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Understanding the Impact of Measuring and Choosing RFID-Transponders for Applications in Logistics

Abstract

Automatic identification (Auto-ID) is the fundament of the Internet of Things. Besides barcodes and 2Dcodes, Radio Frequency Identification (RFID) is used. In the different applications in logistics, the objects to be identified consist of different materials, and therefore this chapter provides basic knowledge about testing and selecting the right RFID-transponders for specific substrates.

Keywords

RFID, Transponder, Measurement

1 Preface / Overview

1.1 Didactic fundamentals

Effort in lecture hours:	• theory: 2 x 45 minutes • lab experiment: 60 minutes
Effort for self-study material	• reading (1.5 hours) • VR-game (20 minutes)
Suggested Credit Points (CP)	the lab experiment is part of a 2CP lecture
Necessary background	• physics related to radio frequency communication • fundamental knowledge about Auto-ID technologies
Additional information	student teams of 2–3 people suggested

1.2 Learning Objectives

After completing this unit, students will be able to:

- name the components of an RFID-transponder,
- state the advantages of testing in a closed measurement cabinet,
- apply the basic measurement settings for RFID testing,
- analyze basic measurements from an RFID measurement cabinet
- list the influence of different carrier materials on reading behavior.

2 Introduction to RFID-Transponder Testing

2.1 Use-case Introduction

On March 3rd, 2022 there was a job offer from Porsche AG in Stuttgart, Germany on the Web (https://jobs.porsche.com) asking for a specialist on Auto-ID in logistics to work on *"Design and planning of automation solutions in logistics based on process requirements from project start to acceptance with a focus on Auto-ID and IIoT [Industrial Internet of Things]"* and requesting fundamental technical knowledge on Auto-ID, especially RFID. One of the important technical topics for an RFID specialist to understand is the behavior of different RFID-transponders on different materials, which will be called substrates in the following. RFID-transponders are designed to work in specific frequency ranges and are quite often optimized for specific applications. Substrates may detune the RFID-transponders, so that poor read results are achieved. Therefore, RFID-transponders should be tested on those substrates which will be used in real logistics scenarios. If, for example, an RFID-transponder is supposed to produce good reading results on a propylene box, it should be tested on polypropylene and compared with other transponders to identify the appropriate transponder.

2.2 How to Identify the Right RFID-Transponder for a Given Application

2.2.1 Basics of RFID frequencies

There are different frequency ranges available for RFID. A distinction is made between LF (Low Frequency), HF (High Frequency), UHF (Ultra High Frequency), and MW (Microwave). The frequency ranges have different characteristics, such as the maximum possible read range between a reader and a transponder. Therefore, the appropriate frequency range is selected depending on the respective application.

While high-frequency (13.56 MHz) transponders are used for applications such as access control or identifying books in libraries, in logistics applications the ultra-high frequency range is used. Unfortunately, the ultra-high frequencies allowed are different around the world (Fig. 1) due to country-specific regulations. RFID-readers must comply with the frequencies allowed in the different regions and countries, and RFID-transponders need to be designed to work in the frequency ranges where they will be used.

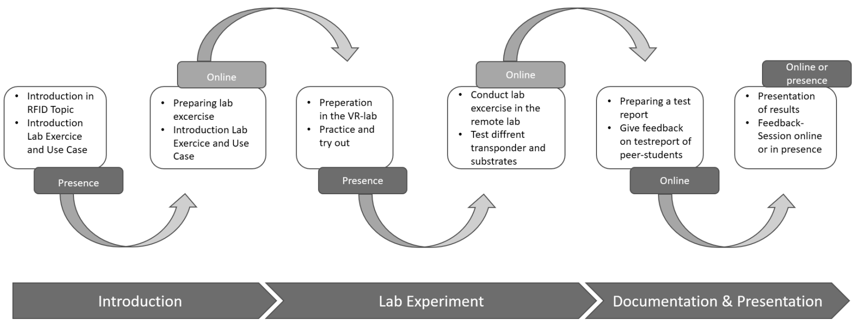

Figure 1: Overview of some of the UHF ranges for RFID, for details see: https://www.gs1.org/docs/epc/uhf_regulations.pdf

Consider a ship with RFID-equipped goods traveling from Tokyo to Hamburg. The RFID-transponders should thus be readable in both frequency ranges. They should have similar read results using frequencies 865–868 MHz (Europe) and 916–923 MHz (Japan). This requires specially designed broadband transponders.

2.2.2 RFID-transponders for Logistics Applications

As RFID is getting more and more popular, there are numerous different RFID-transponders available from different manufacturers for specific applications. Special attention is needed if liquids (an RF-absorbing material) or metals (an RF-reflecting material) are in close proximity to the RFID-transponder.

Typical examples in logistics include transponders for substrates such as

- Returnable polypropylene boxes (e.g. as specified in VDA 4500 for the German automotive industry)
- Electrostatic discharge (ESD-)boxes (which have a strong negative impact on RFID-transponders, e.g. as specified in VDA 4504)
- Cardboard (beware, the moisture level of the cardboard may impact the read results)
- Wood (e.g. pallets)
- Metal (so-called on-metal transponders are needed for good read results)
- Glass

All these substrates have a different impact on the reading results. Other aspects to consider are environmental influences (e.g. dry retail environments or wet outdoor environments) and usage (e.g. open-loop one-time application vs. closed-loop long-time application (see section 5.1). Transponders can be optimized for these different substrates and usage requirements, by using, for example, different chips, antennas, housings, or fixtures.

RFID-transponder manufacturers provide data sheets that show the most important data for their different products (Table 3).

Table 3: Typical specification data provided in a transponder data sheet

Specifications of the transponder	Example	Comments
Transponder type / specification	UHF RFID EPCglobal Gen2V2	Refers to the general frequency range and communication standard
Operational Frequency range	860–960MHz	Specific frequency range
Chip manufacturer and specification	Impinj Monza 4QT	The chip is responsible for processing and storing the data
Memory	EPC: 128 bit User: 512 bit TID: 96 bit	The chips have different memory sizes. The memory is divided into different memory banks, which contain for example the TID (Tag ID), EPC (Electronic Product Code), and user memory
Antenna design	Omnidirectional, (radiation pattern)	The radiation pattern indicates the readability from different angles
Read range (ETSI regulation)	Plastic: <10m Cardboard: <4m	This example shows the impact of different substrates on reading distance

Specifications of the transponder	Example	Comments
Designed for substrate / surface material	Non-metallic surfaces	A little generic in this example, as probably ESD-boxes may cause problems but are not made of metal
Mechanical specification	White, printable, PET, self-adhesive, dimensions, installation instructions	
Environmental specification	Temperature range, water resistance, chemical resistance, expected lifetime, …	Influenced largely by the housing

2.2.3 How to find Missing Information about Unknown Transponders

If data sheets are missing, the transponder and its specifications need to be identified.

- Visual check: Does the transponder show written data (e.g. manufacturer, type)? What are the dimensions of the transponder? Does the housing tell you something about the transponder (e.g. antenna polarization, fields of application)?
- Identifying the chip manufacturer: The Transponder ID (TID) contains information about the chip manufacturer and the type of chip (see, e.g. a corresponding JSON-file for chip identification at https://www.gs1.org/docs/epc/mdid_list.json with corresponding HEX and binary values).
- Antenna layout: Sometimes in RFID-label transponders, the antenna layout can be seen, for example, by holding it against a light source. Some of these layouts are well known and can be searched for on the Web (search term: UHF RFID inlays).

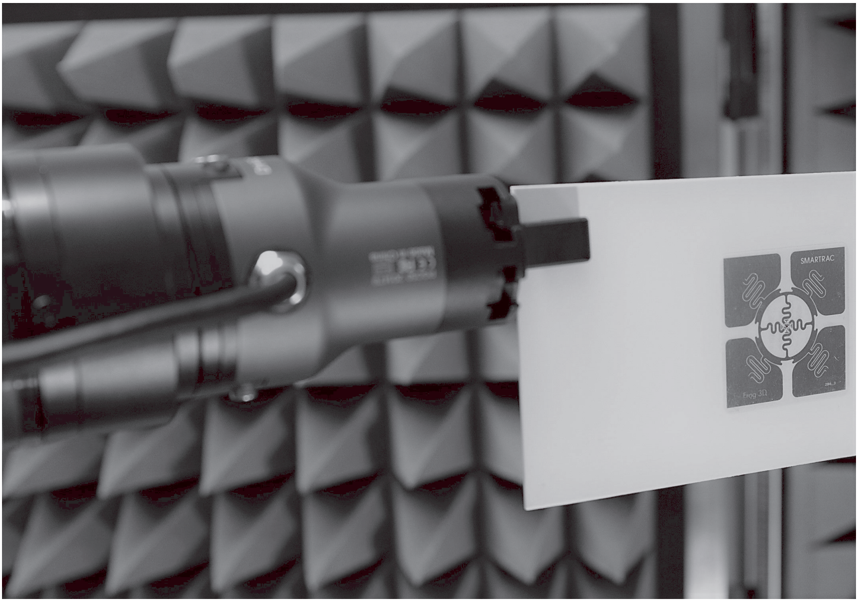

Figure 2: A UHF RFID-transponder ready for testing—a visual inspection shows information about the manufacturer (Smartrac) and the antenna design (Frog 3D). The square layout indicates orientation insensitivity to horizontal or vertical usage.

2.2.4 Comparison of Different RFID Test Methods

While the transponder data sheets provide basic data about the transponder specifications, application-specific testing still remains a state-of-the-art procedure to ensure reliable operation.

There are two easy, commonly used "quick and dirty" static test procedures for RFID-transponders using standard RFID-readers. The first easy approach is to fix transponders onto a substrate, set up a corresponding RFID-reader and antenna, and measure the maximum reading distance at a given power setting. Starting from a far distance outside the antenna field, a linear movement at walking speed toward the antenna is carried out. The threshold distance when the RFID-transponder is read by the reader is recorded. Multiple measurements need to be performed. Usually, the transponder which offers the longest reading range is considered to be the best for logistics applications, as the chip, antenna, transponder housing, fixing, and substrate will work well together, thus enabling these long reading-distances. Writing distances are shorter than reading distances, as a more stable connection is needed.

However, the reading field is not homogeneous, ambient conditions, reflections from the ground or surrounding objects, and interference from other RF devices may influence the results. Thus, the accuracy and repeatability are questionable. On the other hand, these tests show the reading results in a real environment.

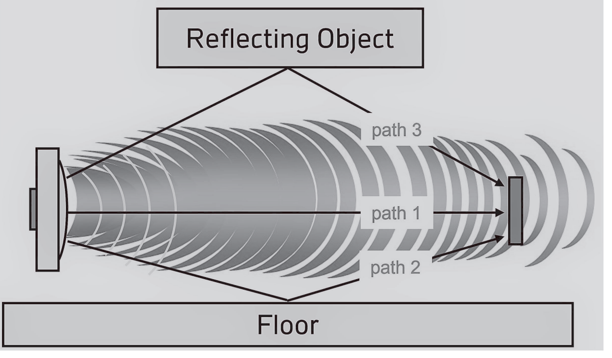

Figure 3: Antenna on the left, reflections from the floor and reflecting objects lead to positive or negative interference

The second method is based on keeping the same distance between the RFID-transponder and the reader's antenna. In this case, the power-settings on the reader are changed from high to low power levels, and the threshold value is recorded when communication is lost. For this method, a table-like structure made of rigid foam plates, as used in the insulation of buildings, can be used (Fig. 4). The rigid foam has minimal effects on the test results. The reader's antenna is placed on the bottom layer of the table structure, while the RFID-transponder is placed on the top layer. Unfortunately, RFID-readers usually limit the power settings, e.g. from 15 dBm to 30 dBm. Sometimes RFID-transponders are even read at a 2m distance from the antenna at a minimum 15 dBm level. Antennas with a low gain may be used in order to avoid further amplification of the reader's signal.

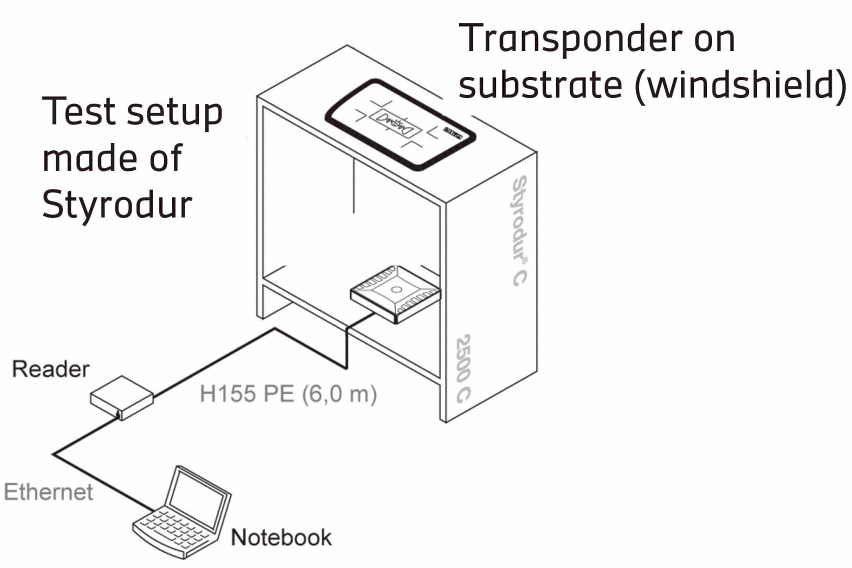

Figure 4: Test setup to measure towards the sky in an outside environment to avoid reflections from the ground or from walls

Both test scenarios mentioned have their advantages. The cost of the equipment is low and the transponders can be tested in a real-world environment. However, the accuracy and repeatability of these setups are limited, and the testing may be quite time-consuming. Therefore, testing and comparing RFID-transponders for specific substrates in an RFID measurement cabinet is recommended to improve accuracy, repeatability, and speed of testing and to perform other tests of interest (e.g. rotation testing). Additionally, a closed chamber allows the transponder to be tested in frequency ranges that may be used in other regions (e.g. USA, Asia, Europe), which is otherwise not allowed. However, an RFID measurement cabinet is costly and still needs to be complemented by real-world testing scenarios (see chapter *Applied RFID in Logistics*). Transponders in movement can be tested (dynamic testing) on a conveyor belt in a real-world scenario in this lecture.

Table 2: Comparison of different test methods for RFID-transponders

	1. Changing the reading distance, vertical setup	2. Changing the power settings, horizontal setup, reader antenna facing the sky	3. Measurement cabinet
Test scenarios	Threshold (distance)	Threshold (power)	Automated threshold (power) and orientation testing, …
Distance between reader (antenna) and transponder	Changing	Fix	Fix
Power-setting on RFID-reader	Fix	Changing	Changing
Frequency range	Fixed or variable within the regionally allowed frequency band (usually secured by the RFID-reader manufacturer)		Broad frequency range (e.g. 800–100 MHz)
Reflections	High in reflective environments	Low	None
Interference from other RF equipment	Depends on sources of interference in the environment (maybe measured with a spectrum analyzer if available)		None
Equipment needed	RFID-reader and antenna, a stand for RFID-transponder	RFID-reader and antenna, a structure to place the RFID-transponder horizontally over the antenna at a minimum distance of 1m	RFID measurement cabinet (costly)
Measurement accuracy and repeatability	Poor	Better, fewer reflections	Very good
Speed of testing	Slow, numerous tests at different distances need to be performed	Fast, if RFID-reader has an automatic threshold test	Very fast

3 Measurements with an RFID measurement cabinet

A typical RFID measurement cabinet resembles an anechoic chamber (Fig. 5) in a small package.

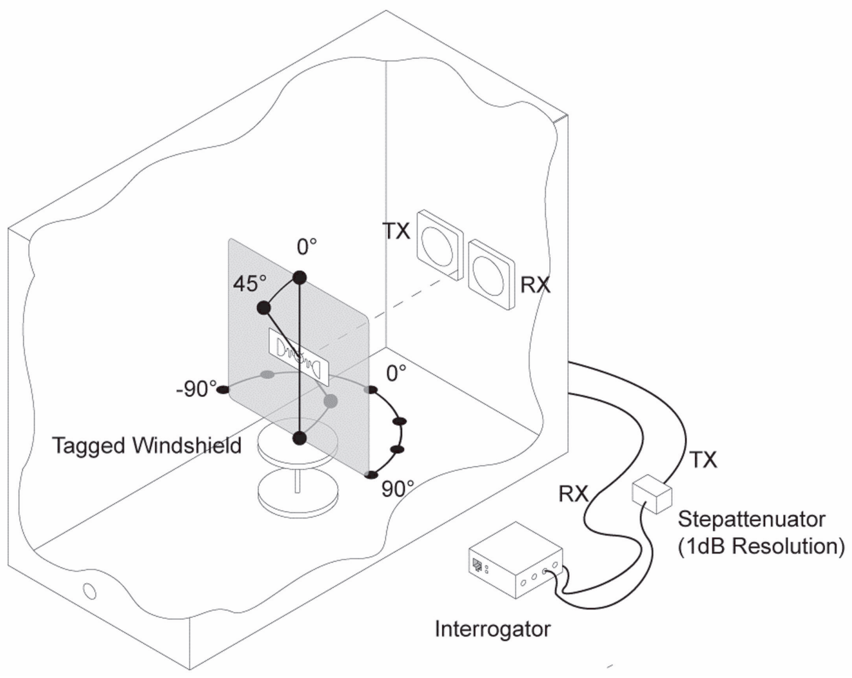

Figure 5: An anechoic chamber with shielded walls, a turning stand for probes, transmitting (TX) and receiving (RX) antennas, a measurement device (interrogator), and a step-attenuator to reduce the signal step by step

The RFID measurement cabinet at HFT Stuttgart uses a single antenna for transmitting and receiving signals. The measurement device controls the integrated step-attenuator and the rotation of the stand to enable automated threshold and orientation testing. Please refer to guidelines: *Perform RFID test series with the Remote Measuring Chamber of the HFT Stuttgart* on how to run the measurement.

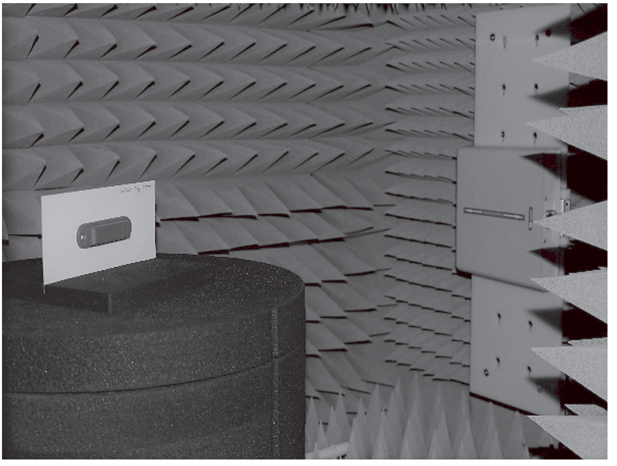

Figure 6: The RFID measurement cabinet inside, turntable with a blue RFID-transponder on a white plastic substrate to the left; linear polarized reader-antenna on the right; surrounding absorbers

3.1 Threshold Measurement

The goal of this test is to identify the threshold (minimal power setting) for the transmitted power needed to communicate with the transponder at each frequency of interest. This value can be converted into a theoretical read range. The cabinet allows testing between 800 and 1000 MHz. Frequency range, frequency steps, and power-steps for testing should be chosen to get a meaningful data set at an appropriate time. The data is visualized as a graph and a downloadable data set. It is easy to identify the optimal frequency for the transponder and the frequency range it is suited for (all frequencies in a 3 dBm range from the optimal frequency). The threshold power is recorded in a logarithmic value, dBm (decibel milliwatts). 3 dBm corresponds to doubling the power.

3.2 Orientation Measurement

The rotation test measures the orientation sensitivity at a predefined frequency, while the turntable with the RFID-transponder is rotating. Again, the power steps and the angle steps to control the turntable need to be set appropriately. The results tell us how well the transponder can be read at different angles. On-metal transponders on a metallic substrate usually cannot be read from the back. Transponders for non-metallic applications of materials such as cardboard should produce an 8-shape. If the transponder cannot be read at all, please check the right orientation of the transponder, as the reading antenna in the RFID measurement cabinet is linearly vertically polarized (please refer to the chapter *Applied RFID in Logistics* for more information).

3.2.1 Questions you Should ask Yourself

Think of the Porsche job offer mentioned at the beginning. Let's consider you have an RFID specialist in the job interview who wants to test your RFID knowledge. Do you feel confident in answering these questions during your job interview?

- How would you choose the right RFID-transponder for a logistics application?
- What is the information you need about the specific logistics application to choose the right transponder?
- What types of (static) tests would you choose to identify the best transponder?
- What values would you measure?
- What do these values tell you about the usefulness of the transponder tested for the specific logistics application?

4 Summary

Successful RFID deployment requires choosing the right equipment such as RFID-readers, antennas, and transponders. Transponder data sheets provide useful information concerning the transponder. However, for specific applications, the impact of the substrate on the reading results should be tested. Simple tests may be performed using a standard RFID-reader. More accurate and repeatable results may be achieved in an anechoic chamber or a smaller measurement cabinet with specialized measurement interrogators. The data obtained from the measurements can be used to

- select the best transponder out of a set of transponders,
- analyze the useful frequency of the transponder range for regional or global applications,
- analyze the orientation sensitivity of the transponder,

- evaluate the usability of a transponder for a specific application in logistics and beyond.

5 Further Resources

5.1 Definitions

Closed-loop applications: Within the context of RFID for supply chains, this term is used to describe that the RFID-transponders are used in a loop such as in combination with returnable transport items. The transponders are used, again and again, thus ensuring the longevity of the transponders.

Open-loop applications: Within the context of RFID for supply chains, this term is used to describe that the transponders leave the boundaries of a closed loop, such as e.g. in retail applications. Transponders used in open-loop applications are very price-sensitive, as the benefits of their repeated usage are lacking.

5.2 Recommendations for Additional Resources

- Guidelines: Perform RFID test series with the Remote Measuring Chamber of the HFT Stuttgart (on Moodle)
- Measurement Report Template: RFID Test Report Use Case (on Moodle)
- Follow-up: Chapter on "Applied RFID in Logistics"
- Scientific RFID testing: This chapter is focused on the educational basics of RFID transponder testing. Please read VDI/AIM 4472 Part 10 on *Requirements to be met by transponder systems for use in the supply chain —Test methods to check the performance of transponder systems (RFID)* as well as ISO/IEC 18046 series on *Information technology—Radio frequency identification device performance test methods* if you are planning to do scientific tests.

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1 Didactical Considerations for Understanding the Impact of Measuring and Choosing RFID-Transponders for Applications in Logistics—Handout for Lecturers Lab environment

(Remote) RFID Measurement Cabinet at HFT Stuttgart

2 Didactical Analysis

Short Description: This unit explains the theoretical background and fundamental basics of testing RFID (Radio Frequency Identification) transponders. It focuses on the frequency range UHF (Ultra High Frequency) and passive RFID transponders, as they are used in many applications in logistics and production. The basic knowledge acquired in this chapter will be necessary for the later practical laboratory exercise.

Target Group: The unit addresses bachelor's students in engineering disciplines such as production engineering, computer science, logistics, and related engineering degrees in their first two years of studying. Some prior knowledge of physics is helpful but not mandatory. The lab experiment is targeted at groups of two students. 60 minutes of exclusive lab time should be reserved per group.

Institutional Requirements: The lab experiment requires professional measuring equipment (e.g. Voyantic Tagformance). However, as part of the DigiLab4U research project, the measuring equipment has been digitalized and is remotely accessible. As the project funding ends in 2022, access cannot be guaranteed. Please send an email to info@digilab4u.com if you are interested in remotely accessing the RFID measurement cabinet at HFT Stuttgart.

Subject matter: The chapter is recommended as preparation for the practical laboratory exercise with the remote RFID Measuring Chamber. On the learning platform, students will find templates for the systematic preparation of the lab exercise, informative video resources on the topic, quizzes for self-assessment, and supporting methodological handouts for self-directed work and working in teams.

In addition, the chapter and laboratory exercise from the University of Parma "Applied RFID in Logistics" can be completed afterwards to deepen the topic.

3 Didactical Concept

Methodical implementation: We (HFT lab-team) recommend the method of case-based reasoning (CBR) for the use of the (Remote) RFID Lab in a university course. Particularly in areas where complex problems arise and no recipe-like solutions are available, this kind of methodical approach can be beneficial for students. Industry-related laboratories in universities, like the RFID measuring cabinet, especially can provide these kinds of open learning environments, which are particularly suited to CBR. The CBR method relies on solutions to authentic cases and it supports students in deriving solution steps for similar future problems. In lab-based learning scenarios, case studies are bridges between theoretical models and practice. The goal is to use the method to develop, extend, and consolidate generalizable findings for a specific use case from the industry. The close interlinking of expert knowledge, methodical process know-how, and action-guiding values and standards ideally lead to professionally relevant solutions.

The chapter use case is based on a real job offer from well-known automotive manufacturer Porsche AG and can be found on the DigiLab4U learning platform. A complementary specific use case on selecting the right RFID-transponder for different transport-box materials is used for the experiment itself.

Media: The complete laboratory exercise is accompanied with Moodle, and all the required information and learning resources are available to students on this platform. To prepare for the RFID lab, a VR environment resembling the real RFID measurement chamber is offered. This may be used in a browser-based way or live in university VR labs. In general, all media resources can be used to make the case authentic, promote the use of scientific methods, and support analytical thinking.

Learning Organization: For the lab exercise, it is advisable to have the students work together in small groups of two people. Currently, a hybrid learning concept is appropriate for the use of the case-based learning method in the laboratory.

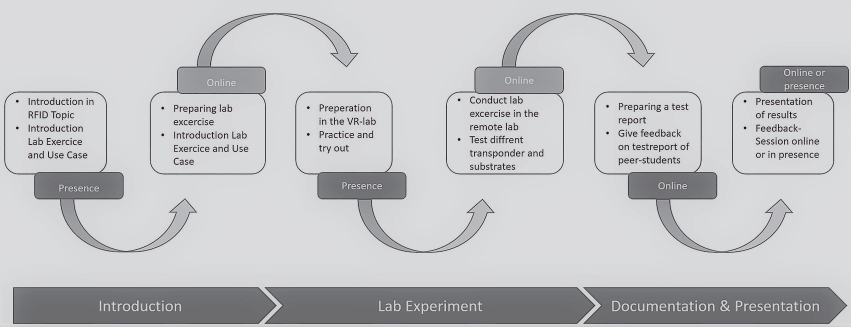

Figure 1: Phases of the lab exercise and organization of the hybrid lab-based learning scenario: lab phases

1. **Introduction**: The lecturer or lab assistant introduces the topic and presents the laboratory process and use case. Additionally, the students receive all the required resources and a detailed description of the use case on the learning platform.
2. **Analyze phase 1**: The students engage with the learning resources and use case scenarios in advance, and in groups prepare a hypothesis for their planned measurements in the laboratory.
3. **Lab preparation**: The students use the VR measuring chamber to prepare their work in the real or remote laboratory. The virtual measurement chamber also allows them to look into the measurement chamber while the measurement is running, which is not possible in real-world testing.
4. **Lab experiment**: The students carry out their measurements on certain substrates with transponders; they document each result and have the opportunity to test disturbance factors in the measurement chamber. The goal is to gain a deeper understanding of RFID measurements in the RFID lab (iconic chamber).
5. **Analyze phase 2**: The students create a test report, compare their results, and make a recommendation for the use case. They have to justify their recommendation based on their measurement results and the theoretical knowledge they have acquired.
6. **Presentation**: Finally, they present and discuss their findings and receive feedback on their test report.

A contact person (lab expert, lecturer, lab assistant) should be available during all lab phases to answer questions, give feedback, and support the students if technical issues occur. A total of three weeks should be planned for this lab experience, which means one week for each section (introduction, lab-experiment and documentation/presentation).

Feedback and Evaluation: In the context of the evaluation of laboratory-based courses, an evaluation in the form of a Teaching Analysis Poll (TAP) is useful.