MEASUREMENT OF BACKSCATTERING FROM RFID TAGS

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ABSTRACT

This paper presents a method for measuring signal backscattering from an RFID tag and calculating tag radar cross-section (RCS), which depends on the chip input impedance. We present a derivation of a theoretical formula for RFID tag radar cross-section and an experimental RCS measurement method using a network analyzer connected to an antenna in an anechoic chamber where the tag is also located. The return loss of the antenna measured with and without the tag present in the chamber allows one to calculate the power backscattered from the tag and find tag RCS. Measurements were performed in anechoic chamber using RFID tag operating in UHF band. Tag RCS was also calculated theoretically using tag impedance and gain obtained with electromagnetic simulation software. Theoretical results were found to be in good agreement with experimental measurements.

Keywords: Antenna Measurements, RCS Measurements, Radio Frequency Identification (RFID)

1. Introduction

Radio frequency identification (RFID) is a rapidly developing technology [1]. Figure 1 illustrates the operation of passive RFID system.

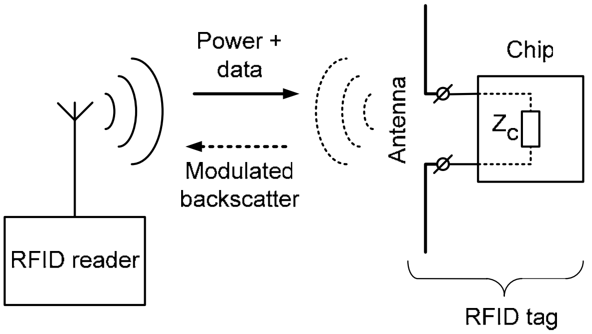

Figure 1 - Passive RFID system using modulated backscatter.

A typical RFID tag consists of an antenna and an integrated circuit (chip), both with complex impedances. The chip obtains power from the RF signal transmitted by the base station (called "RFID reader"). RFID tag antenna is loaded with the chip whose impedance switches between two impedance states, usually high and low. At each impedance state, RFID tag presents a certain radar cross section (RCS). The tag sends the information back by varying its input impedance and thus modulating the back-scattered signal.

2. Theory of RFID Tag Radar Cross-Section

Let us understand how RFID tag radar cross-section can be derived. Consider the tag equivalent circuit shown in Figure 2, where the antenna is represented with its Thevenin equivalent circuit.

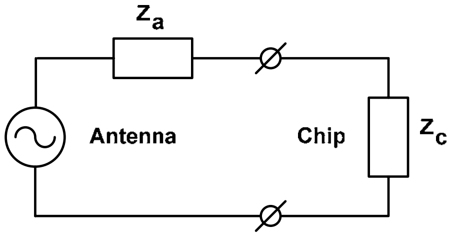

Figure 2 - Passive RFID system using modulated backscatter.

In Figure 2, $Z_a = R_a + jX_a$ is the complex antenna impedance and $Z_c = R_c + jX_c$ is the complex chip (load) impedance. Chip impedance may vary with the frequency and the input power to the chip.

Recently there appeared discussions about limitations of using this equivalent circuit [2-6] for loaded antennas in receiving and transmitting mode. However the circuit shown in Figure 2 has been successfully used by engineers for various antenna problems [7]. We show that this simple circuit can be used as is for calculating the power backscattered by small thin wire antennas (which represent a large class of RFID tag antennas) and that the results are consistent with findings by other authors.

The power scattered back from the loaded antenna can be divided into two parts [8-10]. One part is called "structural mode" and is due to currents induced on the antenna when it is terminated with complex conjugate impedance. Second part is called "antenna mode" and is due to mismatch between antenna impedance and load impedance.

The total backscattered field can also be written as the field scattered by the open-circuited antenna plus the re-radiated field [11]. Re-radiated power can be obtained from the equivalent circuit shown in Figure 2. According to that circuit, an open-circuited antenna doesn't re-radiate any power. The antenna may still scatter back some power but for many antennas used in UHF RFID tags this amount is typically small compared to the power scattered back by the same antenna terminated with the complex conjugate matched load.

The power density of electromagnetic wave incoming to RFID tag antenna is given by

$$S = \frac{P_t G_t}{4\pi r^2} \tag{1}$$

where G_t is the gain of the transmitting antenna, $P_t G_t$ is the equivalent isotropic radiated power (EIRP) and r is the distance to the tag. The power collected by the antenna is given by

$$P_a = S A_e \quad , \tag{2}$$

where A_e is the effective area of RFID tag antenna. The power given above is the maximum power that can be delivered to the complex conjugate matched antenna load.

The power re-radiated by an RFID tag in the direction of the transmitting antenna is given by the power dissipated in the antenna resistance multiplied by the tag antenna gain *G*:

$$P_{re-radiated} = S A_e \frac{4R_a^2}{|Z_a + Z_c|^2} G \quad . \tag{3}$$

The factor that determines how much power is re-radiated is given by

$$K = \frac{4R_a^2}{|Z_a + Z_c|^2} \quad . \tag{4}$$

Table 1 gives values of K for several most interesting cases of antenna load (chip) impedance.

Z_c	0	Z_a^*	∞
K	$\frac{4R_a^2}{R_a^2 + X_a^2}$	1	0

Table 1 – Values of *K* for different antenna load impedances.

An antenna loaded with complex conjugate impedance load re-radiates the same amount of power as gets absorbed in the load. If antenna impedance is purely real, short-circuited antenna re-radiates back four times as much power as complex conjugate matched one.

However, when antenna impedance is sufficiently reactive ($X_a / R_a > \sqrt{3}$), complex conjugate loaded antenna re-radiates back more power than the short-circuited antenna as it is illustrated in Figure 3.

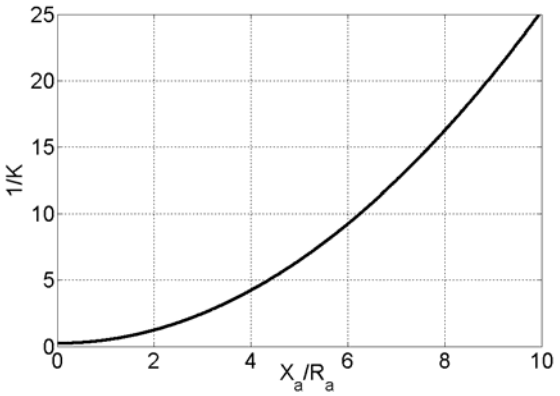

Figure 3 – The power re-radiated by the complex conjugate loaded antenna normalized by the power re-radiated by the same short-circuited antenna as a function of antenna reactance to resistance ratio.

The radar cross-section of the tag can be calculated as

$$\sigma = A_e \frac{4R_a^2}{|Z_a + Z_c|^2} G \quad . \tag{5}$$

This result agrees with the result that was obtained by Harrington [12] using a different derivation.

The effective area of the antenna can be expressed as

$$A_e = \frac{\lambda^2}{4\pi} G \quad . \tag{6}$$

The RFID tag radar cross-section can thus be expressed as

$$\sigma = \frac{\lambda^2 G^2 R_a^2}{\pi |Z_a + Z_c|^2} \quad . \tag{7}$$

This expression agrees with the RCS of antenna loaded with arbitrary load given in terms of reflection coefficient by other researchers for antennas with structural scattering constant close to unity [9-10].

3. Measurement Methodology and Results

There exist various techniques for measuring radar cross-section of loaded antennas [10, 13, 14]. These techniques typically involve RF transmitter and receiver with separate antennas and appropriate RF hardware including decoupling equipment. We propose a simple method of measuring radar cross-section of RFID tag using the network analyzer method shown in Figure 3.

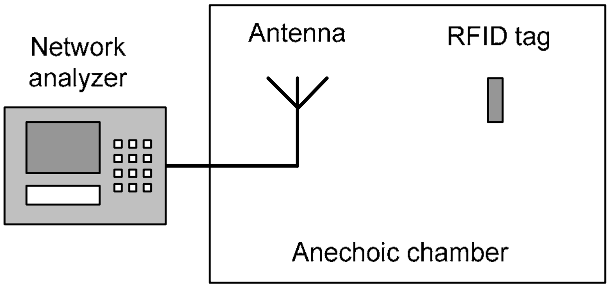

Figure 4 – Measurement setup for determining radar cross-section of an RFID tag.

The return loss of the transmitting antenna is first measured for empty anechoic chamber without an RFID tag. The measured value includes the effects of transmitting antenna mismatch and anechoic chamber multipath. It will be used as a reference level and will be subtracted from the return loss measurements when the tag is present in the chamber. This allows one to calculate the power backscattered from the tag and find the RCS of RFID tag.

We performed the measurements in anechoic chamber using a 6.2 dBi linearly polarized transmitting antenna connected to the HP8719C network analyzer with 3m long coaxial cable. Figure 6 shows the measured return loss before and after calibration. No RFID tag is present inside the chamber in this case. Maxima and minima observed before calibration are due to standing waves.

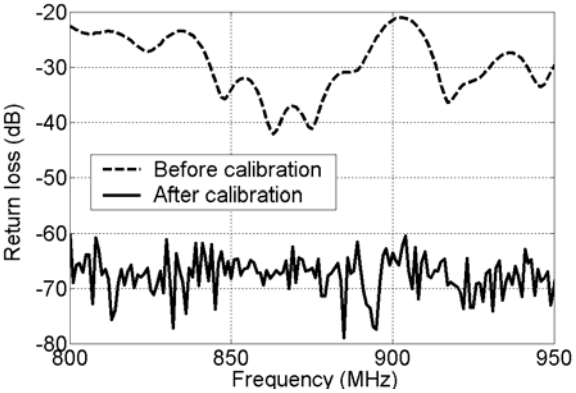

Figure 6 – Antenna return loss measured in empty anechoic chamber before and after calibration.

The power backscattered from the tag can be calculated from the classical radar equation [15] as:

$$P_{backscattered} = \frac{P_t G_t^2 \lambda^2 \sigma}{(4\pi)^3 r^4}, \tag{8}$$

where G_t is the gain of the antenna connected to the network analyzer. The return loss measured after the reference level calibration can be approximated as

$$|S_{11}|^2 \approx \frac{P_{backscattered}}{P_t} = \frac{G_t^2 \lambda^2 \sigma}{(4\pi)^3 r^4}. \tag{9}$$

Hence, the RFID tag cross-section can be calculated from the measured return loss as

$$\sigma = |S_{11}|^2 \frac{(4\pi)^3 r^4}{\lambda^2 G_t^2}. \tag{10}$$

We performed the measurements using RFID tag developed by Intermec and shown in Figure 5.

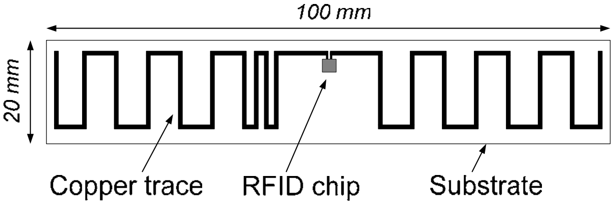

Figure 5 –RFID tag used in measurements.

The tag antenna was small meander dipole etched in 0.7 mil copper on a 2 mil polyester substrate with a dielectric permittivity of 3.5. RFID ASIC chip was mounted directly on antenna terminals. Figure 7 shows measured and modeled backscattered signal from this RFID tag which agree well. The tag was located inside the chamber approximately 0.5 m away from the transmitting antenna.

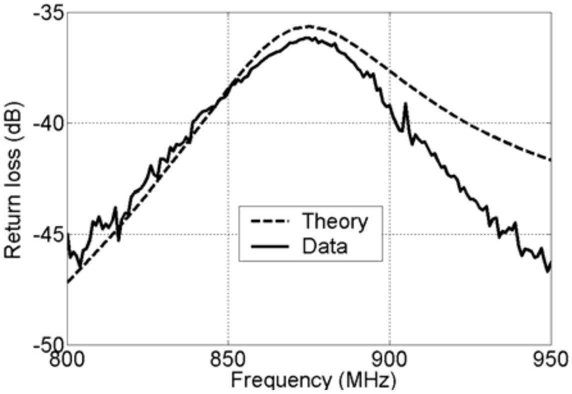

Figure 7 – Antenna return loss measured in anechoic chamber with RFID tag present.

The theoretical return loss was calculated from Equation (9) where tag antenna impedance and gain necessary to find RCS were obtained from electromagnetic simulations using Method of Moments program and the chip impedance was measured experimentally.

The RFID tag resonated in free-space at the frequency of approximately 875 MHz where antenna gain was 1.65 dBi and antenna impedance was 60+j360 Ohm. The antenna impedance was highly reactive (one section of the meander was further meandered for additional inductance) to provide a better matching for the highly capacitive chip impedance, which was measured to be 12-j410 Ohm at the resonant frequency for the power level in experiment.

For the impedance values given above, the RFID tag antenna loaded with chip scattered back at 875 MHz approximately 10 times more power than when it was short-circuited. The peak theoretical value of RCS of the RFID tag calculated from Equation (7) was approximately 0.04 sq. m. (-14 dBsqm) at 875 MHz which agreed within 10% with the measured value of RCS calculated from Equation (10).

4. Summary

The goal of this paper was to demonstrate how to measure the backscattered signal and calculate the radar cross-section for RFID tags. We presented a theoretical formula for RFID tag RCS and described an experimental method of measuring tag RCS using a network analyzer connected to an antenna in an anechoic chamber with the tag inside. Measurements were performed using RFID tag operating in UHF band. The measurement method was validated by numerical modeling of the RFID tag antenna and calculating its theoretical RCS which agreed well with experimental results.

5. REFERENCES

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6. ACKNOWLEDGMENTS

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