Communication

Differential RCS of Modulated Tag

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***Abstract*—Differential RCS characterizes the aptitude of a tag to modulate the backscattered power. This parameter is classically estimated based on the variation of the IQ channels in the time domain. This paper introduces a generalization of the RCS backscattered by a tag and a new definition of the delta RCS in the frequency domain. The analytical model is based on schochastic processes and allows to estimate the delta RCS from the power spectral density of the modulated signal backscattered by the tag. The associated measurement is compared to the classical time domain based methods. Results shows a good agreement with a difference between the different approaches less than 0.5 dB. Finally, the proposed method relies on simple synchronization between the emitter and receiver to estimate the delta RCS while maintaining the accuracy.**

***Index Terms*—Electromagnetic scattering, loaded antennas, modulation, radar cross section, radio frequency identification.**

I. Introduction

SINCE the development of the RFID technology, different performance metrics have been introduced to determine and/or compare the characteristics of UHF RFID tags. For passive tags, read range is mainly limited by the forward link, thus tag sensitivity, which is the minimum received power needed to activate the tag, is the most popular metric. However, for semi-passive tags or high performance passive chips, read range is not limited by the activation power but by the reader sensitivity. In this case, the delta RCS is the preferred metric to characterize the performance of the tag.

The differential RCS (or delta RCS) has been introduced in [1] and characterizes the aptitude of a tag to modulate the backscattered power. Several approaches have been developed to measure this quantity [1]–[3]. All these methods operate in the time domain by estimating the variations of the backscattered signal. In [1], authors determine the delta RCS by measuring the RMS AC voltage of the tag response. This method provides an high accuracy but requires a complex synchronization between the emitter and receiver since the receiver has to use the same local oscillator as the emitter. Authors in [2] and [3] provide a different method based only on the difference in distance in the complex plane between the two states of the chip. This principle leverages the phase synchronization but suffers from a lower accuracy since delta RCS is only estimated using two complex samples and not a continuous acquisition like in [1].

This paper presents a new approach for the derivation and the measurement of the delta RCS. The tag response is modeled as a stochastic process and decomposed into a constant and a variable part. We show that the delta RCS can be expressed as a function of the variable part of the response in the frequency domain. Based on these results, the proposed method allows to measure the delta RCS of any tag using classical laboratory instruments (*i.e.*, a vector signal generator and a spectrum analyzer) and does not require phase synchronization between the instruments as in [1] (in practice a single trigger is used). Also the accuracy of the method is improved compared to [2] or [3] since the delta RCS is computed over the entire acquisition window of the instrument.

The paper is organized as follows: Section II presents the analytical model and highlights a slight difference with the classical definition of the delta RCS introduced in [1]. Section III describes the tag and the measurement bench used to estimate the delta RCS with the proposed approach and presents a comparison with the existing methods. Finally, Section IV concludes the paper.

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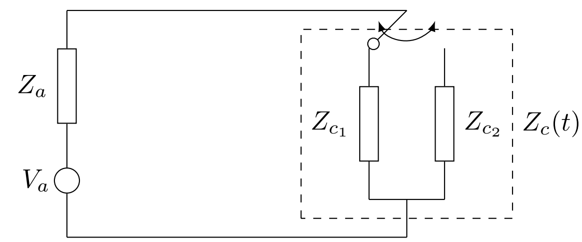

Fig. 1. Equivalent circuit of a minimum scattering antenna loaded by a RFID chip.

II. Analytical Formulation

As previously explained, the modulation done by the tag actually modifies the backscattered power received by the reader. From the total power backscattered by the tag, the definition of the differential RCS in both time and frequency domain is derived using stochastic processes. Analytical expressions can be obtained for any binary modulation scheme and transmitted data.

A. Time Domain

Like in [1], we model the RFID tag as a minimum scattering antenna. These antennas has a maximum RCS for short circuit load and do not reflect any power for open circuit load. They can be described by the simple circuit presented in Fig. 1 where Z_a is the impedance of the antenna and Z_c the impedance of the load (chip). Note that the backscattered power corresponds to the power dissipated in R_a (which is the real part of Z_a). If the tag is modulating, the value of Z_c is switched between the two complex impedance states (Z_{c_1} and Z_{c_2}) with associated power wave reflection coefficient Γ_1

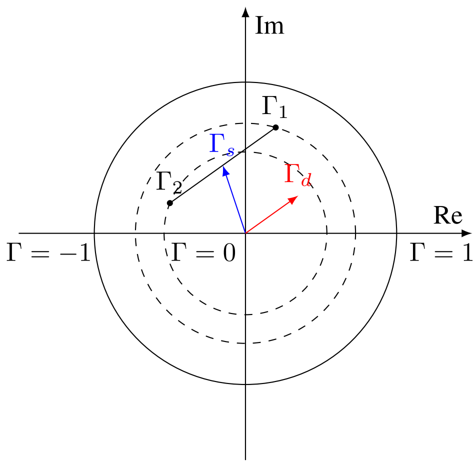

Fig. 2. Smith chart representation of normalized differential RCS with $p = 1 - p = 0.5$.

and Γ_2 of respective probabilities p and $1-p$ and becomes a function of time. Thus, the complex envelope of the current flowing into R_a can be written:

$$I(t) = \frac{V_a}{Z_a + Z_c(t)} = \frac{V_a}{2R_a}\left[1 - \Gamma(t)\right] \tag{1}$$

where $\Gamma(t)$ is the power wave reflection coefficient:

$$\Gamma(t) = \frac{Z_c(t) - Z_a^*}{Z_c(t) + Z_a} \tag{2}$$

Note that $\Gamma(t)$ can always be decomposed into a constant part Γ_s and a variable part $\Gamma_d(t)$ with $\Gamma(t) = \Gamma_s + \Gamma_d(t)$ with:

$$\Gamma_s = p\Gamma_1 + (1-p)\Gamma_2 \quad \text{and} \quad \Gamma_d(t) = \Gamma(t) - \Gamma_s \tag{3}$$

where Γ_s corresponds to the average value of $\Gamma(t)$ and $\Gamma_d(t)$ is a centered continuous time and discrete amplitude $\{\Gamma_1 - \Gamma_s; \Gamma_2 - \Gamma_s\}$ stochastic process which depends on the transmitted data and the modulation used by the tag. We also assume that $\Gamma_d(t)$ is a wide-sense stationary and ergodic process. Note that, in the case $p = 1 - p = 1/2$ *i.e.*, when the tag is modulating, Γ_s and Γ_d correspond respectively to the half sum and plus or minus the half difference of Γ_1 and Γ_2. Fig. 2 presents a graphical representation of the different quantities.

Power backscattered by the tag toward the reader as a function of the complex current $I(t)$ is equal to:

$$P_{bs} = \lim_{T\to\infty} \frac{R_a G}{2T} \int_{-T/2}^{+T/2} |I(t)|^2 \mathrm{d}t \tag{4}$$

$$= \lim_{T\to\infty} \frac{V_a^2 G}{8TR_a} \int_{-T/2}^{+T/2} |1 - \Gamma_s - \Gamma_d(t)|^2 \mathrm{d}t \tag{5}$$

where G is the tag antenna gain. Also since $\Gamma_d(t)$ is ergodic and centered, then $\int_{-\infty}^{+\infty} \Gamma_d(t)\mathrm{d}t = E[\Gamma_d(t)] = 0$ and (5) can be separated:

$$P_{bs} = \lim_{T\to\infty} \frac{V_a^2 G}{8TR_a} \left[\int_{-T/2}^{+T/2} |1 - \Gamma_s|^2 \mathrm{d}t + \int_{-T/2}^{+T/2} |\Gamma_d(t)|^2 \mathrm{d}t \right] \tag{6}$$

$$= \frac{V_a^2 G}{8R_a} \left[|1 - \Gamma_s|^2 + E\left[|\Gamma_d(t)|^2\right] \right] \tag{7}$$

$$= \frac{V_a^2 G}{8R_a} \left[|1 - \Gamma_s|^2 + p(1-p)|\Gamma_1 - \Gamma_2|^2 \right] \tag{8}$$

$$= P_{bs\,s} + P_{bs\,d} \tag{9}$$

where we can see that the backscattered power is composed of a static term and a variable term. Note that the second term is maximum when $p = 1/2$. Also, antenna voltage is related to the antenna characteristics by:

$$\frac{V_a^2}{8R_a} = S\frac{\lambda^2 G}{4\pi} \tag{10}$$

where S, and λ are respectively the power density received at the tag and the wavelength. Radar cross-section, which can be expressed as:

$$\sigma = G\frac{P_{bs}}{S} \tag{11}$$

By injecting (8) and (10) into (11), we can express the (total) RCS of a modulated tag as:

$$\sigma = \frac{\lambda^2 G^2}{4\pi} \left[|1 - \Gamma_s|^2 + p(1-p)|\Gamma_1 - \Gamma_2|^2 \right] \tag{12}$$

$$= \sigma_s + \sigma_d \tag{13}$$

which corresponds respectively to the static RCS and the differential RCS. Note that for $p = 1-p = 1/2$, σ_d is equal to one quarter of the differential RCS defined in [1]. Graphically, delta RCS defined in [1] is proportional to the square of the distance between Γ_1 and Γ_2 (see black segment in Fig. 2) whereas it is proportional to the square of the half distance in (13) (see red segment in Fig. 2). Note that details of this results will be provided in the following sections.

B. *Frequency Domain*

Demonstration can also be conducted in the frequency domain. From (1), the Power Spectral Density (PSD) of the current $S_I(f)$ can be computed:

$$S_I(f) = \frac{V_a^2}{4R_a^2}\left[\delta(f) + S_\Gamma(f)\right] \tag{14}$$

$$= \frac{V_a^2}{4R_a^2}\left[|1 - \Gamma_s|^2 \delta(f) + S_{\Gamma_d}(f)\right] \tag{15}$$

where $S_\Gamma(f)$ and $S_{\Gamma_d}(f)$ are the PSD of $\Gamma(t)$ and $\Gamma_d(t)$ respectively and $\delta(f)$ the Dirac function. Backscattered power received by the reader can be obtained from (15) by estimating the power dissipated in R_a:

$$P_{bs} = \frac{V_a^2 G}{8R_a} \int_{-\infty}^{+\infty} |1 - \Gamma_s|^2\, \delta(f) + S_{\Gamma_d}(f)\, \mathrm{d}f \tag{16}$$

where (6) and (16) are linked by Parseval's theorem. Also, (16) can be separated as:

$$
\begin{aligned}
P_{bs} &= \frac{V_a^2 G}{8R_a} \lim_{\epsilon \to 0} \left[\int_{-\epsilon}^{+\epsilon} |(1-\Gamma_s)|^2 \, \delta(f) \, \mathrm{d}f \right. \\
&\qquad \left. + \int_{-\infty}^{-\epsilon} S_{\Gamma_d}(f) \mathrm{d}f + \int_{+\epsilon}^{+\infty} S_{\Gamma_d}(f) \mathrm{d}f \right] && (17) \\
&= \frac{V_a^2 G}{8R_a} \left[|1-\Gamma_s|^2 + p(1-p)|\Gamma_1 - \Gamma_2|^2 \right] && (18) \\
&= P_{bs\,s} + P_{bs\,d} && (19)
\end{aligned}
$$

Note that this result does not depend on the modulation and the transmitted data. Also, (19) shows that the backscattered PSD is composed of a discrete component located at $f = 0$ and continuous component at $f \neq 0$. This decomposition makes it possible to consider a measurement of the delta RCS in the frequency domain, which will be done in the next section. RCS of the modulated tag can be finally be expressed from (11), (10) and (18) as:

$$
\begin{aligned}
\sigma &= \frac{\lambda^2 G^2}{4\pi} \left[|1-\Gamma_s|^2 + p(1-p)|\Gamma_1 - \Gamma_2|^2 \right] && (20) \\
&= \sigma_s + \sigma_d && (21)
\end{aligned}
$$

where we can see that the total RCS is in fact a sum of a static RCS and a differential RCS. The static RCS corresponds to the response of a linear time-invariant system since the power is located at f_0 whereas the differential RCS is obtained with a power which is not located at f_0. Moreover, these two quantities can easily be separated by filtering. The differential RCS defined in (21) [or (13)] is a generalization compared to the classical definition given in [1] as it embraces the case of modulations having duty cycles which are not 50%. It is interesting to note that delta RCS is maximum when $p = 1/2$ (which is the case for all modulations used by the UHF RFID standard [4]) but would be degraded otherwise. Also, when the tag is modulating with $p = 1/2$, (21) reduces to:

$$
\sigma_s = \frac{\lambda^2 G^2}{4\pi} |1-\Gamma_s|^2 \quad \text{and} \quad \sigma_d = \frac{\lambda^2 G^2}{4\pi} |\Gamma_d|^2 \qquad (22)
$$

where Γ_s and Γ_d correspond, in this case, to the half sum and half difference of the tag power wave reflection coefficients. Note that it is not possible to cancel out the static part of the RCS since $|\Gamma_i| \leq 1$. Finally, at 915 MHz, (22) predicts a maximal delta RCS for passive (*i.e.*, $\{\Gamma_1 = 0; \Gamma_2 = -1\}$) and semi-passive (*i.e.*, $\{\Gamma_1 = +1; \Gamma_2 = -1\}$) UHF tags of -22 dBsm (63 cm^2) and -16 dBsm (250 cm^2) respectively.

The exact characteristics of the PSD depends on the data encoding used by the tag during the communication. The UHF RFID standard [4] defines two different modulations for the tag which are FM0 and Miller (with different subcarrier sequences). Analytical formula of the PSD for FM0 is known and is equal to the Manchester encoding [5]. For Miller modulation, analytical formula is also known [6], but without considering the subcarrier sequences. Fig. 3 presents the PSD of the baseband signals corresponding to the different modulations used by the tag assuming $\Gamma_i = \pm 1$. For FM0, PSD has been obtained using the analytical formula whereas, for Miller modulations, results have been obtained by averaging

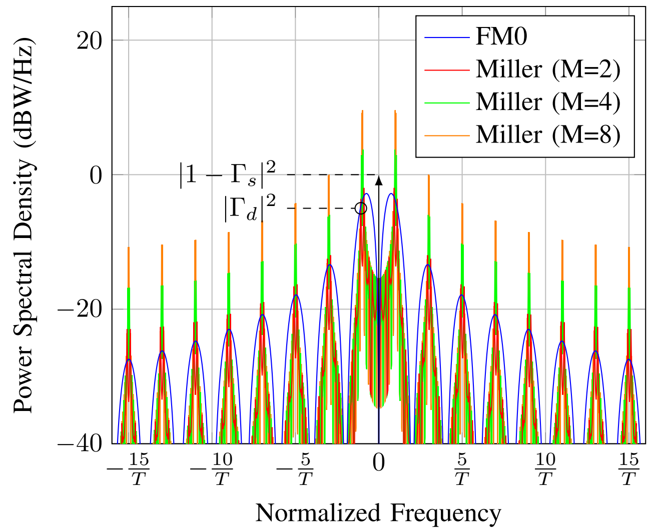

Fig. 3. Power spectral density of the signal backscattered by the tag for the UHF RFID standard [4].

the Fourier transform of the autocorrelation function of a randomly modulated signal [7]. As shown previously, even if the PSD are different and depend on the modulation, their associated power (the area under the curves) are exactly the same and is proportional to the differential RCS of the tag (the power located at f_0 or 0 in Fig. 3 corresponds to the static backscattered power and does not participate to the delta RCS).

C. Energy Conservation

Results presented previously are consistent in time and frequency domain but differ from [1] since the backscattered power is 4 times more important in the latter case.

However, involved powers have to satisfy the law of conservation of energy which states that the total power received by a RFID tag (assuming a lossless antenna) can only be dissipated in $Z_c(t)$ or backscattered in the environment. Keeping the same assumptions and considering the tag as a minimum scattering antenna, the power dissipated into the chip can expressed, based on Fig. 1, as:

$$
\begin{aligned}
P_{Z_c} &= \lim_{T \to \infty} \frac{V_a^2 G}{8TR_a} \int_{-T/2}^{+T/2} 1 - |\Gamma(t)|^2 \mathrm{d}t && (23) \\
&= \frac{V_a^2 G}{8R_a} E\left[1 - |\Gamma_i|^2\right] && (24)
\end{aligned}
$$

Power backscattered toward the reader which corresponds to the sum of $P_{bs\,s}$ and $P_{bs\,d}$ has been computed in (8) [and (18)] and is recalled here for clarity:

$$
P_{bs} = \frac{V_a^2 G}{8R_a} \left[|1-\Gamma_s|^2 + p(1-p)|\Gamma_1 - \Gamma_2|^2 \right] \qquad (25)
$$

The total power received by the tag is of two kinds, the first one corresponds to the received power delivered to the load and is proportional to the effective aperture of the antenna A. The second one is the power backscattered in the environment

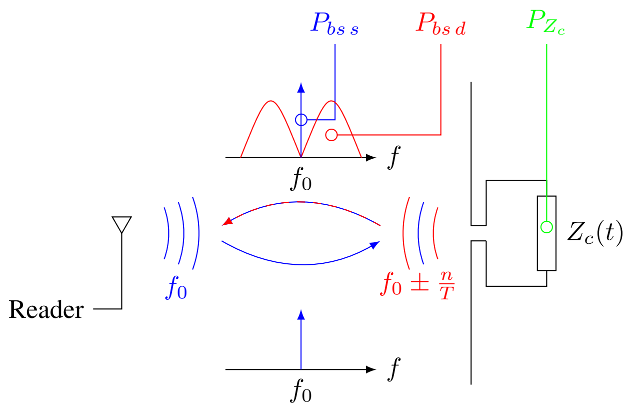

Fig. 4. The law of conservation of energy for a modulating RFID tag.

and is proportional to the RCS of the tag σ. Thus the received power when the tag is modulating can be obtained by:

$$P_r = \lim_{T\to\infty} \frac{S}{T} \int_{-T/2}^{+T/2} A(t) + \frac{\sigma(t)}{G} \, \mathrm{d}t \tag{26}$$

$$= S \times E\Big[A_i + \frac{\sigma_i}{G}\Big] \tag{27}$$

Replacing A_i and σ_i by their expressions for general load case [8], [9], leads to:

$$P_{r_i} = p_i \; S\frac{\lambda^2 G}{4\pi} \left(\frac{4R_a R_{c_i}}{|Z_a + Z_{c_i}|^2} + |1 - \Gamma_i|^2 \right) \tag{28}$$

$$= p_i \; S\frac{\lambda^2 G}{4\pi} \left(1 - |\Gamma_i|^2 + |1 - \Gamma_i|^2\right) \tag{29}$$

where p_i is the probability to be is state i. Finally, we can check that:

$$P_{Z_c} + P_{bs\,s} + P_{bs\,d} = P_r \tag{30}$$

which agrees with the law of conservation of energy. Note that this result does not hold if $P_{bs\,d}$ is multiplied by 4 [1] (this constant was however suggested in [10] by the same authors).

Fig. 4 summarizes the different powers in reception and emission. It is interesting to first remark that the maximization of the harvested power cannot be done jointly with the maximization of the backscattered power due to the energy conservation. Also, modulation done by the tag affects significantly the backscattered power. If the tag is not modulating, the total received power is dissipated into the load and backscattered into the environment only at a single frequency f_0 which is the same as the one used by the reader. In this case, $P_{bs\,d}$ and σ_d are equal to zero, and the tag is a simple linear time-invariant system (as any other object in the environment). When the tag is modulating, the backscattered power still presents a component at f_0, but also around the carrier frequency. In this case, $P_{bs\,d}$ and σ_d are not equal to zero. Also, the tag cannot be considered as a linear time-invariant system. The maximization of $P_{bs\,d}$ (or σ_d) is equivalent to maximize the distance on the complex plan between the two states (as predicted by [1]). Note that this differential power can be easily detected since it is not located at the frequency used by the reader during the emission. Finally, if losses are considered, both static and differential backscattered powers are affected.

Fig. 5. Smartrac Dogbone UHF RFID tag with Impinj chip.

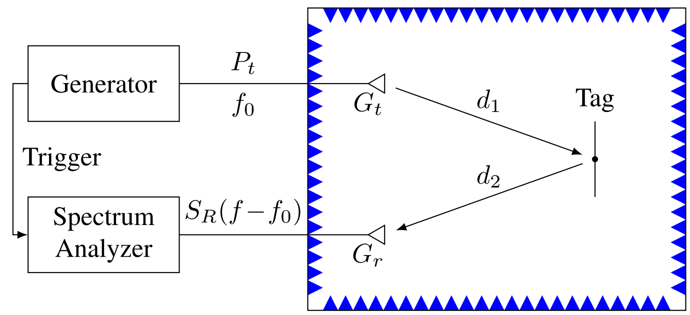

Fig. 6. Measurement bench used to measure delta RCS of UHF tag in frequency domain.

III. Measurements

Assuming narrow band signals, the relation given by (17) allows to estimate both static and differential RCS of a tag located in the farfield region of the antennas from the received power spectral density $S_R(f)$ and the classical radar equation. Static RCS σ_s can be expressed as:

$$\sigma_s = \frac{(4\pi)^3 d_1^2 d_2^2}{P_t G_t G_r \lambda^2} \times \int_{f_0-\epsilon}^{f_0+\epsilon} S_R(f - f_0)\,\mathrm{d}f \tag{31}$$

whereas delta RCS σ_d can be obtained from:

$$\sigma_d = \frac{(4\pi)^3 d_1^2 d_2^2}{P_t G_t G_r \lambda^2} \times \left[\int_{f_0-b}^{f_0-\epsilon} S_R(f - f_0)\,\mathrm{d}f + \int_{f_0+\epsilon}^{f_0+b} S_R(f - f_0)\,\mathrm{d}f \right] \tag{32}$$

where $2b$ is the span of the instrument and ϵ a constant linked to the frequency drift between the transmitter and the receiver. Also, note that (32) is different than zero only when the tag is modulating, but does not depend on the modulation or the transmitted data. Finally, this estimation of delta RCS is different of the one defined in time in [1], [2] and [3].

The rest of this section presents the measurement of the delta RCS using the proposed method [see (32)] and compare the results to the classical methods [1]–[3]. For this study, a UHF tag has been selected and is presented in Fig. 5. Measurement bench is presented in Fig. 6 and is composed of a vector signal generator (Agilent N5182A) and a spectrum analyzer (Tektronix RSA 3408A). Both instruments are connected respectively to the transmitting and receiving antennas (A.H. Systems, inc. SAS-571). Note that a monostatic configuration can also be used with a circulator. The generator transmits a CW at a given frequency $f_0 \in [830\text{ MHz}; 990\text{ MHz}]$ and

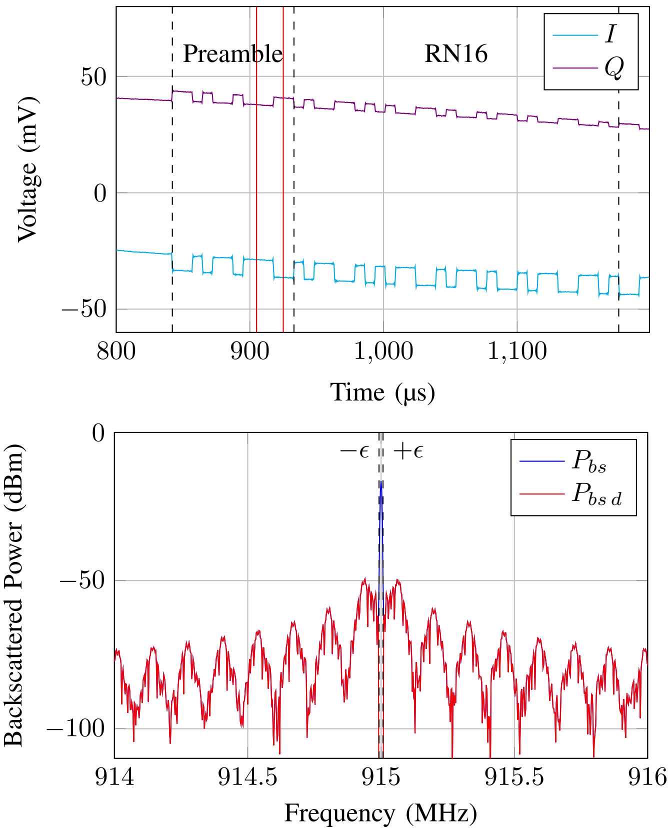

Fig. 7. (a) IQ channels of the backscattered signal using FM0 modulation in the time domain, (b) Power spectral density of the same backscattered signal in the frequency domain.

amplitude modulation is used to realize a query command. This command sets the modulation used by the tag to FM0 (Miller modulations can also be used) and the Backscatter Link Frequency (BLF) to 66 kb/s. The tag has been placed 1 m away from the antennas to fulfill farfield conditions. Transmitted power has been set to a fixed value of $P_t = 17$ dBm and corresponds to a received power which is slightly higher than the sensitivity of the tag. This condition allows, as we will see in the following, to maximize the measured delta RCS value. Spectrum analyzer acquisition is triggered by the generator and set to observe the RN16 backscattered by the tag. Finally, we can remark that except for the trigger, the two instruments use independent local oscillators and are not phase-locked.

Delta RCS can be computed by measuring the power backscattered by the tag in time domain or frequency domain. Fig. 7 presents typical results of an activated tag in both domains. For the time domain method, delta RCS is computed in the preamble of the tag [see red lines in Fig. 7(a)] and corresponds to the half of the distance between the two states in the complex plane. Moreover, computing the AC power as in [1] provides a better accuracy but remains a difficult task since the two instruments do not share the same local ocsillator and undergo drifts higher than the RCS variation of the tag over the acquisition window [see decreasing slope for I and Q channels in Fig. 7(a)]. In practice, to successfully apply this method to our setup, the drift has firstly been estimated using a low-pass filter of cutoff frequency lower than the

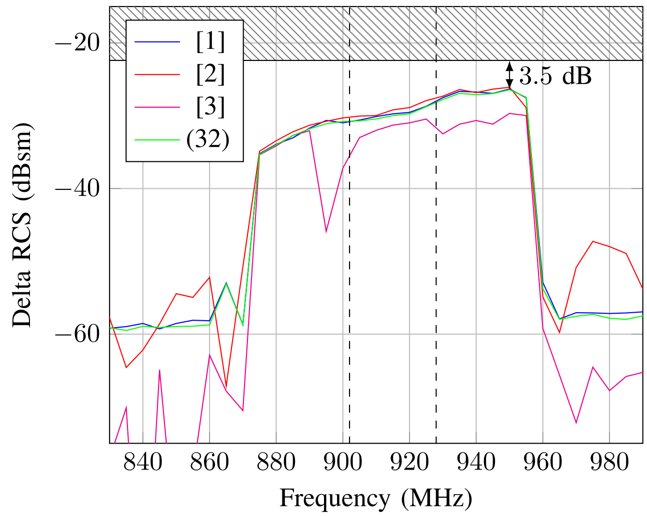

Fig. 8. Delta RCS of Smartrac Dogbone UHF RFID tag as a function of the frequency measured by the different methods. Horizontal black line presents the maximum delta RCS value of a passive dipole tag obtained from (22).

BLF, and then subtracted from the raw I and Q channels. On another side, method described in [3] which corresponds to the difference in magnitude between the two states, is also presented but is not compatible to the definition given by [1] and [2]. Finally, note that all these methods have been applied on the exact same temporal acquisitions.

For the frequency domain approach, from the total backscattered power [blue curve in Fig. 7(b)], the modulated backscattered power [red curve in Fig. 7(b)] is first computed by removing the power located at f_0 due to leakage, reflections in the environment and static contribution of the tag (in practice, only 7 samples have been cleared). The modulated backscattered power is finally re-injected into (32) to obtain the delta RCS of the tag at a given frequency and power. Also, since the frequency representation is observed at f_0 over a span of 2 MHz, this study does not take into account the power located at higher harmonics. Results are presented in Fig. 8 for both time and frequency approaches. We can see that all curves present a plateau when the tag is activated. Note that outside this plateau (*i.e.*, when the tag is not activated), the RFID tag is a simple linear time-invariant system and the corresponding delta RCS is zero. When the tag is activated, both time and frequency methods provide similar results and are 3.5 dB below the maximum theoretical delta RCS obtained with (22). Comparison with [1] shows a very good agreement since the average and maximum error over the activated range is 0.19 dB and 0.46 dB respectively. On the other side, comparison with [2] shows higher difference with 0.59 dB and 1.4 dB for the average and maximum error respectively. Finally, since the frequency method (and [1]) computes the delta RCS over the full RN16 length, these methods provide a better accuracy compared to the one used in [2] (for which the value is extracted from only two complex samples). Also, since the proposed method (and [2]) does not rely on phase synchronization between the emitter and the receiver, implementation can easily be realized using independent instruments.

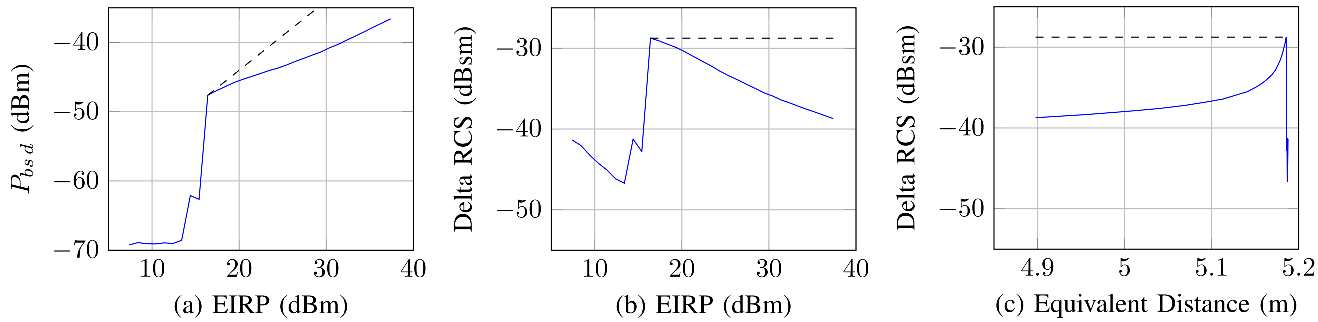

Fig. 9. (a) Differential backscattered power as a function of the EIRP. (b) Delta RCS as a function of the EIRP. (c) Delta RCS as a function of the equivalent distance. All curves have been measured at 915 MHz.

Finally, a special attention should be given to the distances d_1 and d_2 (or equivalently the transmitted power P_t) in the delta RCS estimation using (32). First, note that (32) is only valid in the farfield region of the reader antenna so d_1 and d_2 have to be higher than 50 cm for typical UHF antennas. Second, the delta RCS is equal to zero if the chip does not modulate the reflected signal (*i.e.*, is not activated) so d_1 has to be lower than the maximum read range of the tag which can be higher than 5 m for classical UHF tags. However, even in-between these two distances, delta RCS value can be significantly impacted by the distance and/or the transmitted power since the impedance states of the chip depend on the received power. A study has been conducted to estimate the variation of the delta RCS as a function of the distance. Measurements have been done with the same tag (see Fig. 5) and in the same configuration (see Fig. 6). Distance variation has been "simulated" by reducing the transmitted power (this technique allows to be independent of the multipath variations since the tag support is never moved). Fig. 9(a) presents the differential backscattered power $P_{bs\,d}$ as a function of the Effective Isotropic Radiated Power EIRP $P_t{\cdot}G_t$. We can check that $P_{bs\,d} = 0$ mW when tag is not activated (see measured values below -60 dBm) and that $P_{bs\,d}$ is higher than -50 dBm and increases with EIRP when the tag is activated. Also, note that an increase of 3 dBm of the EIRP does not increase $P_{bs\,d}$ of 3 dBm (*i.e.*, slope is lower than 1). Dashed line in Fig. 9(a) have been added on the curve to clearly see the difference with a slope equal to 1. From Fig. 9(a), delta RCS can be computed as a function of the EIRP. Results are presented in Fig. 9(b) and show that the delta RCS is a decreasing function of the transmitted power since the energy conversion between the received power P_r (located at f_0 and proportional to P_t) and the differential backscattered power $P_{bs\,d}$ is not perfect [slope lower than 1 in Fig. 9(a)]. The dependency of the measured delta RCS related to the distance d_1 and d_2 can now be established. Assuming a monostatic configuration (*i.e.*, $d_1 = d_2 = d$), the equivalent distance corresponding to a fixed EIRP of 36 dBm (which is the maximum EIRP allowed by the regulation) using the classical radar equation can be computed. Note that the term of equivalent distance is used since all measurements have been done at the same distance in anechoic chamber. Results are presented in Fig. 9(c) where we can clearly see that the delta RCS depends on the distance and is an increasing function of d. Moreover, note that the most important point of the curve is the maximum delta RCS value since when the distance is reduced, the backscattered power is always increased (even if the delta RCS value is lower) and does not limit the performance of the transmission. Assuming that the reader sensitivity is the limiting factor, theoretical read range of a tag is then linked to this maximum delta RCS value. Thus, in order to determine the maximum delta RCS value of a tag, distance and/or transmitted power has to be choosen so that the power received by the tag is just higher than its sensitivity.

IV. Conclusion

The paper provides a general definition of the RCS of UHF RFID tags and presents a new method which makes it possible to estimate the delta RCS of a tag in frequency domain. This method leverages the synchronization between the emitter and receiver and can be implemented using independent instruments. Also the accuracy of the proposed method is higher than classical methods since the delta RCS is estimated using the entire acquisition window of the spectrum analyzer. Results shows that difference between the classical method and the proposed one is less than 0.5 dB.

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