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Development, function and test of a static test bench for UHF-RFID ear tags

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Ultra-high-frequency radio frequency identification systems (UHF-RFID systems) offer multiple application possibilities for animal identification. In a present joint project, UHF transponder ear tags and readers are currently being developed especially for use with cattle and pigs. An automatic test bench was developed for measuring the detection area and signal strength of various transponders, the aim being to enable with this test bench comparison of different types of UHF-transponder ear tags in different orientations to reader antennas. Described in this paper is the constructional development and functionality of the test bench as well as trials to determine reproducibility, influence of two trial parameters and suitability of the test bench for the required purpose. The results demonstrate that the test bench fulfilled all the stipulated requirements and enabled a preliminary selection of suitable types of UHF ear tags for use in practice.

Key words
Electronic animal identification, UHF RFID, RSSI, test bench, transponder

Electronic animal identification has established its place in modern livestock production. Its use ranges from the mandatory identification of small ruminants for securing traceability (Schwalm and Georg 2011), over utilisation of the identification data for dairy cows and breeding sows in farm management (Ruiz-Garcia and Lunadei 2011, Trevarthen and Michael 2008), to complex data recording on experimental farms (Bütfering 2011). In addition to the standard systems applied under ISO 11785, based on low-frequency radio frequency identification (LF-RFID, 134.2 kHz), the application of RFID in the high-frequency range (HF-RFID, 13.56 MHz) (Hessel and Van den Weghe 2013, Leong et al. 2007, Maselyne et al. 2014) and ultra-high-frequency range (UHF-RFID, 860960 MHz) (Hogewerf et al. 2013, Ng et al. 2005, Stekeler et al. 2011, Umstatter et al. 2014) is increasingly tested in research in recent years. One reason for this is that anti-collision methods with LF-RFID can only be applied in a very limited form because of the low data transference rate in this frequency range. Anti-collision systems prevent data collisions that occur when a number of transponders are present at the same time within the antenna field of a reader. For instance, widely applied is the slotted ALOHA procedure whereby transponders are allocated random time windows during which they send their respective data to the reader (Finkenzeller 2012, Namboodiri et al. 2012). The quasi-simultaneous reading of transponders hereby enabled is advantageous, e.g., to the RFID system in the detection of animal groups where individual animal identification is no longer required. Compared with LF-RFID, HF-RFID can enable the practical application of quasi-simultaneous reading through a higher data transmission rate (Burose et al. 2010, Hessel and Van den Weghe 2013, Kern 2007). However, the effective reading distance of both systems is a maximum of approx. 1 to 1.5 m. In the UHF range, alongside the simultaneous reading of transponders, a significantly higher reading range of more than 3 m with passive tran-

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sponders can also be achieved (Ruiz-Garcia and Lunadei 2011). Hereby, a large number of application possibilities for UHF transponders in animal production is produced including simultaneous reading of large animal groups, monitoring feeding behaviour or localising to determine activity behaviour of animals in the group. However, there are also disadvantages with the higher working frequency such as marked absorption by water or body tissue, as well as reflection on electrical conductive surfaces. The latter problem causes fluctuating interference patterns that lead to inhomogeneity within the antenna field. Additionally, materials in the vicinity of the transponder cause a change in impedance (alternating current resistance) of the transponder antenna through their permittivity (permeability for electrical fields) and thus a shifting of the transponder resonance frequency. In most cases, a reduction in resonance frequency is to be expected (Rao et al. 2005). All these factors influence the reading range and identification reliability of UHF transponder ear tags and necessitate appropriate adjustment of transponder antennas for use with animals (European EPC Competence Center (EECC) 2011, Finkenzeller 2012, Kern 2007, Lorenzo et al. 2011, Rao et al. 2005).

For assessing UHF transponders for their reading distance, their sensitivity to being attached to various materials, or to transmitting frequency and further characteristics, standardised measurements are conducted in absorber chambers that guarantee freedom from interference and reproducibility of results. A known test of this type is the "UHF Tag Performance Survey" annually conducted by the European EPC Competence Center (EECC, Neuss, Germany) (European EPC Competence Center (EECC) 2011). A precise description of the measuring approach applied there is given by Derbek et al. (2007). Disadvantages of using this procedure include the high technical input involved and the required testing of individual parameters instead of the entire RFID system. In contrast to this, results are not generalisable in practical trials with the entire system and not reproducible over a longer period because of the changing environment conditions. For these reasons, some authors have taken a middle way and conduct tests of UHF systems in model-type laboratory trials, the set-up of which represents a particular section of application in practice, offering a better reproducibility than in practical trials (Jungk 2010, Mainetti et al. 2013). Jungk (2010) emphasises the absolute necessity of sufficiently repeated measurements for securing accuracy of results against environment influences that occur in a trial environment without surrounding absorbance material. Kern (2007) also presented some possibilities for simple tests for transponders and warned of the danger that these applications did not in every case sufficiently satisfy scientific requirements.

Defining problems and objectives

An innovation project supported by the Federal Ministry for Food and Agriculture (BMEL) currently develops UHF transponder ear tags for identification of cattle and pigs as well as readers for simultaneous reading and locating UHF transponders (Forschungsinformationssystem Agrar/Ernährung 2012). Main target hereby is adapting the RFID system to meet the requirements and conditions in animal farming and the attachment of transponder ear tags to animals. For selection of suitable antenna design and ear tag construction, especially with regard to sufficient reading distance, acceptable directional characteristics, and readability in the vicinity of ear tissue, the function patterns of different transponder types were tested in test bench trials before use with animals. For this, two test benches were designed for testing transponders under dynamic and static conditions. In the dynamic tests, a comparison of transponders under various speeds and in different directions is possible which reflect in model form the application of the system in practical driving trials (Hammer et al. 2015).

Additionally of interest is the size and form of the effective transponder ear tag reading area and signal strength in relationship to various factors. These parameters can be investigated with non-moving (static) transponders.

Presented in this paper will be a static test bench that enables measurement of recognition area and signal strength of UHF transponder ear tags in combination with various reading apparatus and their settings. Main target hereby is comparison of ear tags with different types of UHF transponders. This should enable an overall assessment of transponder types as well as observation of individual orientations of the ear tags to the reader antenna. For the measurements involved, the transponder ear tags must be positioned in various orientations within the field of a reader according to defined matrix dots (Kern 2007). In order to efficiently conduct these time-consuming trials, the test bench was to a large extent automated. Because the test bench was not situated in an interference-free testing environment (absorber chamber), influences from fluctuating reflections and absorption characteristics through changes in the immediate environment could not be ruled out. Because of this, preliminary methodical trials were conducted with the test bench to determine the reproducibility of measurements, the influence of the holders used for the ear tags and the influence of the sequence of the measured coordinates. Subsequently, different types of UHF ear tags to be used in testing the actual application of the test bench were compared. In the following, construction and function of the test bench are explained and test results presented. There then follows an assessment of the suitability of the test bench for the planned measurements on UHF transponder ear tags.

Materials and methods

Construction and function of the test bench

Main components of the test stand are two linear drives crossing at right angles within a 350 cm x 350 cm horizontal work area positioned 34 cm above floor level. These represent the x- and y-axes of the area within which a tracked slide slotted into the x-axis drive line can be moved to every coordinate. Hereby, the y-axis supports the middle of the x-axis (Figure 1). A 125 cm high pillar of extruded polystyrene (XPS, Styrodur®) is fitted onto the slide and serves as holder for the transponder ear tags. Polystyrene was selected as holder material because of its small influence on the reader electromagnetic emissions (relative permittivity ε_r = 1.03) and is also used in standardised transponder tests (Derbek et al. 2007, European EPC Competence Center (EECC) 2011, Webster and Eren 2014). The ear tags can be positioned individually in exchangeable polystyrene foam blocks on the upper end of the pillar in all required orientations to the reader antenna. In the tests, the tags are situated 165 cm above floor level. The reader antennas could also be positioned where required, individually or more than one together, at freely selectable points in various alignments around the test bench. In this way, the antennas can also be positioned at greater distances from the test bench so that measurements can also be made for transponders able to be read at greater distances by readers at their maximum settings. Positioning precision of transponders relative to readers represented around 1 cm under consideration of all error sources, such as, in particular, the play of the parallel tracking of the x-axis, the alignment of the transponder in the holder and the positioning of the reader antenna (Adrion et al. 2014).

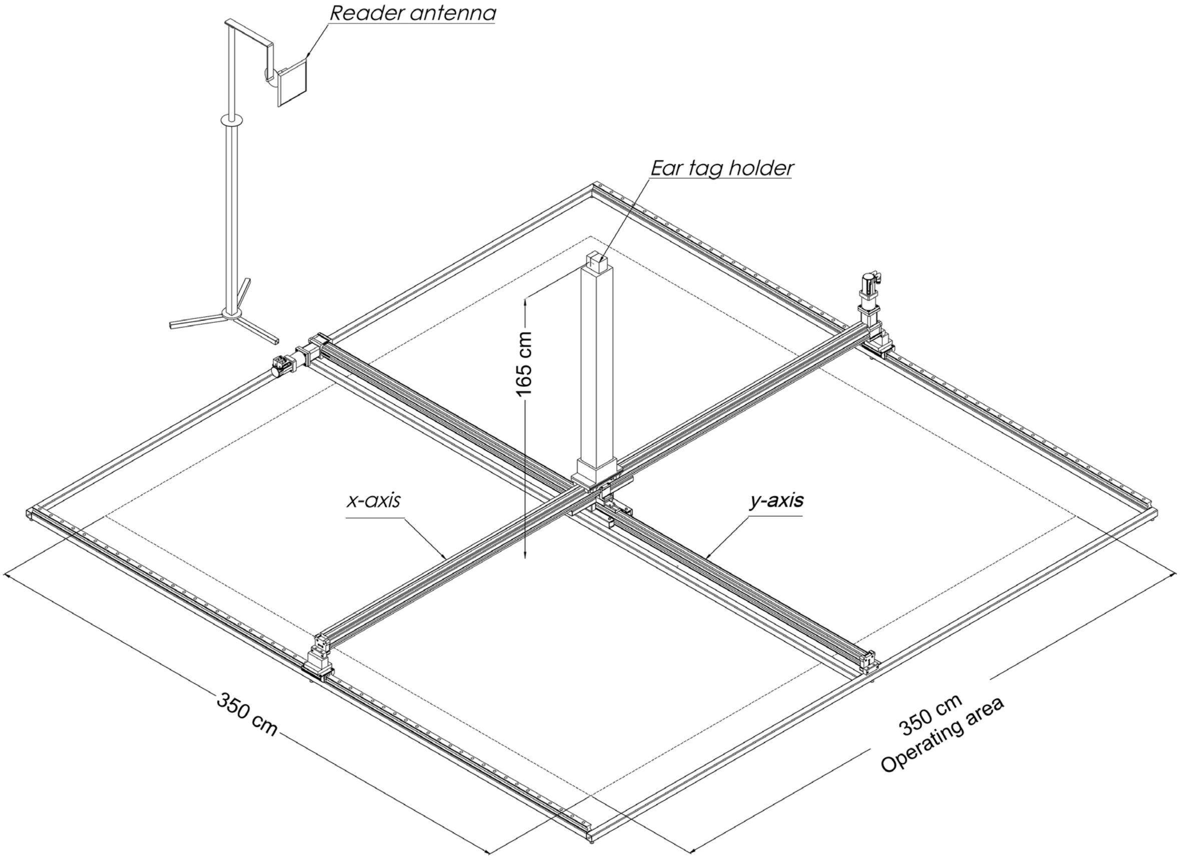

Figure 1: Test bench model diagram

The servomotors of the linear drives and the reader have a central control. The operator can configure the test stand via a LabVIEW® application and call up test results, start tests, and also allow procedure to be followed automatically. The tests were configured beforehand in a central configuration software (Phenobyte GmbH & Co. KG, Ludwigsburg) and stored in a test database. Important parameters such as proven coordinate area, coordinate matrix, transponder number, transponder orientation, reader configuration and antenna alignment are established in this work phase. All readings from each test are entered into the database together with the respective registered coordinates (Adrion et al. 2014).

An individual test run comprises the measurement of a transponder in a particular position with defined reader configuration and position. During a test run, the predetermined coordinate matrix is automatically processed. This can take place either in random sequence or in rising or falling order of coordinate sequence on both axes. On every coordinate the slide is halted during a procedure and the reader, after a short pause (< 1000 ms), activated for a defined period (100 ms to 65000 ms) and the readings from the transponder during this period registered. The number of readings is mainly dependent on the different settings of the reader, such as the interval after which the so-called "inventoried flag" of the transponder is reset in the anti-collision process. But the transponder energy supply also influences the number of readings per time period. Thus, on the limits of the reading area the number of readings sinks because of the poorer energy supply for the transponder (Adrion et al.

2014). During each reading, the reader measures an indicator for the transponder signal reception strength (Received Signal Strength Indicator, RSSI). The size of this value is reader-specific because the received signal is multiplied by a reader-dependent scaling factor. Physically, the measured value is mainly dependent on the distance d between reader antenna and transponder. Further influences on the measured RSSI are the supply power of the reader antenna P_r, the antenna gain G_r and G_t from reader or transponder, the wavelength λ and the backscatter loss ratio L (Equation 1) (Choi et al. 2009, Finkenzeller 2012). In the following, the RSSI is given dimensionless as power level in decibel milliwatts (dBm). Equation 2 may be used for calculation of the units milliwatt and decibel milliwatt. As well as the given factors, the RSSI course may also be influenced by an environment with reflections through changes of the so-called path loss exponent. With an ideal free space propagation, the path loss exponent has the value 2 with regard to one way propagation or 2^2 when taking account of sending and return of a signal between reader and transponder (Equation 1). With wave propagation in the interior of buildings the value can deviate because of, among other things, the multidirectional expansion of waves (Goldsmith 2005). Determining an empirical function for the RSSI course within a test environment with conditions deviating from the ideal free space propagation is enabled by Equation 3. Hereby, the constant K represents the above-mentioned RSSI influence factors and t the squared path loss exponents (Goldsmith 2005). The RSSI is well suited as parameter for comparison of different transponder types and test variants because a high RSSI shows a high reception security and also a high reading range (Catarinucci et al. 2012).

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

$$\mathrm{RSSI\ [dBm]} = 10\ \log_{10}(\mathrm{RSSI\ [mW]}) \quad \text{(Eq. 2)}$$

$$\mathrm{RSSI\ [dBm]} = 10\ \log_{10}(\mathrm{Kd^{-t}}) \quad \text{(Eq. 3)}$$

Test procedure

An overview of all trials and tested parameters is given in Table 1. In a preliminary test, reader positions relative to the test bench were first of all varied to determine the influence of changes in the trial surroundings or, in this case, the transmission direction of the reader before conducting further trials. In all further trials the reader position and the surrounding conditions were not altered. Investigated in these trials were the reproducibility of the measurements, the influence of the polystyrene ear tag holders, and the influence of the coordinate sequence on the results. Following this, a trial was conducted to compare six types of transponder ear tag. The matrix size for all the trials described here was established at 15 cm. According to Jungk (2010), measurement points for analysis of an UHF-RFID system should not be further than a half wavelength from one another. This represents 17.2 cm at a working frequency of 868 MHz and was fulfilled by the selected matrix size. The pause period between automatic positioning of the transponder and activating the reader represented 500 ms, the reading time at each coordinate, 1000 ms. To limit the number of readings, a period of 200 ms was established for resetting the transponder in the anti-collision process so that, per coordinate, a maximum of five readings could take place. In all the trials, the standard position of the reader was in the middle of the test bench with horizontal transmission plane (Figure 1). The middle of the reader antenna was at the same height as the middle of the transponder (165 cm). In the standard set-up, x and y-axes in the operational area of the reader represented those of the test bench. Only when positioning the reader at the side of the test bench, turned 90° to standard direction (Table 1, “90° to the left of the test bench”), were both axes exchanged from the reader aspect. The coordinates were moved to in sequence, in each case in a positive y direction and starting with positive x values (from the reader aspect) (Table 1, “in sequence, y rising“).

Table 1: Overview of trials

Investigated parameters	**Reader antenna position relative to test bench**	**Reproducibility of results**	**Ear tag holder**	**Sequence of coordinates**	**Transponder ear tag type comparison**
Variants	central (standard) shifted 85 cm to left 90° to the left of the test bench	–	ear tag free ear tag completely embedded in polystyrene foam	randomised in sequence, y rising in sequence, y falling in sequence, x rising in sequence, x falling	–
Transponder type (number of examples)	A (1)	A (11) B3-4 (14) B4-4 (17)	A (6) B3-4 (6)	A (6) B3-4 (6)	A (6) ZT (6) B3-4 (6) B4-4 (6) C1 (3) C1-4 (3)
Orientation of transponder to reader antenna	5	5	3 5	5	1 2 5
Coordinate area [cm]	x: -165 to 165 y: 40 to 385	x: 0 y: 40 to 385	x: 0 y: 40 to 385	x: -165 to 165 y: 40 to 385	x: -165 to 165 y: 40 to 385
Test blocks	–	2	6	6	6
Number of test runs	3	84	48	60	90

In all trials, the ear tags were fixed in the required orientation in slits made in polystyrene foam blocks (Figure 2 a) and b)). The orientation numbers presented here agree with those from Hammer et al. (2015). The transponders or ear tags in all trials were positioned with the front side facing the reader (direction 5). For testing the influence of the ear tag holders of polystyrene, the transponder was not fixed in a polystyrene block in the “free” variant, but instead fastened in the same position with only thin wooden pegs on a base of polystyrene foam (Figure 2 b)) . The wooden pegs were hereby positioned on the outer edge of the ear tag to prevent any overlapping with the transponder. The aim of this way of fixing the ear tags was the realisation of a reference variant whereby no influencing of measurements by the holder could be assumed. With this trial, the transponders were also tested in sideways position in order to investigate a possible variation in ear tag holder influence in various directions (orientation 3). In the trial for comparing the various transponder types, the transponders were additionally to orientation 5 also tested in orientation 1 (sideways positioned opposite to orientation 3) and in orientation 2 (from underneath).

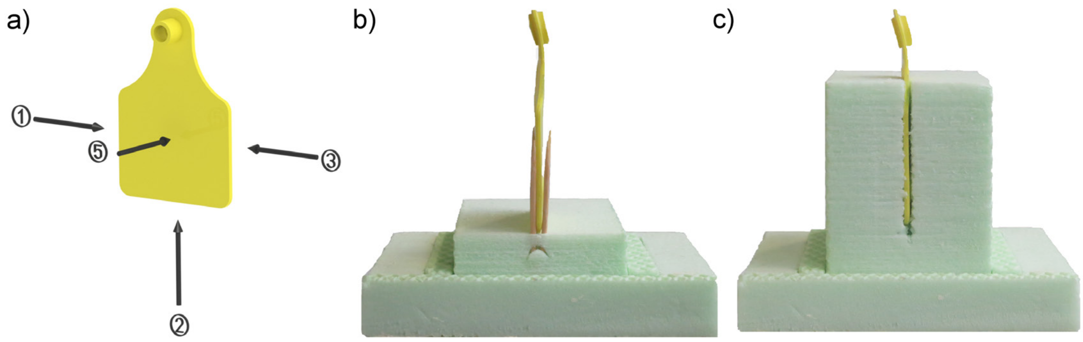

Figure 2: a) Illustration of ear tag orientation to reader (main transmission direction of reader represented by arrows); b) ear tag in "free" positioning (reference variant) in orientation 3; c) ear tag in polystyrene block in orientation 3.

Table 2: Overview of UHF transponders used with ear tags

Transponder type	Characteristics
A	– commercially available (UPM Web®) – folded dipole antenna structure – affixed to cattle ear tag (FlexoPlus®, Caisley International GmbH, Bocholt)
ZT	– commercially available (Smartrac Web®) – folded dipole antenna structure – embedded in air-filled pocket in cattle ear tag
B3-4, B4-4	– developed in research project – PIF antenna structure – base foil material: polyimide (Kapton®) – variation of resonance frequency (B4-4 > B3-4) – size designed for cattle ear tag – grouted into cattle ear tag (Primaflex®, Caisley International GmbH, Bocholt)
C1, C1-4	– developed in research project – PIF antenna structure – variation in base foil material: C1: self-adhesive aluminium foil (simultaneously antenna material) C1-4: polyimide (Kapton®) – size designed for pig ear tag – grouted in cattle ear tag (Primaflex®, Caisley International GmbH, Bocholt)

In the trials ear tags with six different transponders (A, ZT, B3-4, B4-4, C1, C1-4) were used (Table 2). All types used are of passive construction therefore supplied with energy from the reader antenna field only. Transponder type ZT is equipped with a U-code G2iL® chip (NXP Semiconductors Netherlands N.V.), all other transponder types with a Monza 4® (Impinj Inc.) chip. The transponders were prepared for working at 868 MHz. Type A is a commercially available passive UHF label transponder (UPM Web®), optimised for use in logistics. It has a high maximum reading distance of approx. 5 to 9 m (UPM RFID 2011). Additionally, because of its folded dipole structure it features a symmetrical directional characteristic (Detlefsen and Siart 2009, UPM RFID 2011), that offers advantages for methodical testing. For all further trials with the projects' own transponders, this transponder is seen as suitable comparison type for statistical evaluation, enabling a common evaluation of different trials despite possible changes in trial environment conditions. Type ZT is a newer generation of type A that is integrated in a cattle ear tag. The types B3-4, B4-4, C1 and C1-4 are functional examples developed in the research project for application in cattle and pig ear tags. They all have a PIF antenna structure

(Planar Inverted F-Shaped Antenna) (Fujimoto and Morishita 2013). Types B3-4 and B4-4 differ in the length of the last antenna section and thus in their resonance frequency. These variations were included for matching transponder antennas to frequency shift through the grouting into a plastic ear tag and through the attachment to respective animals. The types C1 and C1-4 differ only in the basis material of their antennas. The antenna structural material of all six transponder types was aluminium. More detailed information on design and size of the project's own transponder antennas are not possible because of patent legislation.

A prototype with internal antenna (deister electronic GmbH, Barsinghausen) was used as reader. Working frequency was 865.7 MHz. The effective radiated power (ERP) in all trials was 1 W or 30 dBm by circular polarisation and opening angle of 90°. The communication between reader and transponder took place via EPC class 1 generation 2 specifications (GS1 EPCglobal Inc. 2013).

Trial planning, data processing and statistical evaluation

No statistical trial planning was prepared for the preliminary trial to demonstrate the influence of an altered reader position on measurements. Only three reader positions were tested with a transponder example in this case. With all further trials, the trial plan was so designed that an evaluation of data was possible with a linear mixed model. Trial procedures were blocked to be able to allow for a possible timely alteration in the environment conditions. In the trial concerning reproducibility of the measurements, the blocks simultaneously represented both conducted repeats. In every complete randomised trial block was tested every example of each participating transponder type in every variant. Table 1 shows an overview of the number of individual test runs and transponder examples in every trial. The examples of the transponder ear tags represented the repeats of the transponder types in the trials, while the up to five individual readings of a transponder per coordinate were measurement repeats relating to the RSSI. In the statistical evaluations of the trials, the measured RSSI was applied as dependent variable. In a first analytical step, the average value of the RSSI from up to five readings (measurement repeats) was calculated for every coordinate on which the corresponding transponder was read. However, these coordinate averages were spatially correlated. For this reason the statistical evaluation was calculated from the RSSI coordinate averages, giving a total average for every test run. In this way, there emerged a statistically independent value for comparison of test runs. For arriving at the total mean value, only measurements of the RSSI on the line $x = 0$ were evaluated, because only on this line was the selected orientation of the transponder to reader antenna exactly conformed to. In the remainder of the recognition field the lateral shift of the transponder on every coordinate caused a slightly altered direction of transponder to reader and that is why, for the recognition area of a transponder in general, only a graphic evaluation is practical. Where only of interest is the average RSSI of the transponder in a certain direction, then the measurements can be restricted to the line $x = 0$ (Table 1).

Calculated from the RSSI total mean values in every test was a mixed model with the statistic package SAS 9.2 and the procedure MIXED. In each case the model creation was started with the full model with all double and triple interactions. Table 3 shows an overview of the fixed effects applied and the, after eventual withdrawal of non-significant effects or interactions, models resulting. The random effect in every model was the transponder example. Thus, eventual production-linked differences between the examples in the models could be considered. The normal distribution of the measurement values was present in all tests and was determined via Q-Q plots graphic analysis. In that the transponder types showed differences in their RSSI scatter no variance homogeneity could be achieved. Therefore, the transponder types were determined as grouping variable in the analysis and an own variance component per transponder type estimated. Comparisons of means were conducted with t-tests. There followed a Bonferroni correction for multiple comparisons of means.

Table 3: Overview of fixed effects and final mixed models in trial evaluations

Trial	**Reproducibility of results**	**Ear tag holders**	**Sequence of the coordinates**	**Type comparison transponder ear tags**
Fixed effects in the starting model	transponder type (T), repeat (W)	block (B), transponder type (T), orientation (A), ear tag holder (OH)	block (B), transponder type (T), coordinate order (K)	block (B), transponder type (T), orientation (A)
Final model	RSSI = T + E + r	RSSI = B + T + A + OH + T · A + T · OH + A · OH + E + r	RSSI = T + E+ r	RSSI = B + T + A + T · A + E + r

E = transponder example
r = residual error

The trial for determining reproducibility was additionally evaluated by graphically applying the Bland-Altman method (Bland and Altman 1986). In this form of evaluation, the difference between two repeats of the same measurement on the same measured object (transponder ear tags) is plotted against the mean value from both repeats. The mean value of all differences *d* is, with a given reproducibility, (near) zero and identifies a systematic error in the measurements through a deviation from zero. Further, it applies in the case of normal distribution of the differences that 95 % of the value lies within the area of 1.96 times the standard deviation *s*. This is demonstrated in the diagram through two lines by d ± 1.96 · s. Thus, the limits of agreement of both repeats and the so-called reproducibility coefficient (1,96 · s) were determined and give an indication of how great the difference between two trial variants at least must be, so that this difference can be detected with the presented measurement procedure (Bland and Altman 1986).

Results and discussion

Exemplary detection field and RSSI course

First of all, in Figure 3 is presented for general information the RSSI test results collected in the presented test bench for an ear tag with an example of the transponder type B3-4 in the entire detection area and on the line x = 0. The measurements come from one run of the trial for testing the influence of the coordinate sequence. Clearly detectable is a RSSI reduction up to a distance of approx. 250 cm from the reader antenna in y direction. In greater distances, the RSSI would be significantly influenced through reflections in the trial environment and the resultant interference. RSSI fluctuations and gaps in the detection area can be seen in the outer areas in both presentations. However, it was very possible to match a regression curve according to Equation 3 to the data (adjusted R-squared $R^2 = 0.95$). The resultant path loss exponent *t* lay, with 2.6, in a plausible range for multiple expansion in interior areas (Goldsmith 2005). The basic requirements for the test bench, the measurement of detection field and signal strength from UHF transponder ear tags, could thereby be fulfilled.

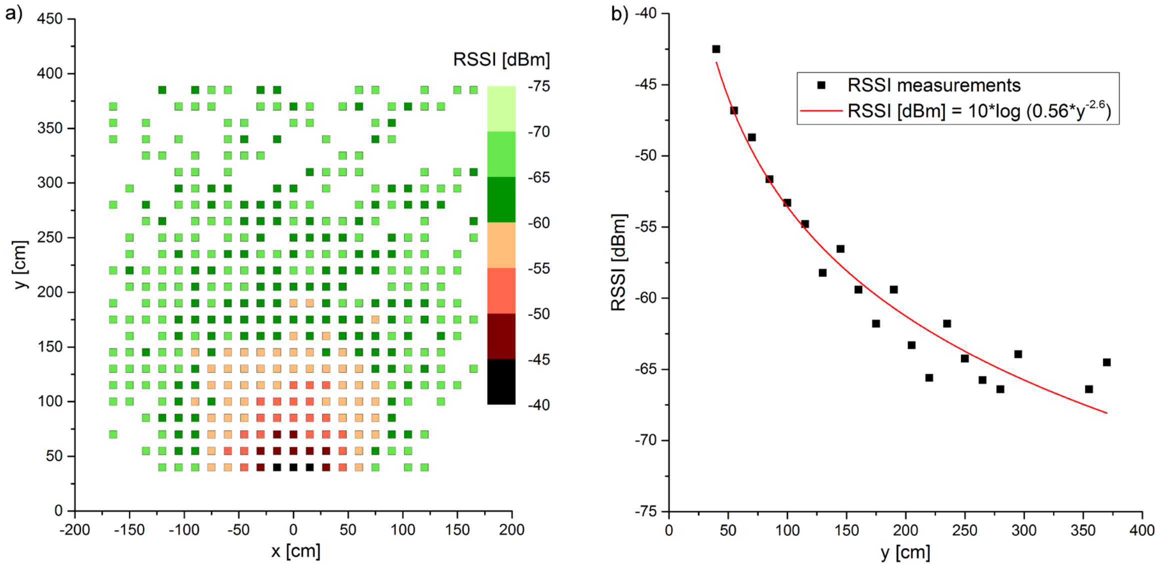

Figure 3: RSSI [dBm] in the detection area of a transponder ear tag with the transponder type B3-4 a) detection field (magnified presentation of the point measurements) b) measurements on the line x = 0 with regression curve

Influence of reader position

The influence of trial environment on recordings was clearly shown through alterations in reader antenna position relative to the test bench. The progression of the RSSI on the line x = 0 changed with the reader position (Figure 4). A progression that was a little more uniform was achieved at the position sideways to the test bench. Especially marked differences between the variants occurred, above all, from a distance of 200 cm from the reader. This indicated that, in the case of increasing distance between transponder ear tag and reader, the transmitted signal of the reader antenna or the reflected signal of the transponder is received via differing paths of the multiple expansion (reflections). In order to keep these always uniform and thereby enable reproducible results, an unchanging reader antenna position is therefore absolutely necessary. Furthermore, this trial emphasises that changes in trial environment can also change resultant measurements (Goldsmith 2005). Within a trial, systematic changes that occur can be taken into account through time-related block building. As already mentioned in the chapter Materials and Methods it is, however, necessary for the comparison of different trials to integrate a transponder type as statistic reference, or as comparative basis, in all trials.

As shown in the following mixed models presentation, some results appear that are in agreement. At first, the block effect was never significant, indicating only small changes of conditions during the trial. In addition, significant in every model were the transponder type and, in so far as this was validated, the orientation of ear tags as well as the interaction of orientation of ear tags and transponder type. These effects will be addressed in the results of transponder ear tag type comparisons. Discussed in the following trials are only the effects decisive to trial issues.

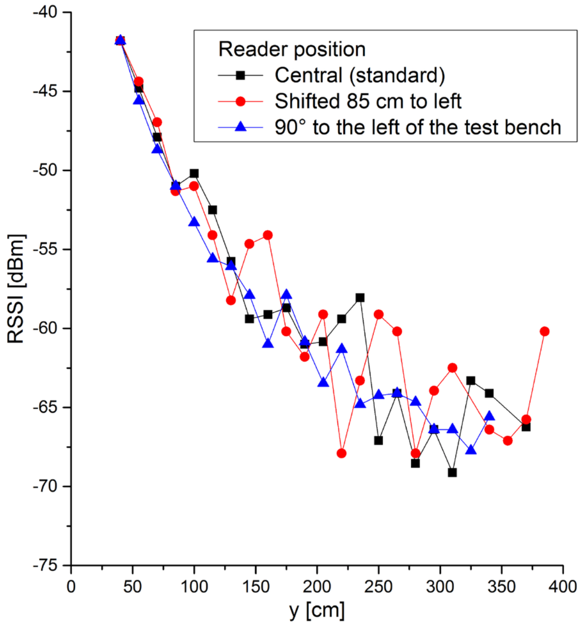

Figure 4: RSSI [dBm] of a transponder ear tag, transponder type A on the line x = 0 with altered position of reader antenna to test bench

Reproducibility

In the creation of the mixed model for this trial, the influence of reproducibility on the results was not significant (Table 4).

Table 4: Type III test of the fixed effects for the mixed model of the trial for determining reproducibility

Effect	Numerator deg. of freedom	Denominator deg. of freedom	F-statistic	P
Transponder type (T)	2	38.8	694.04	< 0.0001

The mean value difference between repeat 1 and repeat 2 for the total mean values of the RSSI was only 0.03 dBm. In the Bland-Altman analysis, this value represents the mean value of differences between repeats (Figure 5). The reproducibility coefficient lay by 0.18 dBm. Only one difference showed a higher result (0.42 dBm). On the individual coordinates, the differences between the two repeats for all transponder types and examples averaged 0.19 dBm with a standard deviation of 0.24 dBm. Hereby, it must be recognised that, through the mean value creation from (in most cases) five single measurements on every coordinate, the scatter of these mean values is lower by the factor than the single measurements. The scatter of the single measurements thus lay by approx. 0.42 dBm. The reader manufacturer gives as factory tested figure approx. 1.0 dBm as guideline value (Maass 2015). The results presented here indicate that precision of readers used in this trial was markedly better when considering the occurrence of imprecisions within the trial construction. In summary, the results show that, with the chosen trial design and the reader used, a good reproducibility of test bench measurements resulted. With regard to applied method one can, however, be critical about the limited scope of the tested types of transponder ear tags. It cannot be completely ruled out that the reproducibility of the results concerning very low signal strength transponder types (< -70 dBm) is poorer than the ones tested here. This is because measurement values in this case are in the vicinity of the lower limits of the reader measurement capability (Maass 2015). For this reason, reproducibility in trials

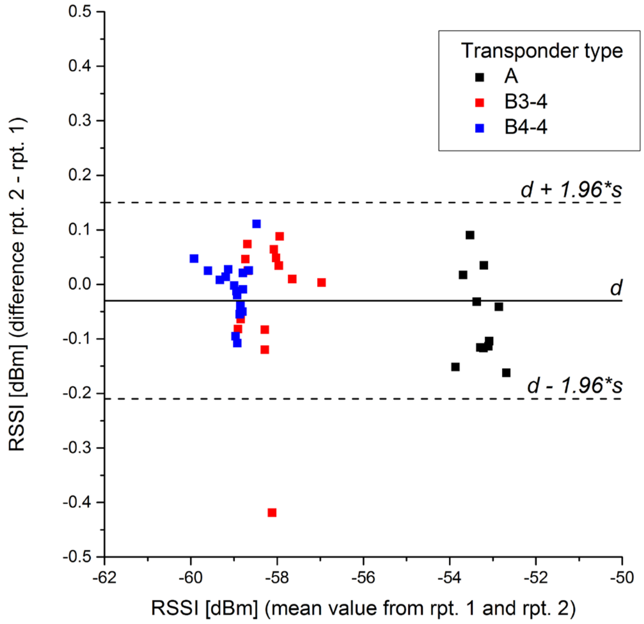

Figure 5: Bland-Altman diagram of trial for determining reproducibility; d = mean value, s = standard deviation of the differences between repeats 2 and 1

with such transponders should be tested once again. Such tests should also take place when another reader is used for the measurements.

Influence of the ear tag holders

Significant in the mixed model of the trial for determining the influence of the ear tag holders were, alongside the effects of the transponder type, orientation of the ear tag and interaction of these, also the effects of the ear tag holder and interaction between transponder type and ear tag holder as well as the interaction of ear tag holder and transponder orientation (Table 5).

Table 5: Type III test of the fixed effects for the mixed model of the trial for determining influence of ear tag holders.

Effect	Numerator deg. of freedom	Denominator deg. of freedom	F-statistic	P
Block (B)	5	4.3	2.66	0.1708
Transponder type (T)	1	5	203.95	< 0.0001
Orientation (A)	1	18.8	707.58	< 0.0001
Ear tag holder (OH)	1	18.8	8.47	0.0090
T · A	1	18.8	562.06	< 0.0001
T · OH	1	18.8	9.57	0.0060
A · OH	1	17.8	11.31	0.0035

A more precise observation of the influences of ear tag holder on the ear tags with both transponder types A and B3-4 showed that only with the type A was there a significant influence of holder on RSSI (Figure 6). The mean value of all measurements of ear tags with transponder type A with holders of polystyrene foam was 0.6 dBm higher than the mean value without holder. With type B3-4 the mean values were identical. The interaction of ear tag holders and orientation of ear tags showed a significant difference of 0.5 dBm between reference variants and polystyrene holders in orientation 5. With orientation 3, on the other hand, there was no significant difference between the two variants. A cause could not be found for the different influence of the ear tag holder on signal strength of the two transponder types. It must be emphasised, however, that the difference for transponder type A is very low in relation to the mean value (approx. 1 % of mean value). Despite this, possible causes are discussed in the following.

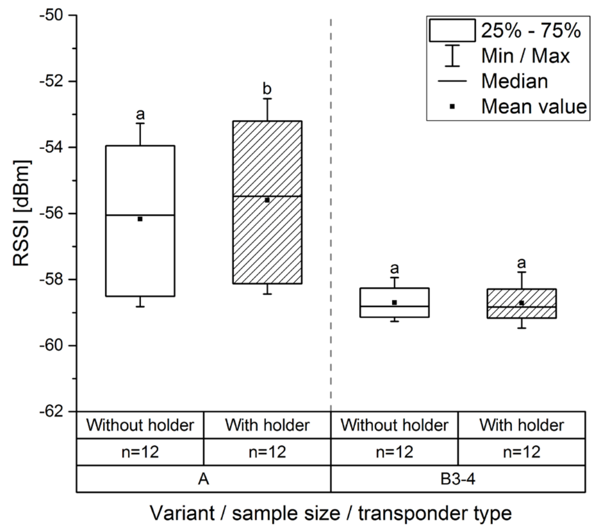

Figure 6: RSSI [dBm] of the ear tags with transponder types A and B3-4 with and without holder of polystyrene foam; n: sample size; a, b: different letters within a transponder type indicate significant differences ($P < 0.05$)
Influence of coordinate sequences

The shift in resonance frequency of the transponder type A through the surrounding holder can be almost ignored for two reasons. One, such a strong influence is not plausible for polystyrene foam because the material has a very low permittivity (Webster and Eren 2014). Secondly, this would also lead to an expected similar influencing of transponder type B3-4, in that both transponders are adapted for use with materials of high permittivity (Rao et al. 2005, UPM RFID 2011). For the same reason, a negative influence of the wooden pins used in the “free“ presentation of the ear tags is also to be excluded. A different influencing of both transponder types through minimally different orientation and position of the ear tags in the “free“ fixing variant is theoretically possible. Should this be the case, then the effect would cease to appear with constant use of the polystyrene holding system. In relation to the different influences of transponder holders in orientation 5 and 3 this effect is also the most plausible, but also ceases through continual application of the polystyrene blocks only. The application of only two different transponder types for the test presented here can also be judged as uncritical in that the conclusions reached also exactly apply for all other UHF transponder types. In summary, it can be concluded that an application of ear tag holders of polystyrene foam only influenced test bench results to a limited extent. Furthermore, the use of these materials allows high reproducibility of position and orientation of ear tags and is therefore preferable to fixation by wooden pins. Thus, in the tests with the ear tags as described here without further electromagnetic influence and, for instance, in trials for determining influences of ear tissue on transponders, polystyrene foam can be used as material for holding ear tags and ear tissue.

Influence of coordinate sequences

An influence on trial results through the sequence of coordinates could not be determined. The corresponding effect in the mixed model was not significant (Table 6). Only the transponder type had a significant effect on the results. The agreement of measurement values with all five variants of the sequence can be explained through the switching-off the reader field between the measurements on two coordinates. If the reader transmits continually, the effect shown with passive UHF transponders is a greater reading distance by the transponder in the case of a movement out of the reading field compared with movements into the field (hysteresis). This can be explained through the required amount of energy for activating the transponder chip being higher than the cut-off threshold. If the reader is switched off between two coordinates this effect disappears because the transponder cannot store energy continually (Derbek et al. 2007, Knop 2014). The use of only two different transponder types for the trial presented here should be assessed uncritically because the described effect occurs for every UHF transponder with commercially available chips. This knowledge means that time savings can be achieved in further trials through starting-off coordinates in order, giving shorter paths compared with a randomised coordinate sequence.

Table 6: Type III test of the fixed effects for the mixed model of the trial for determining the influence from the sequence of the coordinates

Effect	Numerator deg. of freedom	Denominator deg. of freedom	F-statistic	P
Transponder type (T)	1	10	487.02	< 0.0001

Comparison of different types of UHF transponder ear tags

Tested in this trial was the use of the test bench for comparing ear tags with different transponder types in differing orientations. In the mixed model, the evaluation showed significant influences from transponder types, orientations to reader and their interactions (Table 7).

Table 7: Type III test of the fixed effects for the mixed model in the trial comparing different types of UHF transponder ear tags.

Effect	Numerator deg. of freedom	Denominator deg. of freedom	F-statistic	P
Block (B)	5	18.7	0.32	0.8976
Transponder type (T)	5	17.7	407.06	< 0.0001
Orientation (A)	2	35	159.09	< 0.0001
T · A	10	18.2	128.43	< 0.0001

Closer observation of the differences between the transponder types with comparisons of means resulted in a division of types into three groups (Figure 7). The highest average RSSI achieved the ear tags with transponder types A and ZT. Between these two types, a significant difference could be determined. This indicates that the inclusion of the transponder type Web® within an air-filled pocket in the ear tag (ZT) caused no difference in signal strength compared with the adhesion system (A). There were also no significant differences between types B3-4 and B4-4. These were of identical size and form, differing only in a minimal adjustment through which the type B4-4 showed a slightly higher resonance frequency than the type B3-4. This difference showed no influence on the respective measurements at the ear tags. It has to be determined in practical trials whether the transponders return different performances during use on animals. In the third group were the ear tags with transponder types C1 and C1-4. With these, the average RSSI was significantly lower. The difference for these transponders that are designed for use as pig ear tags, compared with the others in cattle ear tag size, could be explained through their smaller antenna area. Otherwise, design and form were similar to types B3-4 and B4-4. The larger the UHF transponder, the higher, as a rule, is the transmitting distance (Catarinucci et al. 2012). Additionally, a lower scatter of measurements with type C1-4 in comparison with type C1 was noticeable, possibly explained by the better constructional quality of the former through its base polyimide foil allowing more even grouting into the ear tag compared with the pure aluminium antenna of type C1. Possibly this leads to reduced scatter between the examples of these type, which also brings with it advantages in practical use.

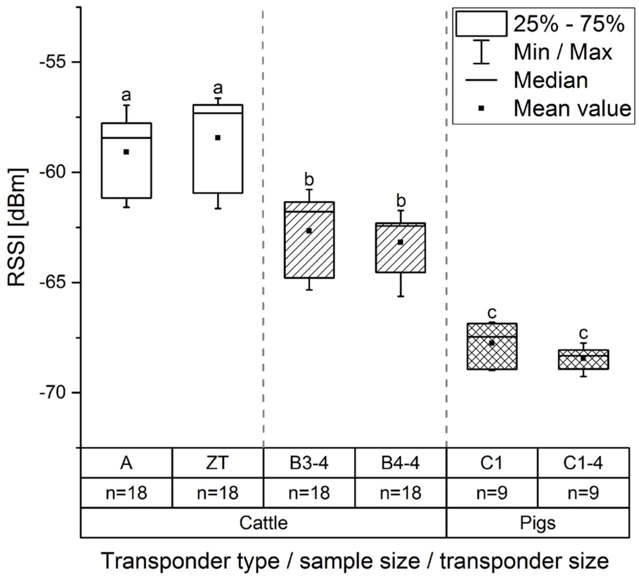

Figure 7: RSSI [dBm] of the tested ear tag types; n: sample size; a, b: different letters show significant differences (P < 0.05)

Presented in Figure 8 are the simulated directional characteristics of the ear tags with the three basic transponder types from the above-mentioned groups. These illustrated in red show orientations where transponder types in combination with the plastic ear tags produced a high signal strength and transmission distance. On the other hand, green and blue areas indicate poorer performance.

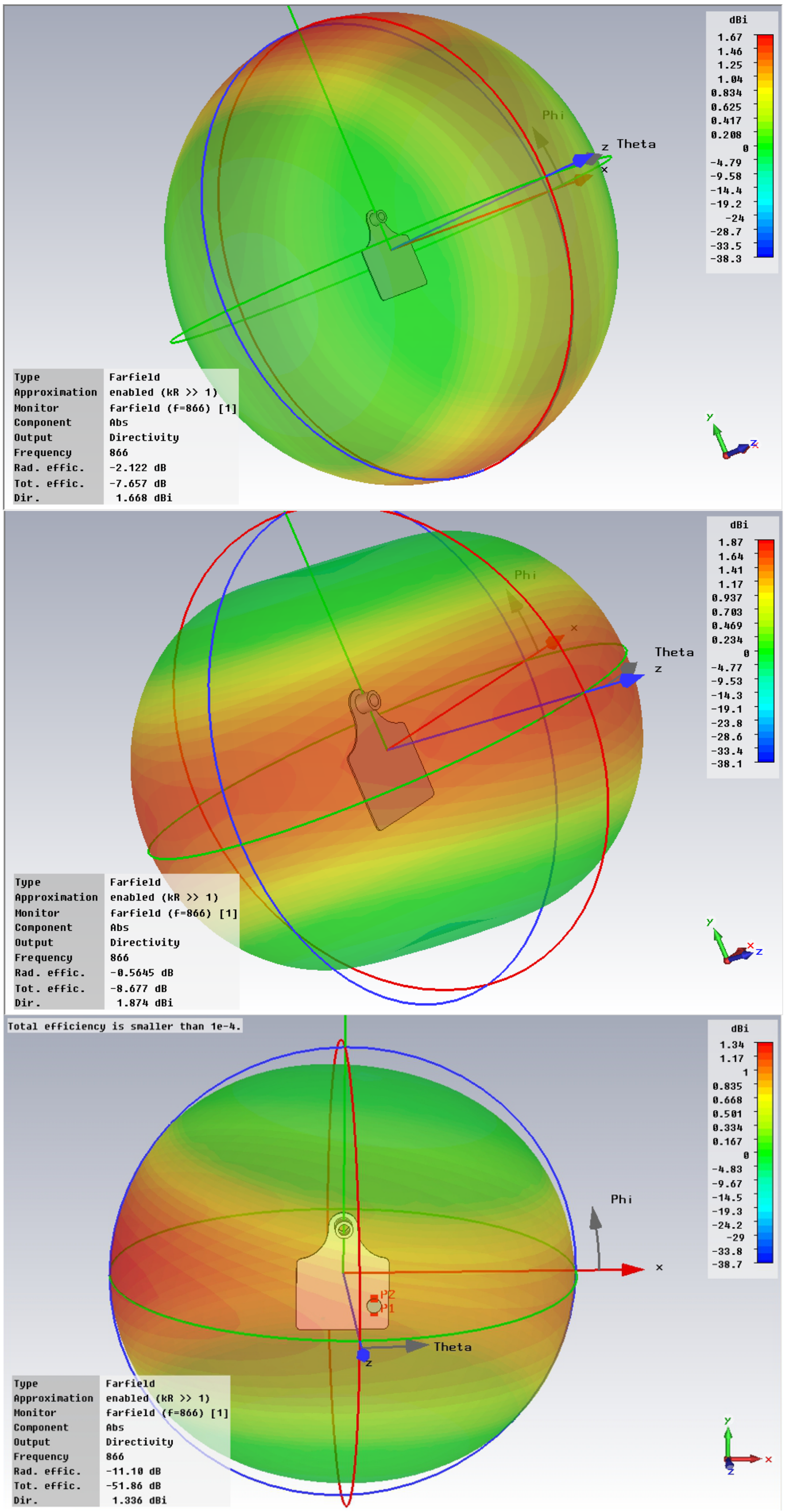

Figure 8: Simulated directional characteristics of ear tags with three basic transponder types (from above: types A and ZT; types B3-4 and B4-4; types C1 and C1-4) (simulation and illustration: deister electronic GmbH, CST Microwave Studio)

A comparison of means was carried out for every transponder type to determine differences of the three tested orientations to the reader (Table 8). With one exception, the measurements on the static test bench determined orientation with the respective highest and lowest signal strength in agreement with the simulation for every transponder type. Only with type ZT was orientation 5 shown to be better than with orientation 2. This could not be explained with the simulation. According to the simulation, orientation 2 should achieve a slightly higher signal strength. Possibly this difference could have been caused by the influence of the air pocket in the ear tag. This was not taken account of in the simulations. With the types B3-4 and B4-4 orientation 1 and orientation 5 were determined best orientation, in simulation as in trial. With C1 and C1-4 no significant statistical difference between the two orientations was determined in the test bench trial. However, measurement values showed, analogue to simulation, a bit higher signal strength in orientation 1. The orientations with lowest signal strengths with all transponder types given in the simulation were repeated in the test bench results. With types A and ZT this was orientation 1, with all the others, orientation 2.

Table 8: RSSI [dBm] of the ear tags according to transponder type and orientation to reader antenna on the test bench; n: sample size; a, b: differing letters within a line indicate significant differences ($P < 0.05$)

Transponder type	**Orientation 1**	**Orientation 2**	**Orientation 5**	**n**
A	-61.3^{c}	-57.7^{a}	-58.3^{b}	6
ZT	-61.1^{b}	-57.4^{a}	-56.8^{a}	6
B3-4	-61.8^{a}	-65.0^{b}	-61.3^{a}	6
B4-4	-62.3^{a}	-64.9^{b}	-62.3^{a}	6
C1	-66.9^{a}	-69.0^{b}	-67.5^{a}	3
C1-4	-67.9^{a}	-69.1^{b}	-68.2^{a}	3

The trial comparing different types of UHF transponder ear tags confirmed that a comparison is possible between ear tags with different transponder types but also that comparison of individual orientations within the types and between the types is possible. An assessment of the transponder types on the test bench before testing on animals is helpful in allowing a preselection and interpretation of results from practical tests (Hammer et al. 2013). The measurement of signal strength and reading distance in separate orientations has also been recognised by other authors as important. Catarinucci et al. (2012) and Jungk (2010) emphasise that a transponder for versatile application and reliable identification in, if possible, all directions should be able to demonstrate uniform readability. None of the transponder types tested here satisfied this requirement. The reason is that transponder form and size restrictions for the planned application often lead to antenna structures with marked sensitivity regarding their orientation to the reader. Most used for UHF transponders are folded dipole antennas or loop antennas. Both are strongly directed (Derbek et al. 2007, Ng et al. 2005). However, this has also advantages in that the effective transmission distance of the transponders oriented in the main transmission direction is greater than that of a similarly-shaped directional characteristic with the same size of transponder. Because not all directional characteristics are symmetrical there should, in addition to the three orientations tested here, be at least another three compared in the opposite orientation in future, so that a comparison taking account of the entire directional characteristic is possible.

Conclusions

The aim of the tests was determination of suitability of the presented test bench for comparing different types of UHF transponder ear tags in individual as well as in all orientations. The basic requirement for the test bench, the measurement of detection area and signal strength of UHF transponder ear tags, was achieved. The methodical trials carried out indicated a good reproducibility of the measurements where position of the reader was constant. The ear tag holding system featuring polystyrene foam had no relevant influence on the RSSI measurements. Also, the sequence of coordinates, where measurements took place, did not influence the measurement results. The possibility of comparing the RSSI of transponder types in various orientations was proven with various types of UHF ear tags in the concluding comparison. A comparison with simulated directional characteristics for the tested transponder types resulted in a very good agreement of results from the simulation and the test bench for different orientations of the transponders. Thus, in summary, all the necessary requirements were fulfilled by the test bench. However, it must be emphasised that with this method no absolute measurements of transponder or ear tag characteristics are possible and that the recorded results can be influenced through changes in the trial environment. To cope with this situation, a suitable statistical experiment plan is required. Furthermore, the conclusions reached regarding reproducibility of results apply only to the respective reader used. A change of reader means that relevant parameters must be recalculated. In addition, reproducibility in the tests of the transponder types with very low RSSI must be assessed separately.

The next step will feature comparative investigations of different function examples of UHF transponder ear tags especially optimised for use with cattle and pigs. Furthermore, the measurement of influences of ear tissue and tissue imitations in the vicinity of ear tags on signal strength and field of recognition will take place. Additionally, trials are planned that have as target a limitation of the reading area in different positions and alignments of reader antennas. Through this, important parameters for monitoring of barn zones such as feeding or lying areas, for health monitoring of animals are to be investigated before use in barns. Finally, the practicability of a system for localisation of UHF transponder ear tags should be investigated. Furthermore, an additional application of the presented test bench featuring measurement of detection areas with LF and HF transponders would be reasonable in that the test bench covers normal reading distances in such systems and also because, in the frequency ranges involved, environment influences can be more easily minimised than in the UHF area.

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