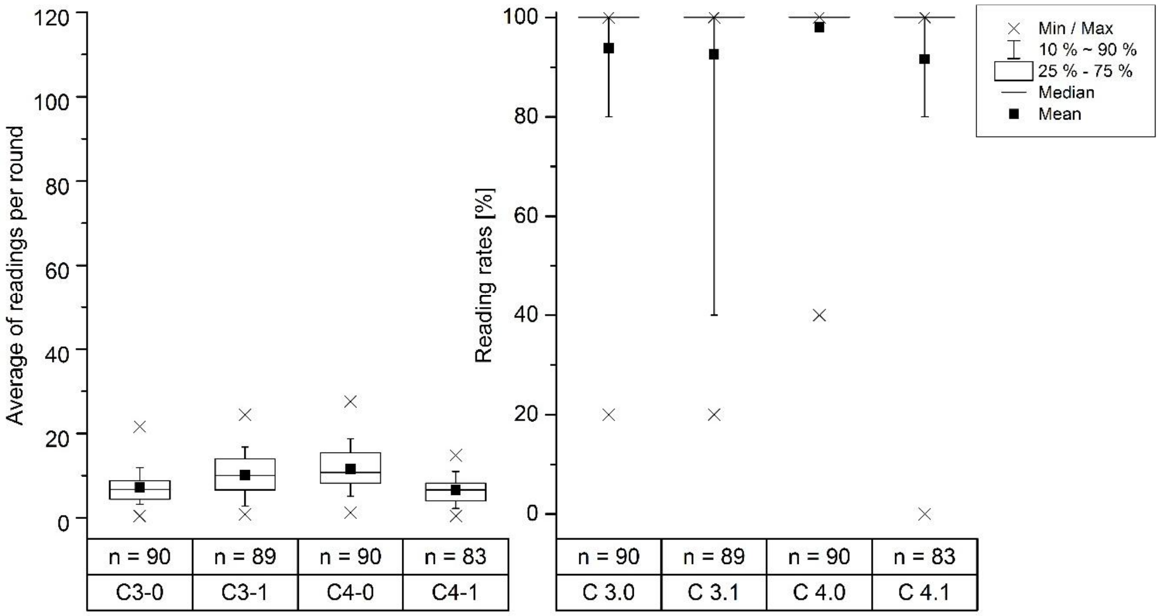

Figure 3.3: Differences in the number of readings per round and the reading rates of pig transponder types C3-0, C3-1, C4-0 and C4-1.

3.3.2 Suitability of the driving experiments with pigs and cattle

The performance of a transponder type could be estimated in advance with the aid of the dynamic test bench, but the durability and functional reliability in a livestock environment could not be assessed until the transponder was used in practice. The suitability of the different UHF transponder types in practice should be tested in the driving experiments. Moreover, not only the suitability of the transponders for simultaneous pig and cattle detection, but also the durability and functional reliability of the whole transponder ear tag should be proved under practical conditions. In these practical experiments, it should be evaluated whether a transponder was generally suited for use on an animal’s ear and if a possible detuning of the transponder’s antenna causing a slightly changed frequency range of further developed transponders is helpful to improve detection rates.

Additionally, a well-functioning reader gate with optimal reader orientations and output powers for simultaneous animal detection should be constructed. Different gates were built for use in fattening pig and cattle husbandry because of different housing conditions. A gate on pastureland was also constructed regarding cattle husbandry to examine the different conditions compared to the stall environment.

The results of all reliable driving experiments were presented in research paper 2 (Chapters 2.2 and 3.3.1). A suitable transponder ear tag type could be developed for both animal species.

Benefits of the driving experiments:

1. A comparison with the results from other authors who also tested RFID ear tags in driving experiments could be made.

   Relatively few authors performed driving experiments with animals in the UHF area. Baadsgaard (2012), Stekeler et al. (2011) and Hogewerf et al. (2013) carried out driving experiments with pigs. In these experiments, rigid UHF transponder ear tags were used and an average reading rate of > 95 % could not be exceeded. Cooke et al. (2010) carried out driving experiments with cattle and achieved merely an average reading rate of 72 %. In the experiments presented here, an average reading rate of 98 % with a pig-sized transponder ear tag (C4.0) could be achieved. In the driving experiments with cattle, an average reading rate of 99 % could be achieved with transponder ear tag type B4-4. The average reading rates of both transponder ear tag types were better than the results from other authors. However, it should be noted that the experimental set-up (e.g. number of antennas, reader/antenna height, reader output power) was different depending on the project and animal species. A simultaneous detection of large animal groups with many repetitions and a defined gate construction should be performed particularly with regard to a widespread introduction of the UHF technology in the animal husbandry field (ISO, 2014).

2. The adjustment of the UHF transponder to an animal's ear could be proved and presented.

   The results of the driving experiments showed that the further development and, thus, the adjustment of the transponder to the ear tag material and its surroundings succeeded. With every further development of the transponders, the number of readings per round increased and usually the reading rate could also be improved. That applied to both animal species. In other driving experiments, there was no comparison of different transponder ear tag types in one experiment (Baadsgaard, 2012; Cooke et al., 2010). Hogewerf et al. (2013) tested only one transponder ear tag type, albeit with two different pin diameters.

3. The UHF transponder ear tags developed in-house could be compared in practical use. The results of the driving experiments were decisive and suitable for the further development of transponders.

   The driving experiments were absolutely sufficient for the purpose of the transponder type development and adjustment within the project. The number of readings per round and the reading rates showed clearly if a further development of the transponder succeeded or failed. The average number of readings per round was more informative about a transponder’s performance, but the reading rate also showed that improvement.

4. Not only the functionality of a transponder ear tag type, but also a first assessment of its durability could be tested on the animal.

   The first pig-sized transponders were grouted into a cattle-sized ear tag. The pigs crunched a lot of these transponder ear tags because of their poor grouting and the large size. The transponder antenna was sometimes only damaged and the transponder ear tag exemplar still worked, but most of the time the chip was bitten through or the whole ear tag was lost (loss rates up to 40 %). Even if only the ear tag material was cracked, it was a question of time until the moisture probably entered the chip and destroyed it. Baadsgaard (2012) gained similar experience within the test of UHF ear tags. The transponder ear tags had the right size for both species by the end of the project. Testing the most recently developed transponder ear tag types with pigs resulted in only one transponder ear tag being lost and one destroyed (5.1 % of the total number of the transponders tested). All other ear tags performed well until the end of the pig’s life. No lost or broken transponder ear tags in the cattle experiment were registered over eight months. Ear tag losses of 5 - 60 % have generally been reported by other authors (Bergqvist et al., 2015). Thus, a loss rate of 5.1 % recorded in our own pig experiments can be declared as a good result.

5. The number of readings per round and the reading rates were appropriate parameters to evaluate a transponder ear tag type in the framework of the project and in practice.

Baadsgaard (2012), Cooke et al. (2010), Hogewerf et al. (2013) and Stekeler et al. (2011) only published the reading rates of their experiments. The reading rate is certainly the most important parameter regarding the use of the transponder ear tag in practice. The farmer only has to know if the animal is present, therefore, one reading is sufficient. However, for development and comparison purposes, the number of readings per round was a very helpful measure to better assess the performance of an individual transponder ear tag type. Particularly in the beginning of the project, when all transponder type exemplars were handmade, a difference between the single exemplars could be more easily found out with the number of readings per round.

Drawbacks of the driving experiments:

1. A randomized and simultaneous test of the UHF transponder ear tag types was not possible because of operational processes on the experimental station and the transponder production process itself. Thus, unfortunately, a statistical analysis was not possible for all experiments.

   The experiments were performed over several days to reduce the influence of animal behaviour, e.g. running speed, group behaviour, outside temperature, performance, of the pigs. There was a number of repetitions to minimise the influence of a special test day. A testing along the whole fattening period would have been appropriate for reliable statements. A sufficient number of repetitions could not always be performed because of the low durability and a small number of transponder type exemplars.

   Regarding the cattle experiments, operational processes on the experimental station and weather conditions prevented a randomized implementation of the experiments.

   The first UHF transponder exemplars could only be produced in a very limited number because they were all handmade. Here, a statistical analysis could only be performed for two experiments.

2. The durability of the first transponder ear tags was too poor to examine different experimental set-ups in the pig experiments.

Because of the low durability, large size and high interest of the animals in the first transponder ear tag types, there was no time to perform experiments with different reader orientations and heights. Some of the ear tags could only be tested for three test days until they were broken or lost. In addition, the reader height used during the pig experiments was not practical. A height of at least two metres should be achieved in order not to hinder operational procedures (Baadsgaard, 2012).

Tests with different reader orientations should also have been implemented to further improve reading rates.

3. The experiments were relatively work-intensive and time-consuming.

   At the beginning of the project, the finding of a suitable experimental set-up for the pig and cattle driving experiments took a lot of time. Diverse settings had to be tested because the function of the UHF RFID system in an animal husbandry environment was not known. Moreover, a continuous development of the UHF readers and software required a constant adjustment of the experimental set-up.
   A specially adjusted reader gate had to be built for each location.

   As a result of limited accommodation facilities, the cattle experiments were linked to the seasons. In summer time, rainy days first prevented the implementation of the pastureland experiments. The danger of injury for the cattle was too high on soil which was too deep or slippery. Therefore, the individual experiments could only be performed within certain time frames and in a special order.

4. The results are very dependent on the individual animal (e.g. running behaviour, running speed, position in hierarchy, form and thickness of the ear).

   The individual animal played a decisive role in the results. The running speed, head posture and position within the group influenced the reading success strongly. These factors are probably influenced by the hierarchic position of the animal in the group. The form and thickness of the ear may also have influenced the number of readings or the reading rate. In some cases, the investigation of individual transponder type exemplars showed that the exemplars of certain animals were often less. The exemplars of other animals were always read better, even if the exemplars showed a similar performance on the dynamic test bench. Unfortunately it was not possible to quantify or examine the animal effects in a more detailed way.

In conclusion, it can be determined that the driving experiments with pigs and cattle were a good possibility to test the different transponder ear tag types in practice. These experiments were crucial to test the different transponder ear tag types according to their durability and adjustment to the animal husbandry environment. The results from these tests were essential for the further development of the transponder ear tag type. A statistical evaluation of the different transponder ear tag types was not always possible because of the small number of exemplars, the transponder production process itself and the operational processes on the experimental farm.

3.4 Evaluation of the cost-benefit analysis of the UHF RFID system

The chances of the UHF RFID system developed for pig and cattle monitoring can be estimated on the market with the aid of the cost-benefit analysis. Within that study, the cost-benefit analysis was oriented towards the recommendations of Potthof (1998) and Pietsch (2003) and was carried out for four example barns. Two fattening pig barns (400 pigs and 1600 pigs) and two dairy cattle barns (71 cows and 624 cows) were chosen to assess the costs and the benefits of the system. On the basis of four standard ground plans (KTBL, 2015a; KTBL, 2015b; KTBL, 2015c; KTBL, 2015d) the UHF system was fictionally implemented into the barns. The costs of the single components were valued by the developers and internet research was performed. Two cost situations were calculated for the analysis. Several monetary and non-monetary evaluable benefit categories for the system were also determined. At the end, net benefits were calculated and a comparison of the costs and the benefits was presented. The absolute advantageousness or disadvantageousness for each barn could be worked out.

Benefits of the cost-benefit analysis:

1. The implementation of the cost-benefit analysis was very helpful to get a first impression of the costs of the newly developed system.

During the developing process, the costs of the single components were never seen in a complex context of the system. The summing up of all costs was necessary to evaluate the expense of the systems per animal place and per product unit (kilogram meat or milk).

In general, statements in terms of probable profitability of such systems are of great importance for its success on the market (Roth & Doluschitz, 2007). But Gampl (2006) pointed out that, at least in the case of traceability systems, the levy of the costs to the product price only succeeded in a few systems. No literature proving this statement could be found, especially for management assistance systems, but there is a presumption that it behaves similarly.

It was also calculated that a system developed further could achieve a reduction of costs through technical changes in the cost intensive areas of the system above all hardware costs. The UHF readers and also the number of antennas needed should be mentioned here.

2. The implementation of the cost-benefit analysis was very helpful to evaluate which benefits the system can render in which area of the production process.

   When performing a cost-benefit analysis, there is the need to consider each part of the UHF system. As the benefits of the system were relatively difficult to calculate, percentage gradations were used to calculate the saving potential of the different benefit categories. This practice turned out to be sensible: a benefit category can have particularly positive or slightly positive effects because of varying parameters (e.g. operational structure, farmer, individual animal). Due to that, a meaningful estimation of the benefits could take place.

3. Parts of the system which produce the highest proportion of costs could be exposed with the cost-benefit analysis.

   With the aid of the analysis, it could be shown that the hardware costs have the largest proportional part. However, at the same time, the greatest reduction of costs is possible with a further development of the system in this area. A detailed breakdown of the costs of all components clarified further saving potential.

Drawbacks of the cost-benefit analysis:

1. A calculation of the costs was very difficult because the system has not yet been implemented in practice.

   The calculation of the costs in a cost-benefit analysis is typically relatively easy, because the prices for hard- and software and for wages can be calculated based on market prices (Andres, 2009). However, the calculation of the exact costs was complicated in this case because of newly developed system components where no market price was given. Here, it had to be based on the estimated costs of the respective developers. An overestimation, especially in terms of the UHF reader costs, cannot be excluded here.

2. No experience reports of end users (farmer) could be used to identify benefit-generating areas of the system better. A monetization of the benefits was very difficult.

   In a non-published study of the University of Hohenheim, a survey with 100 farmers was carried out to estimate possible benefit-generating areas of the UHF RFID system. The basis for that survey was a random sample of fair visitors.

   In this survey, the respondents were in line with the information of the Federal Statistical Office regarding proportional distribution of the farmers of the state (Pfeifer, 2015). The age structure of the respondents showed that more than two-thirds of the respondents were younger than 35 years old. This may lead to the assumption that majoritarian technophile younger people were questioned. The survey showed that only 38 out of the 100 farmers interviewed use general management assistance in the feeding, milking and fertility management of their farms. Out of the 38 farmers, 35 were dairy cattle farmers, suggesting that more benefit of technical management assistance was seen in this agricultural production segment (Pfeifer, 2015). This result is similar to the result of the cost-benefit analysis, where an advantageousness only for the larger dairy cattle farm under the highest benefit scenario was calculated (cf. Chapter 2.3).

However, the situation is different in pig husbandry. The causes might be the shorter lifetime and a lower monetary value of the pigs, as well as a pronounced playing and reconnaissance behaviour of the animals which reduces the operating life of many pieces of management assistance in pig husbandry (Hoy, 2009; Pfeifer, 2015).

Furthermore, a monetization of the benefits was very difficult. A quantification of benefit aspects is always necessary to monetarize benefits (Quaas, 2005). Therefore, subjective and objective approaches are available (Ahlheim & Frör, 2003; Ebner, 2004). Empirical methods could be used to objectify the process of benefit assessment (Ott, 1993; Roth & Doluschitz, 2007). For this, experts from the topic-oriented environment might be conceivable (Roth & Doluschitz, 2007). A better estimation of the benefits would have been possible through the consultation of more and other experts.

In general, the methods of monetarizing benefits are controversial, while a methodological mixture with a subsequent expert evaluation should be used to achieve transparent and objective results (Roth & Doluschitz, 2007).

Moreover, only the benefits from the perspective of the farmer received attention in this analysis. Further benefits from the perspective of the animal, veterinarian or authority should also be taken into account.

3. The non-monetary evaluable benefits could not be taken into account sufficiently.

   When performing a cost-benefit analysis, all costs and benefits have to be measured in monetary terms to enable the decision between different alternatives (Fries, 2006). In the classical cost-benefit analysis, the value of all benefits which do not have a market price are estimated by different methods, such as “cost of illness” or “willingness to pay” (Cato, 1998). In the case of information technologies, Lincoln and Shorrock (1990) and Kleijnen (1980) proposed the extension of the cost-benefit analysis with regard to non-monetary evaluable benefits; but it is very difficult to include the non-monetary evaluable benefits in the analysis. These benefits can rather be considered as an additive and as a last decision support.

In conclusion, it can be stated that the implementation of the cost-benefit analysis was useful to get a first impression of the costs and benefits of the UHF RFID system. Even if the determination of the costs and benefits was difficult, through a gradation of the latter, a good assessment of the system’s potential on the market could be presented in detail.

Horton (1994) stated that even if no classical cost-benefit analysis can be performed because of lack of resources or data, it provides a structured conceptual framework. Consequently, a deeper insight into a rarely researched problem can be achieved. There is the possibility to identify weak points and to make new assumptions (Horton, 1994). However, it also has to be stated that only one interest group was included in the cost-benefit analysis implemented here. In a classic cost-benefit analysis, all stakeholders are included for decision-making (Henson, 1998).

A repeated implementation of a cost-benefit analysis of the market-ready UHF system will be necessary to achieve robust and more detailed results.

4 General conclusions

In this study, the suitability of a UHF RFID system for simultaneous pig and cattle detection is evaluated. Therefore, several UHF transponder ear tags had to be developed and proved in laboratory and practical experiments. Additionally, a cost-benefit analysis of the UHF system based on example barns had to be carried out to estimate the potential of the system for use in practice. A conclusion about the suitability of the system can be drawn based on the following questions.

1. Are UHF transponder ear tags suitable for animal identification?

   Yes, they are. There was a development of a UHF transponder ear tag for pigs and cattle within the project. These ear tags were examined in laboratory and practical tests. During the development, the transponder patterns could be adjusted to the ear tag material and its immediate surroundings. Additionally, its durability could be significantly improved over time. The latest development was also the right size for both animal species. Further experiments concerning the longevity of the transponder ear tags should be performed to increase the sample size in this area. A sufficient durability (percentage lost or broken exemplars = 5.1 %) of the latest pig ear tags over 11 weeks could be achieved. The durability of the cattle ear tags could be examined for eight months. No lost or broken ear tags could be registered there.

2. Is a UHF RFID system practical and affordable for the farmer?

   Not yet. The UHF RFID system presented in this study was only tested on an experimental station and on one private farm. The use of the system on further private farms would be necessary to confirm the usability of the system.

   Regarding the UHF transponder ear tags, a well-functioning, right sized ear tag could be developed for pigs and cattle. However, the pig ear tag should complete long-term tests successfully before they are sold to farmers.

   When performing simultaneous animal detection, very good reading rates could be observed (pig: ø 98 %; cattle: ø 99 %) depending on reader output power, reader orientation and gate surroundings. A well-functioning and practical gate could be built in a stall environment for cattle. Further adjustment should be performed for use on pastureland. Regarding the gate for simultaneous pig detection, development in terms of practical suitability should take place in further tests with different reader heights and orientations.

The external antenna types chosen in most applications were over-dimensioned; smaller and cheaper antenna types should be examined. There are a lot of different antenna types on the market which could be better suited.

The installation of the systems in the stall environment has not yet been technically matured. There are still too many disturbing unprotected cables and to many objects with an inadequate protection class.

The costs of the system are also still too high for the farmer. The costs are not compensated by the benefits with the current production costs of the hardware. The system is not yet profitable for the farmer in fattening pig husbandry. In dairy cattle husbandry, the use of the UHF system in the cheapest scenario and on the largest farm showed little profitability, but with a further development of the system, a reduction of costs can be estimated and the potential of the system was clearly identifiable.

In general, it can be stated that the whole system is not completely ready for implementation in practice at the current level of development.

3. Could UHF RFID make a contribution to precision livestock farming (PLF) and the documentation of animal welfare?

   Yes, it can. One decisive part of PLF is the real-time, on-going and automatic monitoring of individual animal parameters by “smart” sensors which are attached directly to the animal. With the UHF system presented in this work, it is possible to record and collect data about feeding, drinking and playing events via a UHF transponder ear tag.

   Another aspect of PLF applications is that the data collected has to be processed by a computer-based background system, which is challenging because livestock systems are dynamic processes and no standard mathematical model can be used. A first step in that direction was carried out within the project. A special software was developed where sliding averages could consider the individual animal feeding, drinking and playing behaviour over a certain period of time. The farmer’s attention should be drawn to a special animal for substantial deviations from the sliding averages. The results of this analysis should then be the basis of farmer decisions or optimisations in livestock husbandry, which is another aim of PLF.

The hotspot monitoring of pigs worked quiet well on the experimental station. However, the right mounting of the antennas (e.g. antenna orientation, reader output power) on the different hotspots (feeder, drinker, playing device) took a lot of time and standardized applications for any kind of hotspot could not yet be found. A very time-consuming video analysis has to be performed for any hotspot to find out the right reader orientations and settings (Adrion et al., 2015c).

Additionally, the farmer always has the knowledge about the precise location of each animal because of the possible simultaneous animal detection during loading or rehousing processes. Because all this data can be stored in a database specially provided for this purpose, the UHF system can also make a contribution to the documentation of animal welfare. A lot of research still has to be carried out, however, until a system can take full advantage of all the technical possibilities considering individual animal behaviour.

5 General summary

A structural change could be observed within German animal production in recent years. Whereas the number of livestock holdings decreased, the number of animals per livestock holding increased. Because bigger livestock holdings are also often in a conflict of aims between sustainability, animal welfare and economy, a well-functioning and cost-effective management assistance is even more important.

The collection of animal-related data and data from their environment with simple, innovative and low-cost techniques to improve animal welfare, animal health and animal performance, as well as the housing conditions, is a main part of so-called precision livestock farming (PLF). A possible solution for implementation of these thoughts is a technology called radio-frequency identification (RFID).

The suitability of an UHF RFID system for simultaneous pig and cattle detection could be evaluated during a three year project, which was funded by the Federal Office of Agriculture and Food. Therefore, several UHF transponder ear tags had to be developed and tested in laboratory and practical experiments. Additionally, a cost-benefit analysis of the UHF system based on four example barns had to be carried out to estimate the potential of the system for use in practice. Thereby, not only the costs and benefits of simultaneous animal detection were calculated, but also the costs and benefits of hotspot monitoring of the animals in their husbandry environment were estimated.

Nine different transponder types for each animal species were developed within the duration of the project. During the development process, the antenna structure, antenna length and label material had to be varied to adjust the transponder to its immediate surroundings as optimally as possible. The grouting process of the transponder into the ear tag was also continuously improved.

Before testing the UHF transponder ear tag types in practice, they were all tested on a dynamic test bench. Using this test bench, a preliminarily assessment of the in-house developed transponder types by themselves, with foreign and commercially available UHF transponder types under various conditions was possible. The number of readings per round was recorded and used to identify differences between the transponder types.

The UHF transponder ear tag types were tested with the aid of driving experiments using pigs and cattle with a focus on their suitability and durability under practical conditions. While one gate in a stall environment was built in the driving experiments for the fattening pigs, with cattle, reader output power, reader orientation and the test environment were varied. In these experiments, the number of readings per round and the reading rates, which were the more decisive value in practice, were calculated. In the last stage of development, a suitable, well-functioning UHF transponder ear tag type and good average reading rates could be achieved for both animal species (pigs: ø 98 %; cattle: ø 99 %)

While performing the cost-benefit analysis, it could be calculated that, at the present state of development of the UHF system, the benefits do not exceed the costs of the system in the fattening pig husbandry. In dairy cattle husbandry, a positive result could be reached only under the best estimations and the larger farm. However, the costs arising per animal are still too high to implement the systems on the market. Because of the early stage of development, the calculation of the costs and benefits was difficult and still holds uncertainties. Following the assumption that the UHF system will be developed to practical maturity, the costs calculated would be lower and an advantageousness of the system would be also expected for other farms. This work was sensible and necessary to get a first assessment of the costs and benefits.

Great development progress could be achieved for the UHF RFID system and a large potential for PLF could be shown within this project, even if the system is not yet ready for market.

6 Zusammenfassung

Innerhalb der deutschen Tierproduktion konnte in den vergangenen Jahren ein Strukturwandel festgestellt werden. Während die Anzahl der landwirtschaftlichen Betriebe stetig sank, nahm die Anzahl an Tieren pro Betrieb zu. Da jedoch auch große tierhaltende landwirtschaftliche Betriebe häufig im Zielkonflikt zwischen Nachhaltigkeit, Tiergerechtheit und Wirtschaftlichkeit stehen, ist eine gut funktionierende und kostengünstige Managementhilfe umso wichtiger.

Das Sammeln von tier- und umweltbezogenen Daten mit einfachen, innovativen und günstigen Techniken zur Verbesserung von Tierwohl, -gesundheit und -leistung sowie Haltungsbedingungen, stellt den hauptsächlichen Teil des sogenannten Precision Livestock Farming (PLF) dar. Eine Möglichkeit zur technischen Umsetzung stellt die sogenannte Radiofrequenzidentifikation dar (RFID).

Während eines dreijährigen, von der Bundesanstalt für Landwirtschaft und Ernährung finanzierten, Verbundprojektes wurde die Eignung eines UHF-RFID-Systems zur Simultanerfassung von Schweinen und Rindern getestet und bewertet. Hierfür wurden verschiedenste UHF-Transponderohrmarken entwickelt, an Prüfständen und in Praxisanwendungen getestet. Zusätzlich wurde eine Kosten-Nutzen-Analyse des UHF-RFID-Systems anhand von vier Beispielställen durchgeführt um das Potential des Systems für den Einsatz in der Praxis abzuschätzen. Hierfür wurden nicht nur die Kosten und der Nutzen des Systems zur simultanen Tiererfassung berücksichtigt, sondern auch eine Überwachung der Tiere an verschiedensten Punkten ihrer Haltungsumwelt.

In der gesamten Projektlaufzeit wurden für beide Tierarten neun unterschiedliche Transpondertypen entwickelt. Während des Entwicklungsprozesses wurden die Antennenstruktur, -länge und das Trägermaterial des Transponders verändert und somit der Transponder an seine unmittelbare Umgebung so gut wie möglich angepasst. Auch der Prozess des Eingießens wurde stetig verbessert.

Bevor die UHF-Transponderohrmarken in der Praxis getestet wurden, wurden sie auf einem dynamischen Prüfstand beurteilt, sowie mit anderen eigens entwickelten, projektfremden und kommerziell erhältlichen UHF-Transponderohrmarken unter verschiedenen Bedingungen verglichen. Es wurde die Anzahl an Lesungen pro Runde aufgenommen um Unterschiede zwischen den Transpondertypen festzustellen.

Mit Hilfe von Treibeversuchen an Schweinen und Rindern wurde die Eignung und Haltbarkeit der Transponderohrmarken in der Praxis untersucht. Während für die Versuche mit Schweinen ein Lesegerätgate, mit in allen Versuchen gleichen Einstellungen, im Stall aufgebaut wurde, wurden bei den Rindern die Lesegerätleistung, die Lesegerätausrichtung und die Versuchsumgebung variiert. Bei diesen Experimenten wurden sowohl die Anzahl an Lesungen pro Runde als auch die Erfassungsquoten, welche den für die praktische Anwendung wichtigeren Wert darstellen, berechnet. Mit dem letzten Entwicklungsschritt konnte eine funktionsfähige und haltbare UHF-Transponderohrmarke mit guten durchschnittlichen Erfassungsquoten für beide Tierarten entwickelt werden (Schwein: ø 98 %; Rind: ø 99 %).

Bei der Durchführung der Kosten-Nutzen-Analyse konnte gezeigt werden, dass, zum jetzigen Entwicklungszeitpunkt des Systems, der Nutzen die Kosten im Bereich der Mastschweinehaltung nicht übersteigt. In der Milchviehhaltung konnte nur unter den günstigsten Annahmen und für den größten Betrieb ein positives Ergebnis erzielt werden. Die entstehenden Kosten pro Tier sind vermutlich jedoch zu hoch für die Etablierung des Systems auf dem Markt. Allerdings war, aufgrund des frühen Entwicklungsstadiums des Systems, eine Kosten- und Nutzenabschätzung des Systems schwierig und ist mit Unsicherheiten behaftet. Unter der Voraussetzung der Praxistauglichkeit des Systems würden die Kosten sinken und auch für andere Betriebe ließe sich eine Vorteilhaftigkeit des Systems erwarten. Die vorliegende Arbeit war sinnvoll und wichtig um eine erste Beurteilung der Kosten und Nutzen des Systems zu bekommen.

Innerhalb des Projektes konnte ein großer Entwicklungsfortschritt des UHF-RFID-Systems erreicht und das große Potential für PLF gezeigt werden, auch wenn das System bis jetzt noch nicht marktreif ist.

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UHF RFID has “improved to a point that it is no longer a question of if the technology works but how do I get it to work best in a specific application?”

Mitchell, 2013

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