Simple and Accurate Radiation Pattern Measurement of UHF RFID Transponders

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Abstract—In this contribution we describe a simple measurement method to characterize the antenna of radio-frequency identification (RFID) transponders at the ultra-high frequency (UHF) band. The transponder that consists of an antenna and a transponder chip is fixed in a rotation apparatus and exposed to a field produced by a calibrated reference antenna. By monitoring the presence of the transponders response and simultaneously adjusting the transmit power, the transponders minimum operating field can be found. A series of such measurements versus azimuth and polar angle as well as transmit antenna polarization allows to determine the radiation pattern. With this method it is possible to analyze the influence of materials placed in the proximity of the transponder. Measurement results for a dipole-like transponder and an omnidirectional transponder that is subject to a proximity effect are presented.

1   Motivation

Knowledge of the radiation pattern of radio-frequency identification (RFID) transponder antennas is essential for both, the antenna designer and the RFID system engineer. In RFID applications in the ultra-high frequency (UHF) band, the reliability is mainly determined by the performance of the transponders that have to be attached to objects or individuals. Often, when transponders are in the proximity of materials, the performance of their antenna can hardly be obtained by simulation. Especially if the electromagnetic properties of the interacting materials are not determined, trial-and-error approaches are common practice to optimize the antenna or its position on an object [1]. Here, performance measurements are necessary.

One possibility to conduct such measurements is by analyzing the radiated field of the transponder antenna when powered by a perfectly-matched, miniaturized, battery-driven oscillator. In [2] it was shown that this method allows to characterize the radiation pattern and the efficiency of transponder antennas. However, the accuracy depends on the size of the oscillator unit and might be compromised if very small antennas are to be characterized.

A very promising approach is to connect a substantially nonlinear load to the transponder antenna and place it in front of a transmit antenna that radiates a dual-tone signal. The intermodulation products reradiated by the transponder and picked up by a separate receive antenna can then be used as a measure for the antenna gain [4]. However, with the proposed arrangement of transmit, receive, and transponder antenna, the three dimensional radiation pattern can not be obtained entirely. Furthermore, the setup can hardly be calibrated an thus the antenna efficiency can not be determined.

In this contribution, we utilize the basic functionality of the transponder chip to characterize a tag antenna. In Section 2 the measurement method is described that allows to obtain knowledge of the transponder antenna's radiation pattern. With this method no modification of the transponder is necessary. It is characterized as deployed in the final application. The measurement setup used to characterize the radiating field of the transponder antenna is presented in Section 3. For testing, two commercially available RFID tags are characterized. The measurement results are discussed in Section 4. In Section 5 conclusions are drawn and ideas for future work are presented.

2   Radiation Pattern Measurement

The radiation pattern describes how the power that is radiated by an antenna is distributed in space. In principle, the radiation pattern is a function of the polar angle ϑ and the azimuth angle φ. For different polarization modes of an antenna, separate radiation patterns can be determined. This contribution

focuses on the radiation pattern measurement for linear polarization in ϑ-direction $F_\vartheta(\vartheta, \varphi)$ and linear polarization in φ-direction $F_\varphi(\vartheta, \varphi)$. At this point, no statement about the ellipticity of the radiated wave can be made. This will be analyzed in future work. However, from $F_\vartheta(\vartheta, \varphi)$ and $F_\varphi(\vartheta, \varphi)$ alone, many important characteristics of the antenna can be found.

When a transponder is exposed to the radiating field of an RFID interrogator, its antenna receives the interrogators transmit signal. This signal is fed into the transponder's chip where it is converted into a supply voltage for the chip's internal circuitry. If the signal level P_{sig} is greater than or equal to the chip's minimum operating power P_{min}, the tag can respond to commands issued by the interrogator. Since P_{min} is constant over time, it can be used as a reference power level throughout a measurement. The radiation pattern of the transponder antenna can thus be determined by increasing the interrogators transmit power P_{Tx} up to the level $P_{Tx,resp}$ where a response from the tag is first received. With the gain of the interrogator antenna G_{Tx}, the transmission distance d, and the free space wavelength λ_0 the realized gain of the transponder antenna G_r that includes a potential matching loss between the transponder chip and the transponder antenna can be calculated according to

$$G_r = \frac{P_{min}}{P_{Tx,resp}G_{Tx}} \cdot \left(\frac{4\pi d}{\lambda_0}\right)^2.$$

(1)

If one can assume that the minimum operating power P_{min} is exactly known, and that matching between the transponder antenna and the transponder chip is perfect, then the realized gain G_r can be equated with the actual gain G of the transponder antenna.

When a series of measurements of G_r are done versus azimuth and polar angles (covering a sphere around the antenna-under-test) and for both polarizations in ϑ- and φ-direction, the squared radiation pattern of the transponder antenna can be obtained by normalization of the realized gain G_r with the maximum total realized gain $G_{r,max} = \max\{(G_{r,\vartheta} + G_{r,\varphi})(\vartheta, \varphi)\}$ according to

$$F_{\vartheta|\varphi}^2(\vartheta, \varphi) = \frac{G_{r,\vartheta|\varphi}(\varphi, \vartheta)}{G_{r,max}.}$$

(2)

An accurate measurement of the radiation pattern is only possible if the matching loss between antenna and chip is kept constant for the entire measurement. A variation of the antenna impedance that is caused by a rotation-dependent proximity effect (e.g. if the transponder is mounted onto a partly filled water bottle) or a temperature drift of the chip's input impedance or minimum operating power, will corrupt the measurement.

3 Measurement Setup

The measurement setup is depicted in Figure 1. Cross-polarized dipole antennas are used to generate an electromagnetic field at 866 MHz that powers the transponder. A switch feeds the signal that is generated by an *R&S SMU200A* vector signal generator (VSG) into either the horizontal or the vertical input of the transmit antenna.

The transponder is fixed in a rotation apparatus that allows to point the tag antenna at any azimuth or polar angle (φ, ϑ). The apparatus is made of Rohacell with a relative dielectric constant of $\varepsilon_r = 1.04$. It contains no metal parts within a radius of 1.8 m around the antenna-under-test and thus allows to operate the transponder like in free space. The top-part of the apparatus that adjusts the azimuth angle φ is shown in Figure 1. A separate rotator sitting on the floor of the chamber sets the polar angle ϑ. The response of the transponder is picked up by a left-hand circularly polarized antenna that is positioned at the floor of the chamber as well. This antenna will reliably receive the response as long as the transponder does not radiate a right-hand circularly polarized wave towards the pickup antenna. The received signal is fed into an *R&S FSQ26* vector signal analyzer (VSA) that detects a possible response. A computer remotely controls VSG, VSA, polarization switch, and rotation apparatus. For a series of tag antenna tilt-angles and the two polarization modes, the minimum transmit power $P_{Tx,resp}$ where a response is still detected
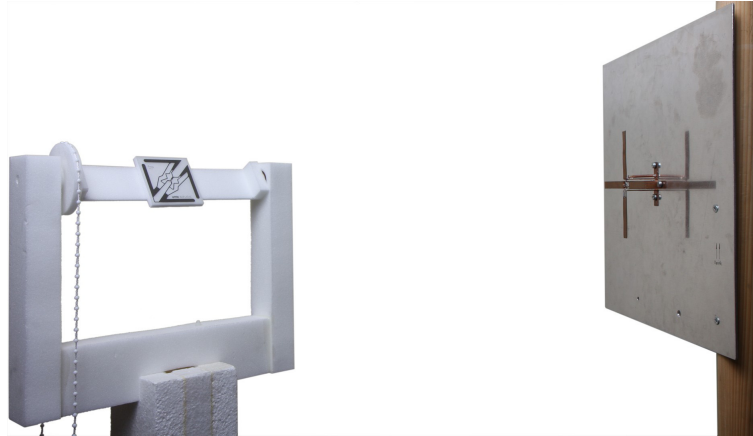
Fig. 1. Measurement setup with a *UPM Frog* transponder mounted in the rotation apparatus (left) and a cross-polarized reference antenna (right).

is determined by a successive approximation method. The search is performed with an accuracy of 1/16 of a decibel. From the results the radiation pattern is calculated according to Equations 1 and 2.

It is obvious that at tilt angles where the transponder antenna has low gain, a strong electromagnetic field is required to make the tag respond. This was achieved by

- choosing the transmission distance $d = 0.76$ m which is barely in the far-field of the transmit antenna,
- and using a highly linear power amplifier (*Minicircuits ZHL-900A-10W*, output 1 dB compression point at 39 dBm) that delivers up to 2 W.

However, for characterizing low-gain near-field transponders, significantly more transmit power is required. Alternatively, the measurement could be carried out in a transverse electromagnetic (TEM) cell.

The signal that is used to make the tag-under-test respond is generated by the VSG. It is modulated with an EPCGlobal Gen2 standard compliant inventory command that requires the transponder to answer with a preamble and a 16 bit random number encoded in the FM0 modulation scheme at a link-frequency of 148 kHz [3]. At the beginning of the sequence there is a pause where no power is transmitted. This causes a reset of the transponder. The whole sequence is continuously repeated to keep the minimum operating power $P_{\min}$ of the transponder as constant as possible.

4 Measurement Results

For testing, measurements were carried out on a dipole-like *UPM Dogbone* tag and an omnidirectional *UPM Frog* tag. Both transponders carry the *Impinj Monza3* chip. The radiation pattern was sampled versus azimuth angle φ and polar angle ϑ in 9 ° steps. Photographs of the tags and their orientation with respect to the azimuth and polar angle are shown in Figure 2.

For the *UPM Dogbone* transponder the measured radiation pattern for linear polarization in ϑ-direction versus ϑ and φ is shown in Figure 3. For reference, the simulation result of an ideal half-wavelength dipole is also plotted. It is seen that the theoretical and the measured curves are in very good agreement. For the chip's minimum operating power of $P_{\mathrm{Rx,min}} = -15$ dBm (claimed in the datasheet) and under the assumption of perfect matching, the antenna has a measured efficiency of 82 %.

To demonstrate the characterization of an antenna that is subject to a proximity effect, results for one *UPM Frog* transponder in free space and when mounted onto a bar of chocolate enclosed in a plastic wrap are given in Figure 4.

5 Conclusion

A simple and accurate way to determine the radiation pattern of transponder antennas was presented. The most important advantage of this non-intrusive method is that the transponder antenna is characterized exactly as it is deployed in the final application. Measurement results can be obtained for tag antennas that

Fig. 2. *UPM Dogbone* transponder (left) and *UPM Frog* transponder on a bar of chocolate (right). The photographs are shown with the coordinate system used for characterization of the antennas.
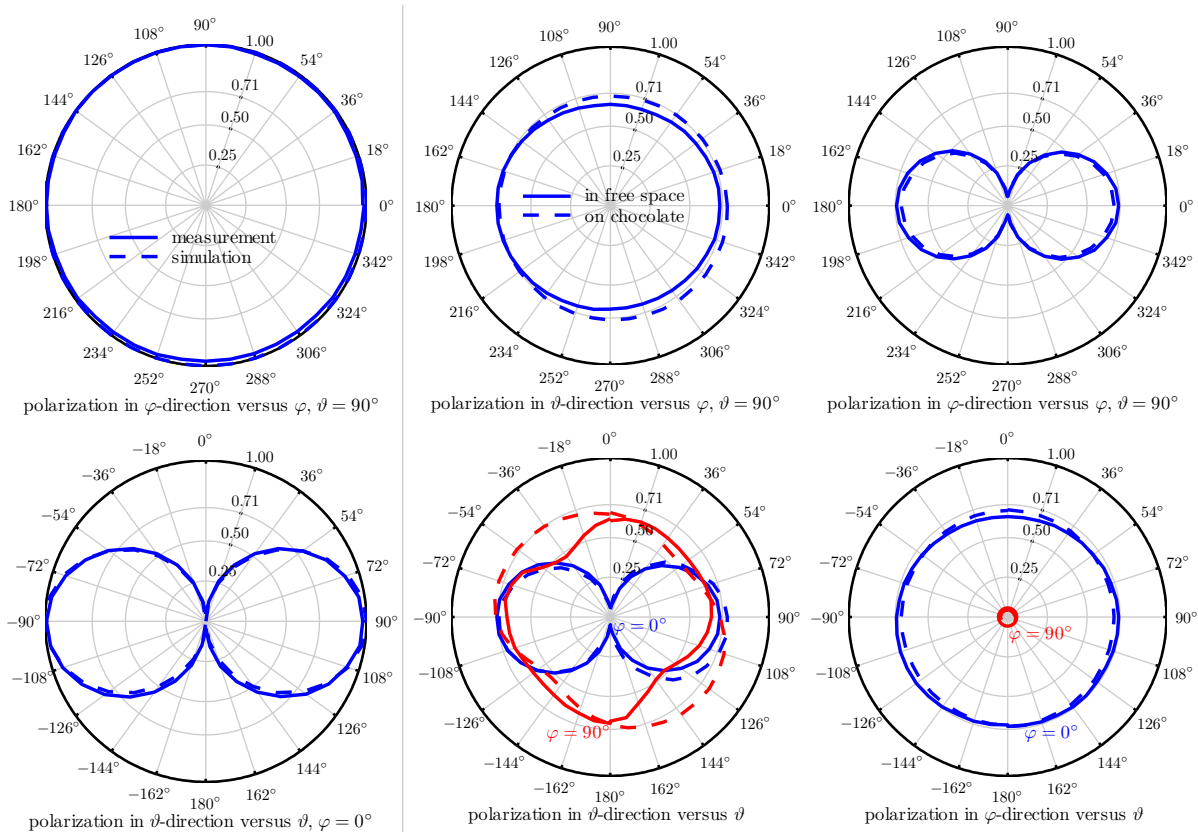

Fig. 3. Radiation pattern of *UPM Dogbone*.

Fig. 4. *UPM Frog* transponder in free space and on a bar of chocolate.

are subject to a proximity effect. Also, the radiation pattern for a third, preferably circular polarization mode can be analyzed to obtain full knowledge of the ellipticity of the transponder's radiation.

The method can also be extended to analyze the absolute gain and the efficiency of a transponder antenna. It is then necessary to exactly determine the minimum operating power of the transponder chip, and to establish perfect matching between the antenna and the chip. The latter can be achieved by a small, tunable matching network.

References

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