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# Measurement of RCS and reading range of UHF tags in free space and with wood support

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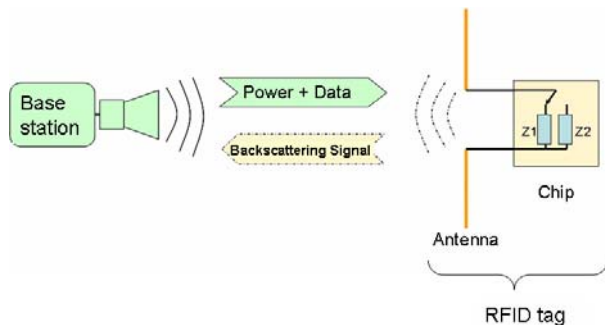
**Abstract**—This communication introduces measurement results of Radar Cross Section (RCS) of UHF passive tags. The RCS theory and its relationship with the reading range of tags are explained. We studied the influence of tag support, particularly those made of wood. Finally, we found that RCS is a good parameter to determine homogeneity of multiple tags of the same industrial mass production.

**Index Terms**— homogeneity of a mass produced series, Radar Cross Section, reading range, UHF tags.

## I. INTRODUCTION

THE increased use of Radio Frequency Identification (RFID) systems for automated object identification on supply chains has created a need for more requirements to ensure the accuracy of the systems. Systems' functions must remain unaffected by environments, packaging and product materials that can impact the performance of the RFID systems.

A typical passive RFID system consists of a RFID tag and a RFID reader, also called a base station. These two elements



communicate by electromagnetic waves sent through the air. The principle of such systems is presented in Figure 1.

Figure 1 : Principle of a passive RFID system

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To modulate the backscattered signal the tag switches its input impedance between two states, which can be identified as an amplitude modulation. For each impedance state, the RFID tag presents a certain RCS. The difference provided between the high and low impedance backscattered signal is called differential RCS and is noted  $\Delta$ RCS.

The chip impedance varies from company to company and the chip is directly connected to an antenna and packaged by manufacturers. For this reason, more realistic measurement results can be obtained if the measurements are done with a no-contact method after IC assembly [1].

One of the main parameters allowing the characterization of an inlay tag is its Radar Cross Section (RCS). Measuring RCS as a function of frequency allows the resonant frequency, the bandwidth and the reading range of the tag, to be determined. It is demonstrated [2], [3] that the setting limit of the reading range is the tag's capacity to power up its passive chip rather than the reader's ability to detect backscattering signals modulated by the tag.

In this paper, we discuss the relationship between reading distance and RCS of RFID passive tags, and we present data from experiments with different tags placed on neutral or disturbing supports such as wood.

## II. RELATIONSHIP BETWEEN RCS AND READING RANGE

### A. Power received by the tag

The power  $P_{tag-R}$  collected by the tag antenna is defined as the product of the incident power density and the effective aperture of the tag antenna.

$$P_{tag-R} = S_i \cdot A_{e\_tag} \quad (1)$$

$$\text{with } A_{e\_tag} = \frac{\lambda^2}{4\pi} G_{tag} \quad (2)$$

$$\text{and } S_i = \frac{P_{reader-T} \cdot G_{reader}}{4\pi R^2} \quad (3)$$

where  $P_{reader-T}$  is the power transmitted by the reader,  $G_{reader}$  is the gain of the reader antenna and  $R$  is the distance between the reader and the tag.

RFID antenna designers use conjugate matching methods to obtain high power transmission between the antenna and the

chip of the tag. The mismatch between antenna and chip impedance is given by the modified reflection coefficient  $\Gamma^*$  expressed as follow [3]:

$$\Gamma^* = \frac{Z_a^* - Z_l}{Z_a + Z_l} \quad (4)$$

$Z_a = R_a + jX_a$  is the complex antenna impedance and  $Z_l = R_l + jX_l$  is the complex load impedance.

We can calculate part of energy transferred to the chip and the one backscattered as a function of the reflection coefficient.

### B. Power transferred to the chip of the tag

We define the power transmission coefficient  $\tau$  as follow:

$$\tau = 1 - |\Gamma^*|^2, \quad 0 \leq \tau \leq 1 \quad (5)$$

$$\tau = \frac{4R_l R_a}{|Z_l + Z_a|^2} \quad (6)$$

Thus, we can calculate the power transmitted to the chip of the tag as a function of power received by the tag:

$$P_{tag-chip} = P_{tag-R} \cdot \tau \quad (7)$$

$$P_{tag-chip} = P_{reader-T} \cdot G_{reader} \cdot G_{tag} \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \cdot \frac{4R_l R_a}{|Z_l + Z_a|^2} \quad (8)$$

The table 1 shows values of transmission coefficients for typical values of the chip impedance.

TABLE 1  
VALUE OF TRANSMISSION COEFFICIENT FOR DIFFERENT VALUES OF THE CHIP IMPEDANCE

	$Z_l$	$\Gamma^*$	$\tau$
SHORT	0	-1	0
OPEN	$\infty$	1	0
MATCH	$Z_a^*$	0	1

We clearly see in expression (5) that an efficient way to expand both the power received by the chip and the reading range of the tag, is to improve the matching between the tag's antenna and its chip.

### C. Power backscattered by the tag

We define the backscattering coefficient  $K$  as follow:

$$K = |1 - \Gamma^*|^2, \quad 0 \leq K \leq 4 \quad (9)$$

$$K = \frac{4R_a^2}{|Z_l + Z_a|^2} \quad (10)$$

And so, we can calculate the power backscattered as a function of power received by the tag:

$$P_{tag-back} = P_{tag-R} \cdot K \quad (11)$$

$$P_{tag-back} = P_{reader-T} \cdot G_{reader} \cdot G_{tag} \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \cdot \frac{4R_a^2}{|Z_l + Z_a|^2} \quad (12)$$

TABLE 2  
VALUE OF TRANSMISSION COEFFICIENT FOR DIFFERENT VALUES OF THE CHIP IMPEDANCE

	$Z_l$	$\Gamma^*$	$K$
SHORT	0	-1	4
OPEN	$\infty$	1	0
MATCH	$Z_a^*$	0	1

The expressions (9) and (12) show that power backscattered by the tag is dependent on the matching between the tag's antenna and its chip.

From tables 1 and 2 we see that power transmitted to the chip is maximized when the chip's impedance is matched to the tag's antenna, and thus the reading range is improved. In this case, we also note that the power transferred to the chip and the power backscattered by the tag are equal. So, it can be concluded that in match cases, Radar Cross Sections of the tag are directly linked to their reading ranges.

## III. MEASUREMENT

### A. Protocol

As discussed in [3], a vectorial network analyzer and a reference antenna allow us to measure the RCS and the experimental setup shown in Figure 2.

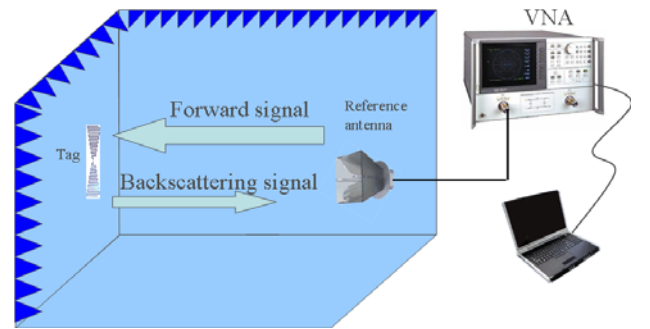


Figure 2 : Experimental setup to measure RCS in anechoic chamber

If the same antenna is used for both the receiver and the transmitter, the tag radar cross section can be calculated from the measured return loss as:

$$\sigma = |S_{11}|^2 \frac{(4\pi)^3 R^4}{G_T^2 \lambda^2} \quad (13)$$

with  $G_T$  the gain of the reference antenna and  $R$  the distance from the reference antenna to the tag.

Measurements are taken in an anechoic chamber (4\*4 m<sup>2</sup>). We used a HP8720D Vectorial Network Analyzer which

outputs a power level up to 5 dBm and band-width between 50 MHz and 20 GHz. We used a linear vertically polarized horn antenna as the antenna reference.

We measured different inlay tags. Each one was designed to work in free space and was disturbed by materials such as wood. We took two kinds of measurements. The first was a study of the RCS of the tags in free space or close to wood; we compared the reading distance. In the second, we studied the variation of the RCS of a series of mass produced tags.

*B. RCS measurements for different tags*

In this section, we present the measurement results of the RCS of different UHF Gen2 commercialized tags (Figure 3). The Figure 4 presents measurements of reading ranges of these tags. The reading range is calculated as a function of the minimum power transmitted by the reader allowing tag activation according to frequency for a determined distance.

The table 3 presents the measurement results of the RCS and reading ranges at 868 MHz.

TABLE 3: MEASUREMENT RESULTS OF RCS AND READING RANG AT 868 MHZ

868 MHz	Tag 1	Tag 2	Tag 3
RCS (sm)	0.0680	0.0210	0.0130
Reading range (m)	7	6.3	4.5

We can compare the RCS to the reading range measured with these tags. The reading ranges and RCS of the tags are linked: the higher the RCS, the higher the reading range.

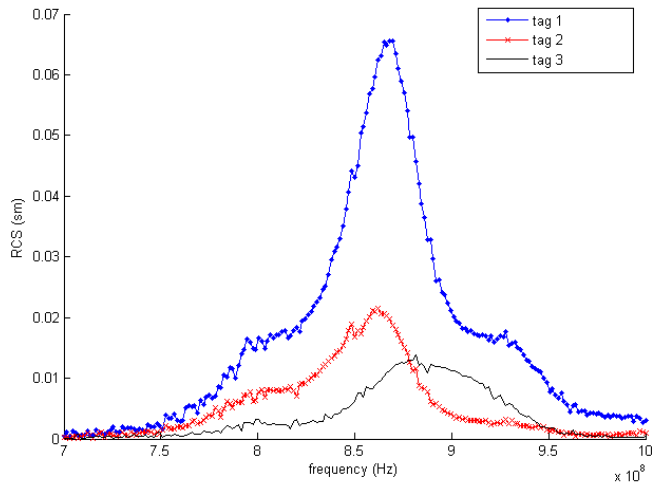


Figure 3 : RCS of UHF Gen2 commercialized tags

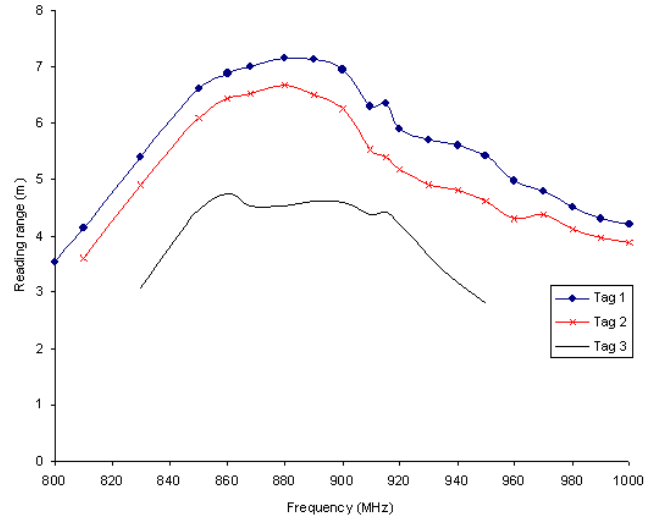


Figure 4 : Reading distance of UHF Gen2 tags

*C. Measurement of a tag placed on wood*

In this section, we compared RCS (Figure 5) and reading ranges (Figure 6) of a tag in free space or on a wood support.

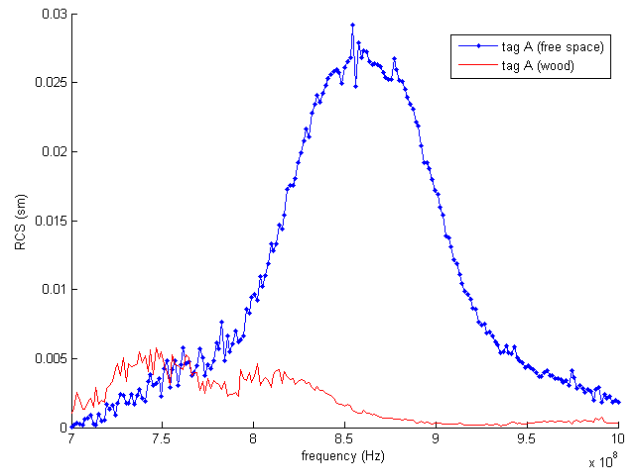


Figure 5 : RCS of tag A in free space and close to wood

As expected the RCS and the reading range decreased when the tag was placed on wood. In fact, the resonant frequency was translated to lower frequencies and the impedances of the antenna and the chip were mismatched.

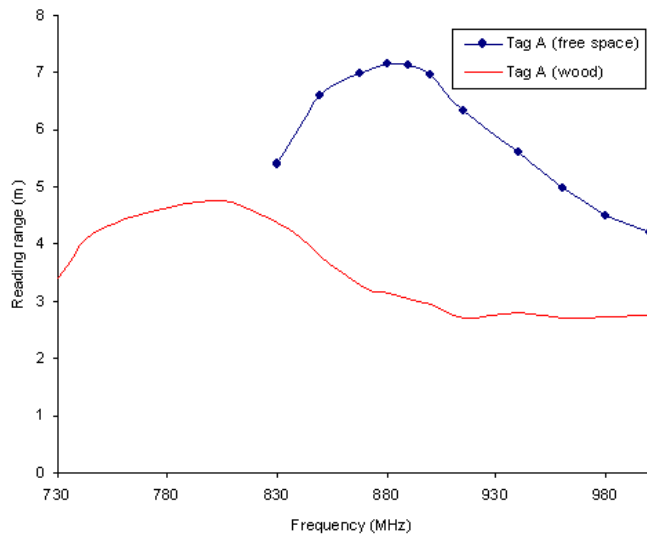


Figure 6 : Reading range of tag A in free space and on wood

**D. RCS measurements of multiple tags of the same mass production**

We found that RCS is a key parameter in determining the performance of the tag. Nevertheless, it does not suffice to only measure one because depending on the type of tag, RCSs from the same mass produced series can vary greatly.

The Figure 7 shows a series of stable tags, whereas Figure 8 presents a series of unstable tags.

The results indicate that we must test a sufficient number of tags in order to average the results and determine the worst case.

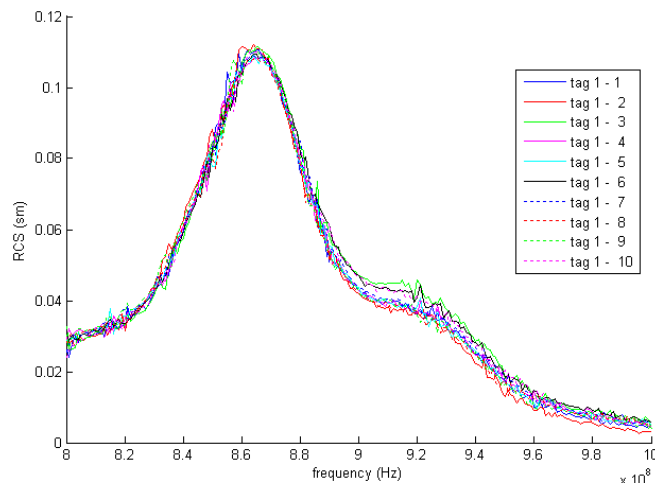


Figure 7 : Series of stable tags' RCSs

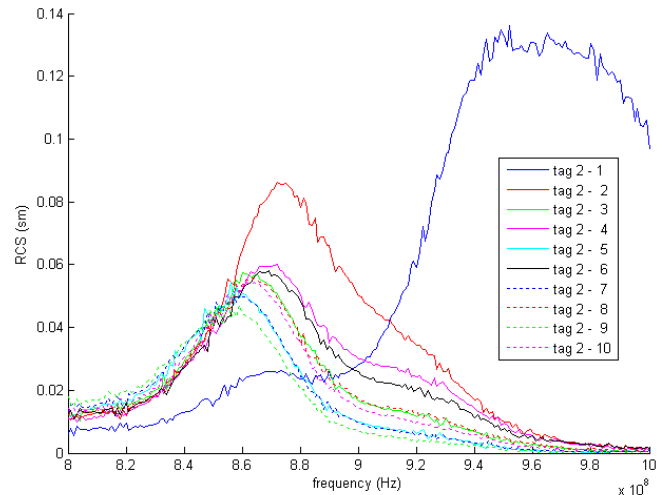


Figure 8 : Series of unstable tags' RCSs

**IV. CONCLUSION**

We presented theoretical relationships between the RCS and the reading range of a tag. We described an experimental method of measuring a tag's RCS using a vectorial network analyzer connected to an antenna in an anechoic chamber with the tag inside. Measurements were performed using a RFID tag operating in the UHF band.

We also demonstrated that the reading range varies according to the RCS of the tag in the matching case. We determined the homogeneity of multiple tags of a same mass produced series. The results show that the homogeneity of the tags may vary from one to another within the same series.

The support influences the resonance frequency of the tags. In this case, the resonance frequency varies when the tag is placed on wood.

In following studies, we would like to study the effects of materials such as bottle of water or a bottle of wine on tag accuracy.

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