MEASUREMENTS AND CHANNEL MODELING FOR SHORT RANGE INDOOR UHF APPLICATIONS

Lukas W. Mayer, Martin Wrulich, and Sebastian Caban

Vienna University of Technology, Institute of Communications and Radio-Frequency Engineering
Gusshausstrasse 25/389, A-1040 Vienna, Austria, Email: lukas.mayer@nt.tuwien.ac.at

ABSTRACT

The recent emergence of short range applications, e.g. RFID (radio frequency identification), requires careful investigation of wave propagation and adequate description of the radio channel. In this contribution, we present indoor channel measurements at 868 MHz that expose the transition between the near and far field as well as the effects of fading. Furthermore, we investigate the appliance of a simple statistic channel model, based on the Rician distribution, and show that the underlying assumptions do not hold in general.

Key words: near field; RFID; short range; indoor; channel model; measurement.

1. INTRODUCTION

In short range applications like RFID (radio frequency identification) the transmission distance ranges from some centimeters to a few meters. The typical environment for these applications is an indoor site where a lot of interacting objects cause scattering. Far off the transmit antenna, the resulting multipath propagation causes fading that is well investigated and can be modeled statistically (e.g. [1, 2]).

Unlike in mobile communications where the channel behaviour can be described by models that only consider wave propagation in the far field of the transmit antenna, the near field has to be taken into account for short range applications too. Because of the very fast decaying strong near field component in the close vicinity of the transmit antenna, conventional channel models are not able to describe the field within the whole range of operation sufficiently. In this contribution, we present measurement results of typical RFID scenarios and investigate the appliance of a model that is based on the Rician distribution.

2. CHANNEL SETUP

2.1. Antennas

Product identification is probably the most important field of application for short range UHF (ultra high frequency) transmission at 868 MHz. To obtain measurement results that accurately reveal the behavior of such a radio channel, appropriate antennas were chosen. Antennas for passive RFID tags have to fulfill very different requirements compared to the reader antenna [3].

The reader antenna was chosen to be a microstrip patch antenna with a resonant frequency of 868 MHz and a measured gain of 7.1 dBi. The half power beamwidth of such an antenna is 70°. Due to their broad radiation pattern, microstrip patch antennas are often used as interrogator antennas in commercial product identification systems.

The tag antenna usually is favored to be small, low profile, and flexible to allow integration into product packaging. Tag antennas are also small compared to the free space wavelength, thus showing a nearly omnidirectional radiation pattern. For the channel measurements presented in Section 3, a coplanar loop slot antenna was built. This antenna was chosen because it can be fed by a coaxial wire. The measured gain of the tag antenna is 0.5 dBi. Figure 1 shows a picture of the interrogator antenna and the tag antenna.

Since both antennas are low profile, the minimum distance for the measurements is 5 cm which means that the antennas are placed within the near field of each other. With the measurements presented in Section 3, direct capacitive and inductive coupling between the antennas as well as the radio transmission loss for higher distances are obtained. For the measurements considered in this contribution, both linearly polarized antennas were aligned to achieve the best transmission. Aggravation of performance due to misalignment is not investigated but subject to future research.

Proc. 'EuCAP 2006', Nice, France
6–10 November 2006 (ESA SP-626, October 2006)

Table 1. Summary of measurement site data.

environment	room size	description	90 % read range
LAB	$8 \times 6\,\mathrm{m}^2$	office with 4 workplaces, laboratory equipment	103 cm
OFB	$23 \times 5.5\,\mathrm{m}^2$	office room divided into 4 chambers, 3 workplaces each	80 cm
OFS	$4 \times 5.5\,\mathrm{m}^2$	office with one workplace	60 cm
MMS	$14 \times 8\,\mathrm{m}^2$	room with heavy metal machining equipment	40 cm

Figure 1. Coplanar loop slot antenna on a foam stand (left) and microstrip patch antenna (right).

2.2. Measurement Setup

For every measurement, an xy-positioning table moves the small tag antenna within a rectangular area of 70 cm by 140 cm (approx. $2\lambda_0 \times 4\lambda_0$). The xy-positioning table is equipped with absorbing mats to reduce reflections at its metal parts. A wooden bar that extends from the table by 1.5 m carries the small receive antenna. To acquire near field transmission data, the transmit antenna is placed closely to the area where the small receive antenna is moving. A network analyzer (HP-8753B) is used to determine the transmission loss between the antenna ports. In every measurement site, different positions of the transmit antenna and the xy-positioning table were investigated to acquire a sufficient number of measurements.

2.3. Scenarios

To render the behavior of indoor short range communication channels at UHF, four different measurement sites, that appeared to be relevant for RFID applications, have been chosen and investigated (see Table 1).

Office Scenario: The office scenario was chosen for near field measurements because it is similar to a lot of other indoor environments. Measurements at three different sites were performed to examine the channel behavior in such a scenario:

(i) An 8 m by 6 m, brick wall laboratory room (referred to as LAB) at the fifth floor of the institute features some workplaces with tables, chairs, computers, some bookshelves, and a table full of measurement equipment. During the measurements, students were working in this room.

(ii) Measurements were also carried out in a small 4 m by 5.5 m office room (OFS) in the second floor, similar to the one described above, and

(iii) an even bigger office room (23 m by 5.5 m, brick wall) that is divided into four chambers by drywalls (OFB).

All rooms in the office scenario have big windows through which a significant part of the radiated power is lost.

Metal Machining Shop Scenario: This scenario was chosen to investigate the transmission behavior in an industrial environment. Especially in the automobile industry there is great potential for contactless item identification. The environment of factories generally features big metal objects like metal parts, robots, machines, and of course the products themselves. To ease component and production management, RFID technology has already been introduced, but is said to become an even more important factor in the future. A metal machining shop is a similar environment, so the results obtained can be applied well to industrial RFID applications. Heavy equipment like mills, lathes, and drilling machines are located in this 14 m by 8 m, brick wall room (MMS).

3. MEASUREMENT RESULTS

The first analysis was performed to give a brief description of the field properties in proximity of the transmit antenna. Common for all measurement setups, a transmission coefficient of -10 dB has been measured at an antenna distance of $d = 5\,\mathrm{cm}$. This is due to direct inductive and capacitive coupling between the antennas and only observed in the reactive near field. The transmission coefficient decreases very fast when the antennas are moved apart. At a distance of approximately 40 cm ($\approx \lambda_0$) the steep decrease ends and turns into a more temperate decay. At this point, the transmission coefficient has dropped to approximately -25 dB. For all following evaluations the area outside the half-power beamwidth cone was not taken into account, since in practice the directional pattern of the transmit antenna restricts the reasonable area of operation.

Since the measurements were carried out indoors, other signals that result from reflections at objects and walls are received by the tag antenna too. Close to the transmit antenna, the direct signal component dominates. Other signals are weaker because of reflection losses at interacting objects and increased path lengths. However, as the direct component decays over distance, standing waves are present in space which will impair the transmission. Particularly, this happens if the direct signal component is less than or approximately equal to the reflected signals. Measurements showed that the mean signal strength of the reflected signal components in the area far off the transmit antenna ($d > 2\,\mathrm{m}$) is fairly constant over transmission distance. The mean signal strength of the reflected components depends on the properties of the scenario. A comparison of the scenarios investigated is given in Table 1.

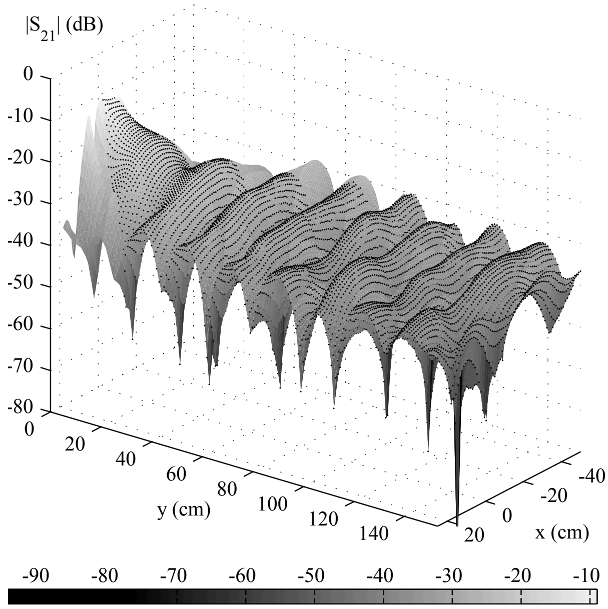

Figure 2. Transmission coefficient versus receive antenna position in the metal machining shop (MMS). The transmit antenna is located at the origin (0,0) and aims at positive y-direction. Channel coefficients within the half-power beamwidth cone of the transmit antenna are marked with dots. Only these data points were taken into account during the statistical evaluation.

3.1. Metal Machining Shop

Figure 2 shows the representative transmission coefficient of one measurement that was carried out in the metal machining shop (MMS). In this figure, the origin (0,0) represents the position of the transmit antenna that was aimed at positive y-direction. The area in front of the antenna is covered well but shows a steep decrease of the channel coefficient versus the transmission distance. At a transmission distance of 1 m and more, deep fading makes the channel loss hard to predict and thus influences the reliability of energy and data transfer necessary for communication with a product tag. Areas not directly radiated by the transmit antenna (directional pattern) show deep fading of more than 40 dB. For all measurements in the metal machining shop, deep fades start to occur from 25 cm transmission distance on. This clarifies that in such an environment special care has to be taken when choosing and positioning the transmit antenna. RFID tags that are placed outside the half-power beamwidth cone of the transmit antenna will not be recognized reliably—even when placed close to the transmit antenna.

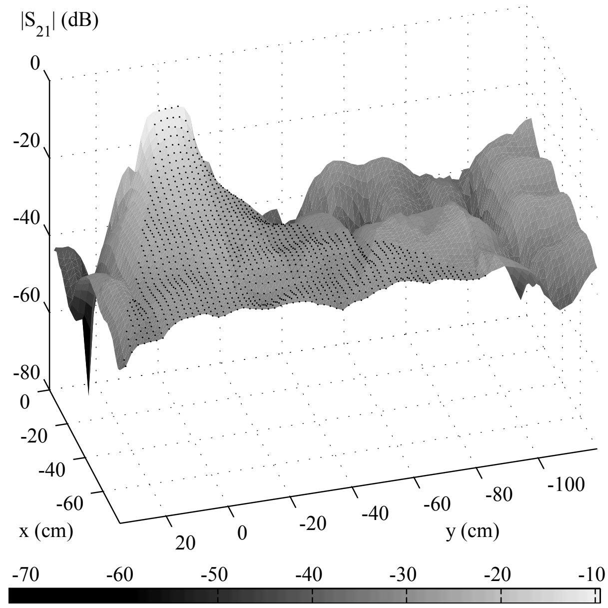

Figure 3. Transmission coefficient versus receive antenna position in the laboratory room (LAB). The transmit antenna is located at the origin (0,0) and aims at negative x-direction.

3.2. Office Area

Figure 3 depicts the representative transmission losses of one measurement that was carried out in the laboratory room (LAB). It can be seen that the direct signal component dominates reflected signals for a quite long transmission distance. This clearly distinguishes the office scenarios from the metal machining shop scenario. Furthermore, a comparison of the measurements performed in the office areas revealed that bigger rooms tend to show more stable channel properties.

3.3. Comparison of Scenarios

To determine whether a tag can be identified in a given scenario and at a specific transmission distance the properties of the transmission system have to be known. Commercial readers (also referred to as interrogators) provide a dynamic range of 90 dB to 100 dB (e.g. like those available from Feig Electronic GmbH, Alien Technology Corp.) and an output power of 0.1 W to 5 W dependent on the regional radio frequency regulations. To estimate the read range of passive tags, the maximum channel loss has to be evaluated. Since the reflection and modulation loss at the tag is approximately 20 dB, a total channel loss of more than 70 dB will make the backscattered signal impossible to be read. This implies that the channel attenuation must not exceed 35 dB for each the forward and the return link. With 0.1 W transmit power and a channel loss of 35 dB, the power available to operate the tag chip is 31 μW and thus sufficient for state-of-the-art tag chips (e.g. Atmel ATA5590). Since available reader and tag hardware shows very different performance, the results can not be applied to every reader and tag hardware combination, so it should be noted that typical values were chosen for reader and tag to compare the scenarios with each other.

Figure 4 depicts the percentage of points that show a channel coefficient better than -35 dB versus transmission distance. Obviously the reliability of radio transmission is always good if the tag is close to the transmit antenna. This is trivial since the strong near field component outweighs all other reflected signals present in space. When increasing the transmission distance, the metal machining shop shows the worst performance. However, due to the strong reflected signals, the mean power level can be quite high at points where the near field component has already declined. This is the reason why the reliability decreases slower over distance in the metal machining shop.

At first sight, it seems that the behavior of the three office rooms strongly depends on the room size. Figure 4 shows that the bigger the room, the more reliable is the radio transmission—even at larger transmission distances. In bigger rooms, reflections from walls and objects are weaker because of the increased path lengths. This reduces fading and improves the transmission quality. But, in conjunction with the results from the metal machining shop, room size is not so important as soon as there are interacting objects near or in the area of operation.

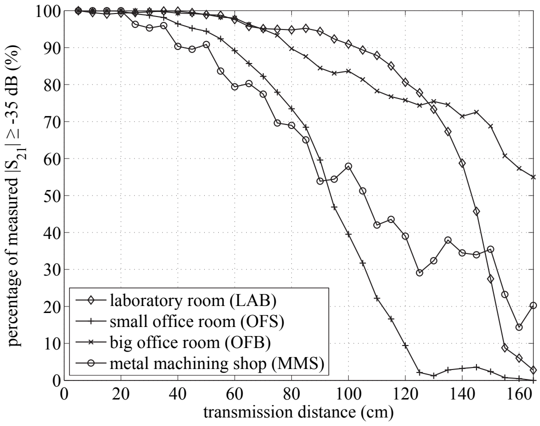

Figure 4. Percentage of positions with channel loss lower than 35 dB versus transmission distance.

4. CHANNEL MODELING

Indoor measurement results and statistical channel modeling as performed by numerous authors (e.g. [1, 5]) leads to the impression that the statistical behavior of the magnitude of the RFID channel transmission coefficient might be Rician [6]. This assumption seems obvious, since the received power consists of a line-of-sight (LOS) component that decays with the transmission distance, and a superposition of signals caused by reflections at interacting objects. Accordingly, the complex amplitude of the received signal $s(d)$ as a function of the transmission distance d can be expressed by

$$s(d) = Ad^{-\varepsilon}e^{-jkd} + \sum_{i=1}^{N} b_i e^{-jkd_i}, \qquad (1)$$

where A denotes the maximum amplitude, and ε the deterministic path loss exponent of the direct signal component. The reflected signals are described by their amplitudes b_i and phases kd_i, determined by the lengths of their propagation paths d_i and the wave number $k = 2\pi/\lambda_0$.

By using the central limit theorem it can be derived, that the real and imaginary part of the sum of all reflected waves obeys a Gaussian distribution, if

- the amplitudes b_i show identical distributions,
- the phase $mod(kd_i, 2\pi)$ is uniformly distributed in the interval $[0 \ldots 2\pi]$,
- b_i and d_i are statistically independent,
- and the number of signals N approaches infinity.

The magnitude of the superposition of such signals is found to be Rayleigh distributed. With a determined signal component ($Ad^{-\varepsilon}e^{-jkd}$) added to this superposition, the magnitude of the signal $s(d)$ for a specific transmission distance d_0 shows a Rician distribution

$$f(s|d = d_0) = \begin{cases} \frac{s}{\sigma^2} I_0 \left(\frac{ms}{\sigma^2}\right) \exp\left(-\frac{s^2+m^2}{2\sigma^2}\right) & s \geq 0 \\ 0 & s < 0, \end{cases} \qquad (2)$$

whereas I_0 denotes the modified Bessel function of the first kind. In our context the Rician parameters σ and m both depend on the transmission distance d.

To determine the parameters of Equation (1), Rician distribution fitting with the measurement data was performed. This fitting was carried out for different transmission distances to be able to derive the deterministic path loss exponent ε from the Rician parameter m. A histogram analysis revealed that the measurement data does not show a Rician distribution at the different transmission distances.

The main reason therefor is that in our measurement campaigns, due to the low transmission distances, a few interacting objects cause reflections that outweigh the reflected waves from more distant objects. Thus, the phase kd_i is not distributed uniformly anymore, and the number of paths N is far below infinity. The received waves are arriving rather clustered, causing different directions to be far stronger than others. Furthermore, the transmit antenna spatially weights the emitted power according to its directional pattern, so that the resulting multipath components do not show an identical distribution of their amplitudes b_i. These observations clearly show that the very common Rician description of the channel is oversimplified in the context of indoor short range UHF transmission. Similar conclusions have been drawn in the MIMO channel modeling literature, where recent advanced radio channel models base on the concept of multi-path clusters. These clusters consist of many multi-path components (MPCs) showing similar parameters such as azimuth and elevation of arrival and departure, as well as delay (cf. [4]). Equivalently, a modeling of the RFID channel based on a clustering concept seems to be a much more promising way to obtain a statistically valid description of the measured data. Further research is planed to prove this conjecture.

5. CONCLUSIONS

In RFID applications, the reliability of the radio transmission channel is a limiting factor. A measurement campaign has been performed to identify the area of operation of an RFID system in different scenarios.

The measurement data obtained were used to estimate the read range of a typical RFID tag/reader combination in various environments. Basically, three conclusions can be drawn: (i) depending on the properties of the scenario, reader-tag-reader communication is only reliable close to the reader antenna, (ii) comparison of the obtained read ranges showed that the number of interacting objects has to be minimized in order to avoid strong reflected signal components that might impair the direct LOS component, and (iii) special care has to be taken when choosing and placing an RFID reader antenna to optimally cover the desired range of operation while suppressing reflections from potentially interacting objects. A statistical evaluation of the measurement data revealed that a channel model based on the Rician distribution is not sufficient to describe the behavior of the transmission coefficient. A more promising approach seems to be a cluster based model that is able to describe the few dominating signal paths more precisely. More measurements and analysis have to be performed to develop such a new cluster based model.

REFERENCES

[1] Rappaport T.S., McGillem C.D., 1989, UHF fading in factories, IEEE journal on selected areas in communications, Volume 7, Issue 1, Pages 40–48

[2] Valenzuela R.A., Landron O., Jacobs D.L., 1997, Estimating local mean signal strength of indoor multipath propagation, IEEE transactions on vehicular technology, Volume 46, Issue 1, Pages 203–212

[3] Seshagiri Rao K.V., 2005, Antenna design for UHF RFID tags: A review and a practical application, IEEE transactions on antennas and propagation, Vol. 53, No. 12

[4] Czink N., *et.al.*, 2006, A framework for automatic clustering of parametric MIMO channel data including path powers, Proc. IEEE vehicular technology conference fall 2006, Montreal, Kanada

[5] Wong D., 1999, Estimating local mean signal power level in a Rayleigh fading environment, IEEE transactions on vehicular technology, Vol. 48, No. 3

[6] Karasawa Y., 2000, Formulation of spatial correlation statistics in Nakagami-Rice fading environments, IEEE transactions on antennas and propagation, Vol. 48, No. 1