Threshold Power-based Radiation Pattern Measurement of Passive UHF RFID Tags

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Abstract—This paper is concentrated on explaining threshold power-based radiation pattern measurement of passive ultra-high frequency (UHF) radio frequency identification (RFID) tags. This measurement technique is wireless and the tag is measured in active state, i.e., in operation with the microchip. Information about the radiation pattern of an RFID tag is important in analyzing the strongest operation directions of the tag both in air and attached to identified objects. In this paper we present examples of measured radiation patterns of a passive UHF RFID tag.

1. INTRODUCTION
Measuring the radiation pattern of passive ultra-high frequency (UHF) radio frequency identification (RFID) tags is challenging due to the special characteristics of RFID systems. Traditional antenna measurements where cables and matching circuits are attached to antennas are not recommendable because attaching cables affects the properties of tag antennas. In addition, these kinds of measurements do not give proper information about the functioning of the tag. Therefore, novel and contactless radiation pattern measurement systems have been proposed to be used in RFID tag antenna radiation pattern measurement [1–3]. In this paper, we will measure tag’s radiation pattern with threshold-power based method in active mode, i.e., when the tag is characterized in operation with the microchip.

Radiation pattern measurement of RFID tags is important in characterization of tag functioning. Similarly as the traditional antenna radiation pattern measurement, it gives information about the best radiation directions of the tag. More importantly, radiation pattern of a tag can be measured when the tag has been attached to the identified object. This way the effect of the identified material on the radiation pattern of the tag can be verified.

Figure 1 presents the components of a passive UHF RFID system. The operation abilities of passive UHF RFID systems depend mainly on two fundamental operational principles of passive UHF tags [3]:

1. The capability of the tag for wireless energy collection from the reader, i.e., tag’s energy harvesting. This depends on the impedance matching between the tag’s antenna and the microchip and the microchip’s sensitivity. The energy harvesting information provides factors that define a minimum transmission power level for the reader unit to turn the tag on over a certain reading distance, i.e., tag’s threshold power.

2. The strength and clarity of desired backscattered signal from the tag, i.e., the radar cross section (RCS) properties of the tag.

Figure 1: Components of a passive UHF RFID system.
First operational principle describes the quality of forward communication link whereas the second one defines the properties of the reverse link. In addition to the tag’s backscattering properties, the reader unit’s receiver sensitivity is a strong defining factor in the reverse link.

The radiation pattern of an RFID tag can be measured based on these two fundamental operational principles analyzing the forward and reverse communication links [3]. In practice, the forward link limits the read range of passive UHF RFID systems. Therefore, in this paper we concentrate on threshold-power based radiation pattern measurement of passive UHF RFID tags. Threshold power-based technique is demonstrated in measuring $E$ and $H$ plane radiation patterns of an RFID tag in air and on a package containing metallic cans.

2. THRESHOLD POWER AND FORWARD LINK OF THE RFID SYSTEM

As stated in Introduction, threshold power of an RFID tag can be defined as the minimum transmission power required to activate the tag and to receive a response to ID query at a certain frequency and distance from the transmitter antenna. Introduction chapter also states that the forward link communication typically limits the read range of passive UHF RFID systems. This statement can be analyzed with the following measurement results and RFID system characteristics.

Typical sensitivity of an RFID microchip can nowadays be around $-14 \text{ dBm}$ [4]. Sensitivity of the receiver of the reader unit can be around $-80 \text{ dBm}$ [5]. We measured the threshold power level and backscattered power of a typical, dipole-type tag [6] at 4 m measurement distance and we got the following results: 22 dBm for threshold power and $-50 \text{ dBm}$ for backscattered power. In the case of the used measurement set up, 27 dBm is the maximum allowed transmitted power. From these results we can see that at the 4 m measurement distance, there is a 5 dB safety margin in the forward link whereas in the reverse link there is a 30 dB safety margin. This shows that the forward link runs out of transmitted power first when the measurement distance is further increased and therefore the forward link limits the achievable read range of passive UHF RFID systems.

3. DEFINING THE RADIATION PATTERN BASED ON THRESHOLD POWER MEASUREMENTS

Normalization of RFID tag radiation patterns differs from the process used in conventional antenna measurements where the maximum power is used as a reference power level [7]. In the case of threshold power-based measurement, the results cannot be normalized to the maximum threshold power because it presents the worst result. The results have to be normalized and plotted as a function of angle using the minimum threshold power and the following calculation technique.

When the received power is defined to be the sensitivity of the microchip, the Friis transmission formula [8] can be presented as

$$P_{IC,th} = G_{TX}G_{tag}L\left(\frac{\lambda}{4\pi R}\right)^2 P_{t,th}$$

where $P_{IC,th}$ is the sensitivity of the microchip, $G_{TX}$ is the gain of the transmitter antenna, $G_{tag}$ is the gain of the tag antenna, $L$ is attenuation factor including cable loss, polarization loss etc., and $P_{t,th}$ is transmitted threshold power.

In the above equation, only $P_{t,th}$ and $G_{tag}$ are functions of an angle. Other factors remain constant and can be expressed with $K$. Based on these definitions, $G_{tag}$ can be defined as

$$G_{tag} = \frac{P_{IC,th}}{G_{TX}L\left(\frac{\lambda}{4\pi R}\right)^2 P_{t,th}} = K \frac{1}{P_{t,th}}$$

For normalizing the tag’s gain the minimum threshold power, $P_{th,min}$, should be used as a reference power value. Normalized gain of the tag can then be written as

$$G_{tag,\text{norm}} = \frac{(K/P_{t,th})}{(K/P_{th,min})} = \frac{P_{th,min}}{P_{t,th}}$$

$$G_{tag,\text{norm}} (\text{dB}) = P_{th,min} (\text{dBm}) - P_{t,th} (\text{dBm})$$
4. MEASUREMENT SET-UP

Tagformance measurement system [9] was used in the threshold power measurements carried out for this study. Tagformance system allows power ramping at a defined frequency and thereby threshold power analysis. The core operations of this system are performed with vector signal analyzer. Measurements were carried out in a compact measurement cabinet, inside of which is presented in Figure 2. Measurement distance was 0.45 m and measurement frequency was 866 MHz, which is the UHF RFID band center frequency in Europe. Gain of the transmitter and receiver antenna in the measurement system was 8.5 dBi.

Figure 3 presents the measured commercial dipole-type tag [10] on a Styrofoam (in-air measurement) and Figure 2 mounted on a package of metallic cans. The purpose of this measurement was to study the effect of metallic material in the vicinity of the tag on its radiation pattern. There was an approximately 5–7 mm air gap between the tag and the metallic cans, which is sufficient to enable operation of a dipole tag in the vicinity of metallic surface [11].

5. MEASUREMENT RESULTS

Figure 4 presents the measured radiation patterns in air (Free-space) and on the six-pack of metallic cans. The results show that in air both the $E$ and $H$ plane radiation patterns of the measured tag are symmetrical and in agreement with the expected dipole antenna radiation pattern. However, when the dipole-type tag is attached to the six-pack of metallic cans, changes can be seen in the radiation pattern. Figure 4 shows that there is distortion in the $E$ plane radiation pattern due to reflections of the electromagnetic wave from the metallic surface. In addition, the shape of the $H$ plane pattern has changed from the in-air omnidirectional pattern to a directive pattern with a back lobe. This is also due to the reflections of the electromagnetic wave from the metallic surface.

![Figure 2: Measurement cabinet and the measured tag on six-pack of cans.](image1)

![Figure 3: The measured tag [10].](image2)

![Figure 4: Measured $E$ and $H$ plane radiation patterns in air (free-space) and on six-pack of metallic cans.](image3)
6. CONCLUSION

In this paper, we present a threshold power-based radiation pattern measurement technique for passive UHF RFID tags. This measurement method is contactless, which means that no extra cables need to be attached to the tag antenna. The tag is measured wirelessly in active mode, i.e., in operation with the microchip. Forward and reverse links of an RFID system are analyzed and a calculation technique for the radiation pattern is presented. This technique is based on Friis transmission equation and normalization with minimum threshold power level. Measured radiation pattern of a commercial RFID tag is presented and the effects of metallic material on the shape of the radiation pattern are analyzed.

REFERENCES