Gain Determination of Small UHF RFID Antenna Structures

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1. Introduction

In previous publications it has been shown that the determination of the performance and impedance of RFID tag antennas is far from trivial. In many cases, the evaluation of the antenna is derived from read range measurements. As this is strongly related to the mismatch between the chip and the antenna, information about the true antenna performance itself cannot be given. The difficulty in measuring RFID antennas are related to the fact, that they are very small and that they are mainly designed with symmetrical feeding to the RFID chip. Therefore, a standard coaxial measurement cable cannot be connected without coupling and interferences to the tag antenna. In [1] an advanced method has been proposed which requires an additional battery-powered oscillator as calibrated transmitter on the tag. This allows a quite accurate measurement but always requires the additional transmitting device. In the following, a new method is presented, which is a combination of impedance measurements of the tag antenna and the RFID chip as well as the measurement of the wakeup power of the complete tag which is compared to a reference antenna with RFID chip. In an easy way, this allows the determination of the real gain of the tag antenna with sufficient accuracy.

2. New Measurement Principle

The gain G of an antenna is defined as directivity $D\eta$, with η as efficiency factor of the antenna. Using conventional measurement equipment (e.g. anechoic chamber with turntable) the gain g (= 10 log G) of an antenna is derived from a comparison between the AUT (antenna under test) and a reference antenna (e.g. standard gain horn) with well defined gain over frequency range. With modern measurement systems a network analyzer is used and the power transfer between a test antenna with defined polarization and the AUT is measured. To obtain the correct gain value of the AUT the antenna mismatch of the AUT has to be calculated and included into the gain calculation. The new measurement principle is based on similar techniques. Instead of using a VNA the advantageous properties of the RFID chip itself can be used. This is based on the fundamental principle of the wake up behaviour of the RFID chip by electromagnetic energy. In an electromagnetic field, the chip gets activated, when the available power from the tag antenna exceeds the threshold power level of the chip. Exactly this level has to be measured and compared to the behaviour of a reference antenna with known gain. Good antenna-chip impedance matching is the decisive factor for the performance of a RFID tag. Maximum power transfer results for the case that the antenna impedance $\underline{Z}_{Ant}$ is conjugate complex to the chip impedance $\underline{Z}_C$. Otherwise mismatch between the antenna and the chip results, which reduces the available power P_C into the chip to

$$P_C = P_{Ant}\frac{\left(1-\left|\underline{r}_{Ant}\right|^2\right)\left(1-\left|\underline{r}_C\right|^2\right)}{\left|1-\underline{r}_{Ant}\underline{r}_C\right|^2}, \tag{1}$$

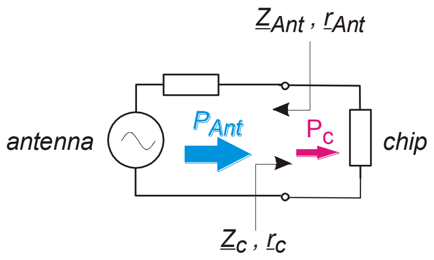

Figure 1: RFID power transfer between antenna and chip

with P_{Ant} as maximum available power from the antenna and $\underline{r}_{Ant}$ and $\underline{r}_C$ as complex reflection coefficient of the antenna and the chip respectively. Substituting the reflection coefficients in (1) by the impedances $\underline{Z}_C = R_{Chip} + jX_{Chip}$ and $\underline{Z}_{Ant} = R_{Ant} + jX_{Ant}$ the power P_C can be written as:

$$P_C = P_{Ant} \frac{4R_{Chip}R_{Ant}}{\left(R_{Chip} + R_{Ant}\right)^2 + \left(X_{Chip} + X_{Ant}\right)^2} \qquad (2)$$

The relations P_C/P_{Ant} defines the mismatch of the antenna and the chip and plays an important role for the further gain measurement procedure. Therefore, special care has to be taken on the measurements of the impedances of the antenna and the RFID chip.

2.1 Impedance measurement

Conventionally, the chip is directly measured without any special matching procedures. As RFID chips react very sensitive to the applied power, great care has to be taken on the power level of the measurement system [2]. Reason for this is the system architecture and the working principle of the chip [3]. At a certain wakeup power threshold the integrated electronic circuit gets activated. This results from the electromagnetic field strength which is harvested by the antenna and transformed directly into dc power. As the rectifier is the first stage of the chip it mainly determines the port impedance. Unfortunately, the (monolithic microwave integrated circuits) rectifier shows a strong nonlinear voltage current relationship, which means, that the chip impedance is always a function of the applied power. Thus, the accurate impedance can only be determined with the appropriate measurement power. As the power is unknown, it has to be varied. Therefore, the chip is directly connected to the measurement port of the impedance analyzer and the analyzer is operated in the power sweep mode at one single frequency (e.g. 868 MHz). Then, the threshold value is clearly visible in the curve (see Fig. 2). This has been verified with a measurement method similar to that in [2] which needs an additional signal generator.

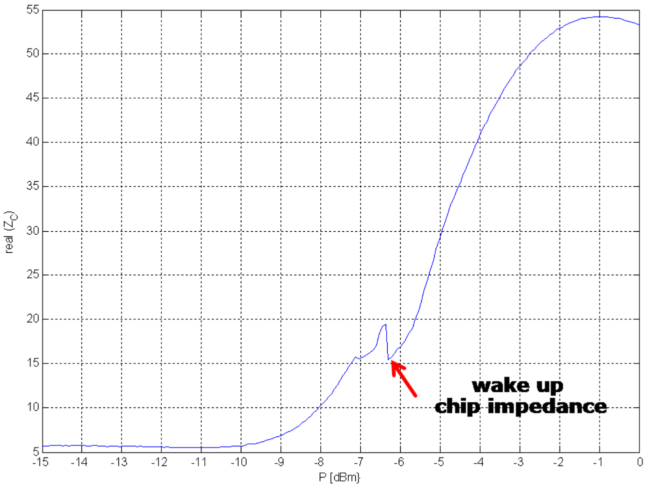

Figure 2: Real part of the chip impedance $\underline{Z}_C$ as a function of measurement power at 868 MHz

The measurement of the antenna impedance is also a very critical part in the procedure. As most of the RFID tag antennas are designed in a symmetrical form, conventional single ended measurements should not be applied. Due to the unsymmetrical coupling of the measurement cable to the symmetrical antenna cable, currents would exist and measurement errors would result. Therefore, with modern multi port network analyzers symmetrical measurements of the port impedance have to be performed. The antenna must be placed in such a way that coupling to the environment or the measurement equipment is avoided.

2.2 Measurement of the Wake Up Threshold

The fact that the chip gets activated when the applied power changes within less than a tenth of a dB, is used for the measurement principle. A RFID chip is connected to a symmetrical antenna structure (AUT) and gets activated by the incident power P. This is performed in an anechoic chamber and requires a signal generator which is ASK modulated with the start sequence of the transmit code referred to the RFID standard, i.e. EPCglobal Class1 Gen2 ISO/IEC 18000-6c. The measurement setup is displayed in Fig. 3. The output signal of the generator is steadily increased and fed to the test antenna from which it is radiated towards the AUT. Similar to the typical RFID situation the chip will be activated and starts its answering and identification process when the power at the chip exceeds the wake up threshold.

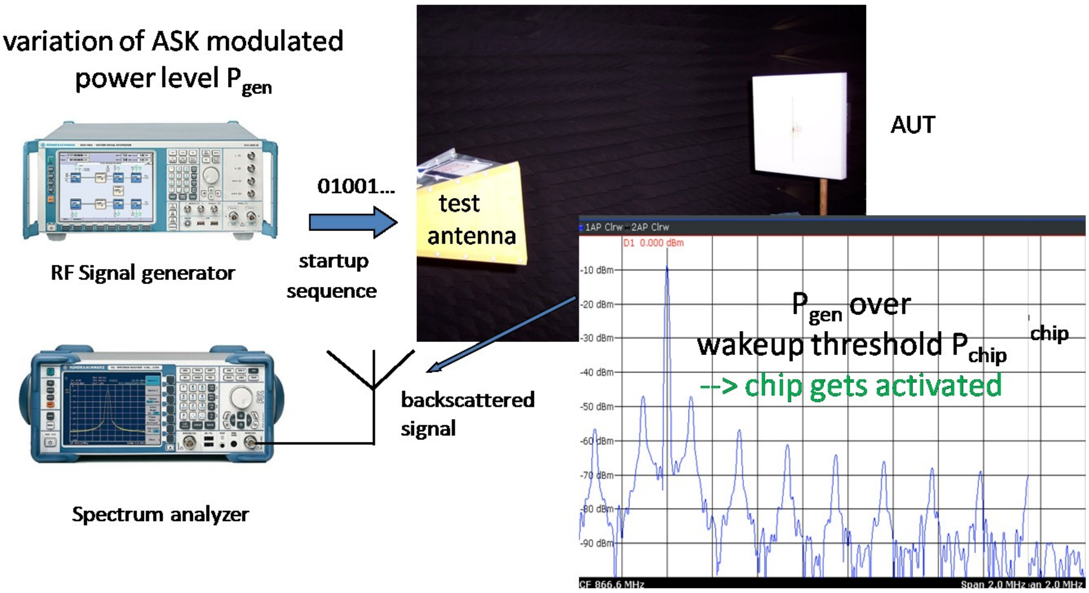

Figure 3: Measurement setup for gain measurement with answering signal of the chip

The re-modulated signal of the RFID chip shows a significant difference to the original signal and therefore the answering signal can be monitored easily by using a spectrum analyzer and a third additional receiving antenna. It changes immediately within some hundreds of dB change of the incident signal strength. Therefore the detection is very reliable. Due to the ASK modulation a clear difference can be seen in the spectrum (see Fig. 3).

2.3 Gain Determination

Similar to conventional antenna measurements the antenna gain g_{AUT} of the AUT will be determined from a comparison with an antenna with known gain. In our case, a dipole is used, which includes an RFID chip of the same type. By measurement of the required wake up power of the reference dipole a power difference P results and a comparison of both antennas is possible. The gain of the dipole has been found out by simulation and is 2.35 dB. To achieve better matching between the dipole and the chip the length of the dipole has been chosen to 195 mm, which is slightly longer than $\lambda/2$. However, the mismatch of both antennas a_{Ref} and a_{AUT} between the antennas and the RFID chip has to be included into the gain calculation. Then the gain in dBi can be given directly as:

$$g_{AUT}\,[\mathrm{dBi}] = 2.35\ \mathrm{dBi} + P\,[\mathrm{dB}] - a_{Ref}\,[\mathrm{dB}] + a_{AUT}\,[\mathrm{dB}] \qquad (3)$$

3. Measurements

To validate the above method three different antennas have been chosen. Antenna Nr. A was a meander dipole with a size of ca. 50 mm on low loss material Rogers RO4003 with $\varepsilon_r = 3.57$ and $\tan\delta = 0.0021$, antenna B was the same type of antenna on regular FR4 substrate ($\varepsilon_r = 4.3$, $\tan\delta = 0.018$) and antenna C was a small self designed RFID on metal tag antenna, which was covered with plastic with a size of (39 x 19 x 5) mm. On all antennas, including the reference dipole, the RFID chip G2XM from NXP with package style SOT886 was soldered. The

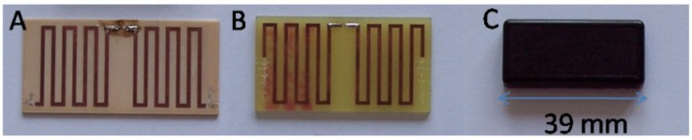

Figure 4. Antennas for gain comparison

Table 1: Measurement results, calculated gain and simulated gain at 868 MHz

antenna	**impedance [Ω]**	**P referred to dipole [dB]**	**mismatch loss to chip [dB]**	**gain [dBi]**	**gain simulated [dBi]**
Dipole	121,3 + j156,9	0	4.9	-	2.35
Meander RO4003	21,4 + j163,9	-2.4	0.1	-0.05	0.75
Meander FR4	21,8 + j155,9	-1.6	0.2	-0.75	-0.4
Metall tag (on plate)	6,3 + j136,5	+4.4	4.1	-2.85	-4.7

measured impedance of the chip was (16 – j160) Ω. Table 1 shows the values of the impedance and power level measurements of the different antennas and the simulated values of the dipole. With (3) the gain of the different antennas could be calculated. It is displayed in table 1. It can be seen that the gain of the meander dipole is ca. 2 dB lower than that of the reference dipole. Additional losses appear, when the antenna is mounted on FR4. In comparison, the metal tag antenna, which is also realized with FR4 and which is embedded in plastic mould shows a further degradation of the antenna gain. This results from the small antenna structure but also from the lossy plastic mould around the antenna. Further simulations have been made to prove the new method. As simulation tool EMPIRE [4] has been used. The simulated values show a small difference to the measured values. However, the difference of the values of the meander antennas is almost the same. The simulation of the metal tag antenna provides a bigger difference. Most critical part here is the precise knowledge of the material parameters. This mainly influences the simulation results. Overall, a quite good agreement between measurement and simulation can be found.

4. Conclusions

The presented method provides a new way to measure the gain of small tag antennas. No additional cables must be connected, only a reference RFID chip with reference dipole is required. Therefore, this method allows measurements of the real tag antenna performance in the true environment, even on lossy materials, e.g. on small packages or objects. The method seems to be accurate enough and the results are similar to standard antenna measurements but more practical due to the advantage of a cable free measurement. Further investigations will be made to compare the method and to improve the accuracy furthermore.

References

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