1. Introduction

Radio frequency identification (RFID) has become one of the most expanding technologies within the last years and it is applied to a wide spectrum of applications. Most important part of an RFID system is the RFID tag, which consists of an electronic chip attached to an antenna. Using passive RFID technology, the chip becomes activated by the energy, which is sent out from the RFID reader or interrogator. To achieve maximum system performance, which means maximum reading distance, the antenna has to be matched to the chip, which herein represents the load. This means that the antenna impedance $Z_A$ has to be conjugate complex to the impedance $Z_C$ of the electronic circuit. In this paper, investigations are made, which show the small degree of freedom in the design process of RFID tag antennas. A measurement system is presented, which allows extended measurements of RFID tags.

2. RFID UHF measurement system

Main problem is to find the optimum alignment between the chip and the antenna [1]. With perfect conjugate match the transponder sensitivity will be best. This means, that the necessary transmit power to activate the chip will be lowest. Any mismatch between chip and antenna leads to an
increased power to wake up the electronic circuit. This principle is used in the measurement system. The available power $P_C$ into the chip results from the maximum available power $P_{max}$ delivered from the antenna which is reduced due to the mismatch between chip and antenna. Therefore $P_C$ is given as

$$P_C = P_{max} \frac{(1-|r_A|^2)(1-|r_C|^2)}{|1-r_A r_C|^2}$$

with $r_A$ and $r_C$ as reflection coefficients of the antenna and the chip.

Using a professional rf signal generator the activation threshold of the chip can be detected precisely by variation of the transmit power in very small steps. Nearly all commercial chips which have been used in this investigation show a definite and digital respond within 0.1 dB power level change. Therefore, the measurement system consists of a rf signal generator which can be modulated with the start sequence of the transmit code referred to the RFID standard, i.e. EPCglobal Class1 Gen2 ISO/IEC 18000-6c. The power is fed to a transmit antenna. Assuming that the power at the location of the tag is big enough the processor in the tag will be activated and starts its answering and identification process. This can be monitored easily by using an additional receiving antenna and a spectrum analyzer. Due to the ASK modulation a clear difference can be seen in the spectrum. Fig. 1a shows the measurement setup and Fig. 1b shows the modulated signal from the generator respectively the response signal of the tag. This signal represents the backscattered energy from the tag to the receive antenna. Assuming that the response is measured at the wakeup threshold (i.e. -15 dBm), the backscattered signal not too far away from the RFID tag is big enough to be detected. Compared to the radiated signal from the transmitter, which should be in accordance to the regional RFID specifications (i.e. Europe 4W EIRP 868 MHz), the received signal is reduced only by two times the path loss and the losses of the backscattering process. Therefore, this methodology allows a fast and accurate comparison of RFID tags and it is also used for the optimization of the chip antenna alignment. Table 1 gives a comparison of 4 different RFID tags regarding the required power. No.1 – 3 are commercial tags and no. 4 is a homemade reference dipole of length 170 mm capacitively coupled to the chip. The overall performance of the first three tags is more or less the same. The comparison of No. 2 and 3 shows, that equal performance can be achieved even with different antenna structures. Therefore antenna gain and matching to the chip seems to be good. Tag No. 4, which is coupled capacitively to the antenna structure requires 3.7 dB higher power, which is caused from the mismatch between the tag and the antenna.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Chip</th>
<th>Required power referred to No.1 in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alien Squiggle (ALN-9540)</td>
<td>Alien Higgs 2</td>
<td>0</td>
</tr>
<tr>
<td>KSW microtec</td>
<td>NXP G2XM</td>
<td>0.9</td>
</tr>
<tr>
<td>UPM Raflatec</td>
<td>NXP G2XM</td>
<td>1.0</td>
</tr>
<tr>
<td>dipole with cap. coupled chip</td>
<td>NXP G2XL</td>
<td>3.7</td>
</tr>
</tbody>
</table>

3. Antenna measurements

With RFID antennas standard measurement methodologies (i.e. farfield/nearfield measurement) fail due to the size and structure of the antenna. The measurement cable often influences the small antenna or problems arise due to the unbalanced cable which has to be connected to the symmetric antenna structure. With the above method, these problems do not appear and the radiation behavior of a RFID tag can be measured as well. In that case, the antenna is mounted in a semi anechoic chamber (Fig. 3) and rotated along the axis while being excited with the transmit signal. Fig. 2a
shows the simulated and measured pattern of a conventional dipole antenna with a length of 200 mm. This length has been optimized to the chip U-Code HSL SL3 ICS3001 from X-Ident to achieve best performance. Furthermore, a RFID metal tag was measured with the above method and in addition in a regular anechoic chamber. The results are displayed in Fig. 2b. In both cases a good accordance can be seen. The advantage of the above method applied to a RFID metal tag is even much higher. For the measurement in the chamber the chip had to be cut out of the structure, a balun had to be used and the measurement cable had to be fed from behind through the metallic plate. The accuracy of the RFID antenna measurements is within 1-2 dB. Higher accuracy could be achieved, when performing the measurements completely in an anechoic chamber. However, the intention is to show that also a low cost system provides sufficient accuracy.

4. Chip-antenna alignment
Main goal in the design process of a UHF RFID transponder is to find the optimum alignment
between the chip and the antenna. The antenna impedance $Z_A$ is of course a function of the antenna structure and the environment and has to be tuned to the chip impedance $Z_C$, which is not always easy. The input impedance of modern RFID circuits is mostly given as a resistor $R$ parallel to a small capacitor $C$. Therefore, the required antenna impedance $Z_A$ has to be somewhere in the upper right part of the reflection coefficient plane. With given antenna impedance the mismatch between the chip and the antenna can be calculated. This mismatch in dB should be equal to the additional required wake up power above the wake up threshold. To proof this, the length of a dipole has been varied and the resulting mismatch $a$ referred to the chip impedance $Z_C$ was calculated. For each length of the dipole the wake up power was measured. This has been performed in the semi anechoic chamber with the dipole together with chip being mounted on a Rohacell block with low $\varepsilon_r$. Fig. 3 shows both curves. The minimum required power is achieved with a dipole length of 200 mm. This is in very good accordance with the minimum calculated mismatch at the same length. With an overall length of 190 – 210 mm the dipole impedance is quite close to the optimum matching. However, additional matching elements and a final optimization would further improve the performance of this transponder.

Especially with RFID transponders on metal surfaces this alignment is most important. In most cases those transponders are designed in such a way, that the antenna is laminated on a special rf isolating layer, which decouples more or less the antenna from the very close metal surface. Another approach is to use impedance matching layers in addition to a purely rf isolating layer. In both cases optimum impedance matching between the chip and the antenna is required in order to compensate losses resulting from the dielectric and/or magnetic layers [2]. Therefore, the above technique has been used to optimize and design such metal tags. For example, Fig. 4 shows the mismatch circles of a Higgs2 chip and the impedances of different dipole lengths on a two layered laminate. With this method, a 4.1 mm thin metal tag has been designed, which requires only 3.3 dB more wake up power compared to a transponder in free space. With special matching elements on the antenna the mismatch was minimized and optimum performance could be achieved. It is obvious, that the target area of $Z_A$ should be on the lower left side close to the matching point. However, the area right of this point should be avoided, because of the steep descent of the mismatch there.

Conclusions

In this work, a RFID measurement methodology has been presented, which allows a precise performance evaluation of RFID tags and which also gives the possibility to measure the antenna characteristics. A comparison of mismatch and transponder sensitivity was made and the impedance and mismatch behaviour of a metal tag is shown. These investigations are extremely helpful in the design process of highly effective RFID tags.

References