3D Passive RFID Tag Over-The-Air Measurement

Hans Adel*†, Jan Bauer*‡, Christoph Grabowski*§
*Fraunhofer Institute for Integrated Circuits IIS
Am Wolfsmantel 33, 91058 Erlangen, Germany
†hans.adel@iis.fraunhofer.de
‡jan.bauer@iis.fraunhofer.de
§christoph.grabowski@iis.fraunhofer.de

***Abstract*—The knowledge of the three dimensional directivity of RFID tag antennas can help with the design and implementation RFID tags for various applications. Especially a careful choice of the tag position and orientation has the potential to improve the overall RFID system performance dramatically. The task is much easier to handle with the knowledge of the full 3D directivity of the passive RFID tag. This paper describes a setup and a method to measure the three dimensional directivity of passive RFID tags. A spherical nearfield scanner is used combined with additional RFID measurement equipment. The three dimensional measurement results of a standard RFID label are presented as well.**

I. Introduction

With the increasing number of RFID applications the problems to solve for RFID tag designers and engineers become more and more complex. Reliable measurements on RFID systems and tags are not easy to perform. Particularly if the tag is mounted on a large and complex object the number of viable mounting positions is very high. In many cases the best position to mount the RFID transponder is not obvious, even with expert knowledge on antennas and RFID.

Single direction read range measurements of various mounting positions can be used to find a good placement for the transponder. However the complex near field interactions between RFID transponders and the objects they are mounted on can lead to zeros in the radiation pattern. In a single direction optimization this can disqualify mounting positions that may perform much better when considering the mean read range over all directions.

Therefore three dimensional "antenna" measurements of passive RFID tags could prove to be helpful. Having the RFID tag directivity can be a powerful tool. It could e.g. help the tag designer to verify the 3D simulations results of the tag antenna. A full comparison of different tag mounting positions is possible and easy. Different antennas, RFID ICs and diverse mounting positions could be compared and evaluated. Lastly the data could also help to optimize the tag surroundings.

This paper shows a possible method and a setup to measure the three dimensional RFID tag directivity. A spherical nearfield scanner together with a laboratory RFID tester is used to establish a 3D RFID tag measurement system. In this system the tag is measured "as is" without any modification. It is also possible to measure the tag together with the tagged object to get the real directivity and performance for a specific application.

A similar system is commercially available [1], however it does come with limitations in the maximum size and weight of the objects the transponder can be placed on, also its only two dimensional.

In Chapter II the fundamental ideas behind these measurements are explained. Chapter III describes the measurement setup used for the 3D RFID tag measurements. In chapter IV the measurement results of a standard RFID tag are presented and discussed.

II. Measurement Principle

Measuring the radiation patterns of RFID transponder antennas is problematic mainly for two reasons. Firstly RFID transponders are usually electrically small and secondly available UHF RFID ICs have a complex input impedance, that the transponder antennas are matched to. For those reasons connecting the transponder antennas to standard antenna measurement gear is problematic.

A different method of measuring the radiation pattern is to measure the whole RFID tag including the RFID IC through a threshold power sweep. The basic idea is to increase the output power of the RFID reader to the point where the RFID tag turns on and responds to the commands of the RFID reader. The method follows from the Friis transmission equation [2]

$$\frac{P_{IC,min}}{P_{TX,min}} = G_{tag}\left(\vartheta,\varphi\right) G_{TX}\left(\frac{\lambda}{4\pi R}\right)^2 \tag{1}$$

where $P_{IC,min}$ denotes the constant minimum power required at the transponder antenna for the IC to respond, $P_{TX,min}$ is the minimum power the RFID reader needs to transmit for the RFID IC to wake up and $G_{tag}\left(\vartheta,\varphi\right)$ is the directional gain of the transponder antenna. The rest are constants that depend on the specific measurement setup. Therefore we can measure the gain through the threshold power transmitted by the RFID reader

$$G_{tag}\left(\vartheta,\varphi\right) = \frac{P_{IC,min}}{G_{TX}\left(\frac{\lambda}{4\pi R}\right)^2}\cdot\frac{1}{P_{TX,min}} = C\cdot\frac{1}{P_{TX,min}} \tag{2}$$

Thus the gain of the tag antenna in a certain direction is proportial to the inverse of the minimum transmitted power required to wake the RFID IC multiplied by a constant factor.

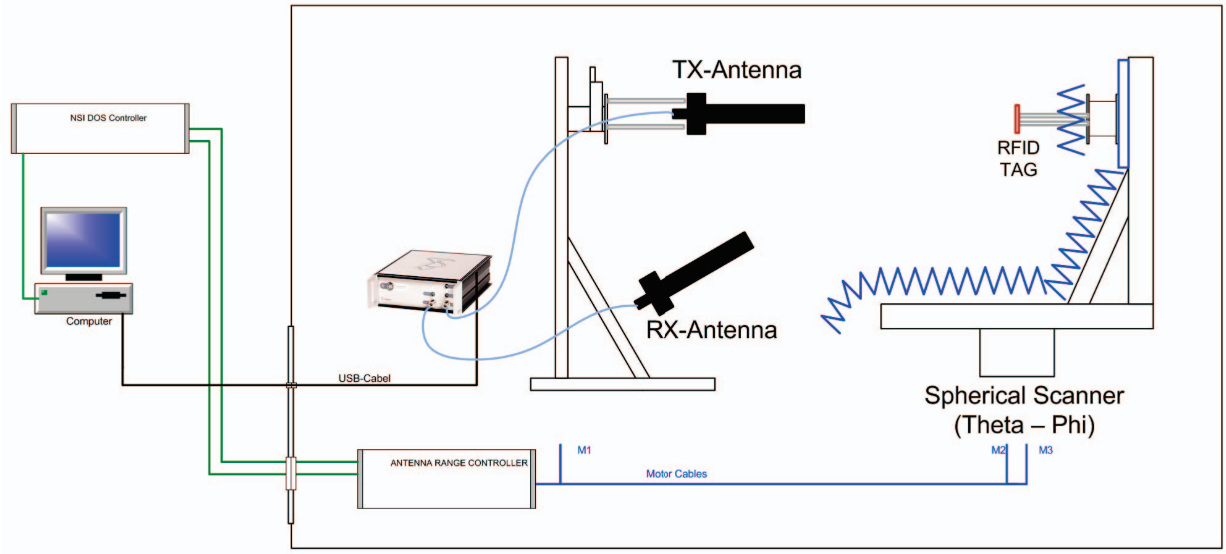

Fig. 1. System overview

III. Setup

The introduced measurement setup consists mainly of four components: a laboratory RFID tester with transmit power and frequency sweep capability, two high gain helix antennas, a spherical nearfield scanner and a PC to control and automize measurements through the use of a custom LabVIEW program. An overview of the whole setup is shown in Figure 1.

A laboratory RFID tester [1] was used for communication with the RFID tags under test. With this unit we can power RFID transponders at frequencies ranging from 800 MHz to 1000 MHz. Additionally the transmit power of the RFID tester can be adjusted between 0 dBm and 27 dBm.

The RFID transponder under test is mounted on the spherical scanner near the centre of rotation. This is important to ensure that the distance between the RFID transponder and the reader antennas remains constant and that the tag stays within the main lobe of the reader antennas for all possible values of theta and phi. Otherwise the path loss between the reader and the transponder would vary with the position of the nearfield scanner. Therefore the assumption, that the observed difference in transmit power required to wake the transponder is entirely a result of the directivity of the transponder antenna, would be incorrect.

As probe antennas we used circular polarized high gain helices (gain 12 dBi with RHCP at 868 MHz). The frequency range is from 750 MHz to 950 MHz with a VSWR of maximally 1.5:1. The circular polarization of the reader antennas eliminates the need to follow the orientation of the usually linear polarized transponder antenna, at the expense of dynamic range.

The 3D measurement then consists of rotating the RFID transponder to a certain (ϑ, φ), increasing the transmitted power of the RFID reader from 0 dBm to the point at which the RFID tag responds, printing the required transmitted power and the received backscattered power to a file and repeating those steps for all combinations of (ϑ, φ).

The measurements were conducted in the Fraunhofer IIS anechoic chamber. It is a spherical nearfield scanner system with a ϑ, φ coordinate system as shown in Figure 2 [3].

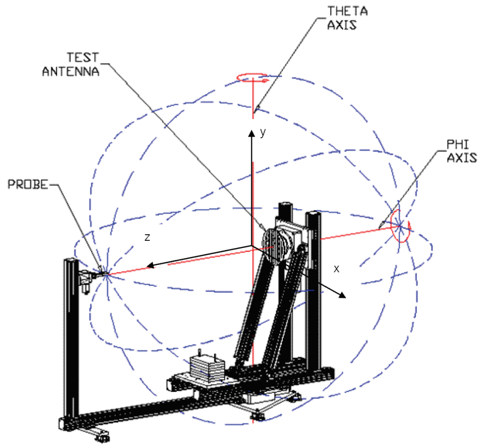

Fig. 2. ϑ, φ coordinate system of the used spherical scanner

We decided to use a bistatic setup because of the much better isolation compared to a monostatic setup. In a monostatic setup a single antenna is connected to the RFID tester with a circulator [4]. With a closer look to the performance of the circulator the isolation from RX to TX port is about 30 dB (datasheet value with an antenna return loss better than 12 dB). Caused by the limited input matching of the antenna any reflected power is sent to the RX port. Even with an ideal circulator and a well matched antenna with a reflection coefficient of -15 dB the power level reflected into the RX port is only 15 dB lower than the TX power. Looking at the power levels observed with our setup the TX power is about 25 dBm while the power of the received signal is about

-70 dBm. That means that the reflected power in this case of 10 dBm is much higher than the desired reception signal. This is the main reason for us to choose a bistatic setup with two separate antennas placed several meters apart shown in figure 3. This setup offers a much higher isolation and avoids any problems with limited antenna matching.

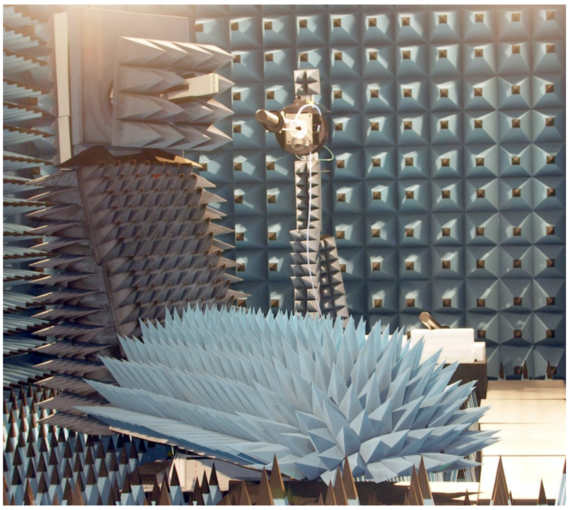

Fig. 3. Anechoic chamber with RFID measurement system

We measured a standard RFID tag (Alien Squiggle H3 label) with the described measurement system. It is mounted in the centre of rotation on a dielectric Rohacell post to reduce any influence on the tag behaviour. The scanner itself is covered with pyramidal absorbers (Figure 4).

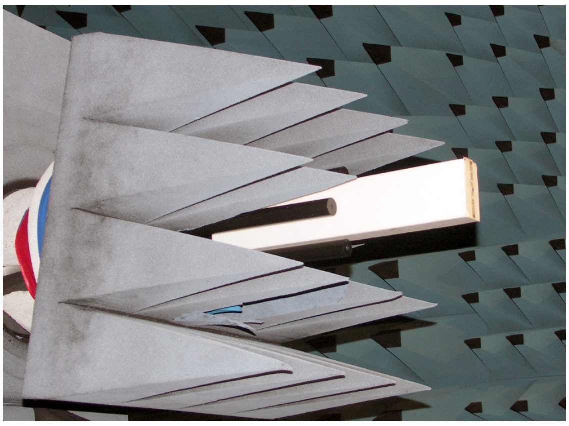

Fig. 4. Transponder mounted on the positioner

Typically the limiting factor in passive RFID systems is the maximum available transmit power of the TX antenna, resulting in an electric field strength at the tag that is too low to supply the RFID IC with power. The RX path is not that critical, so the distance between the tag under test and the RX antenna is not crucial. To reduce the free space loss we tried to reduce the TX-antenna to tag-under-test distance as much as possible. For this task we used a probe stand extension Figure 5.

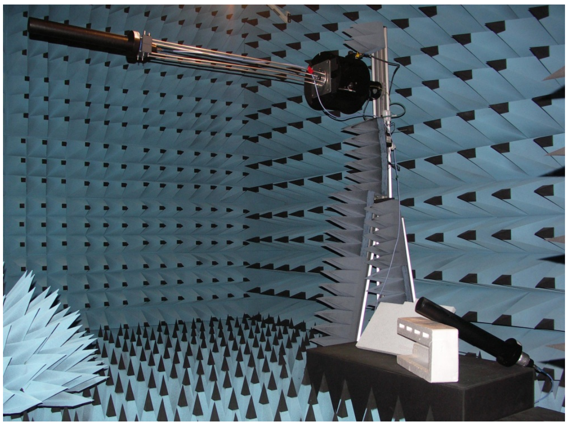

Fig. 5. Reader antennas with extended probe stand

The distance between the TX antenna and the RFID tag is about 1.7 m. While the distance between the RX antenna and the tag under test is 3.9 m.

IV. Measurement and Results

Prior to the 3D measurement a frequency sweep was used to find the frequency at which the transponder achieves the highest read range. This is done to maximize the dynamic range of the 3D measurements. For the Squiggle H3 we achieved the highest performance at 866 MHz, which also happens to be the exact frequency defined by ISO/IEC for read range measurements in the European UHF RFID band.

The Transponder was measured over the whole sphere with an angular resolution of 10°, resulting in 648 measurement points. The duration of one measurement was about 90 minutes.

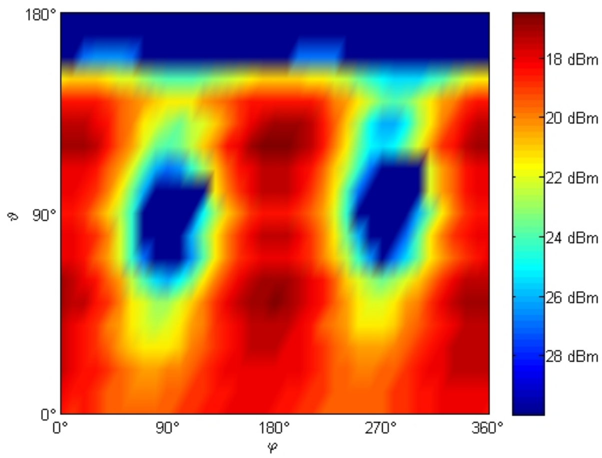

Fig. 6. 2D surface plot of an Alien h3 RFID tag

Figure 6 shows the 2D Diagram with all measured datapoints. The bad signal reception at the top of the graph around $\vartheta = 180°$ is caused by shadowing through the positioner. The other two zeros at $\vartheta = 90°$ correspond to the expected zeros of the dipole like transponder.

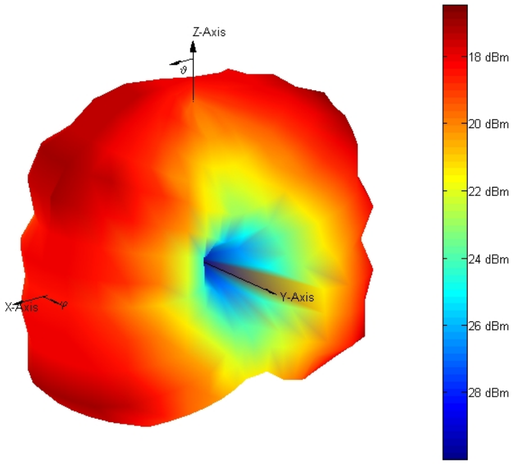

Fig. 7. 3D diagram of Alien h3 RFID tag

Figure 7 shows the same data in a 3D Diagram. The donut shaped radiation pattern of a dipole is clearly visible in this representation. The shadowing of the positioner is at the bottom in this diagram and therefore only barely visible.

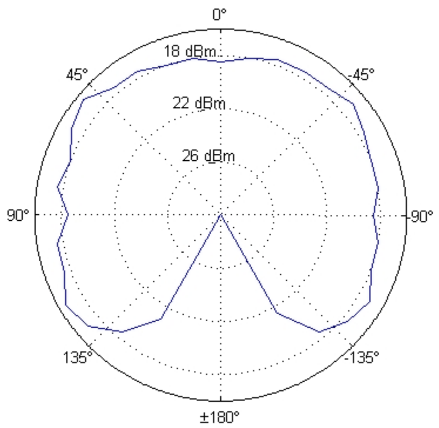

Fig. 8. Polar plot of Alien H3 RFID tag at $\varphi = 0°$

Lastly figure 8 shows a polar 2D plot of the measured radiation pattern. Again the shadowing of the scanner at $\vartheta = 180°$ is very obvious.

Clearly the directivity of the measured Alien tag is very dipole like. This matches our expectations based on the general design of the Squiggle H3 and from simulating similar transponder antenna designs with a 3D field simulator.

V. Conclusion

With the shown combination of RFID measurement equipment and a spherical scanner controlled by LabVIEW it is possible to measure the 3D directivity of RFID tag antennas. The measurement example of a common RFID tag shows the correct function of the system.

The measurement data provides a wealth of information that helps to evaluate and improve RFID tags. It is also possible to measure the RFID tag together with the tagged object which shows the true directivity of the tag on the object.

The data could also be used to verify tag simulations or help to find an appropriate mounting position on an arbitrary object.

In the future the measurement time could be significantly reduced by employing a more involved power sweep algorithm which uses the measurement results of the neighbouring measurement points as a starting point for the power sweep. Also different antennas and polarizations could be investigated.

References

[1] Voyantic Ltd., "Tagformance catalogue," http://www.voyantic.com.

[2] H. Friis, "A note on a simple transmission formula," *Proceedings of the IRE*, vol. 34, no. 5, pp. 254 – 256, may 1946.

[3] R. Wansch, C. Schmidt, K. Linberg, and H. Humpfer, "Antenna Test Range," *25th ESA Antenna Workshop on Satellite Antenna Technology*, 2002.

[4] MCS Microwave Limited, "P-5027 type RFID Circulator Duplexer," http://www.mcsmicrowave.co.uk/.