Th3B-2

Long-range Chipless RFID for Objects in Translation using Doppler-modulated Depolarizing Tags

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Outline

- Introduction
- Motivation
- Model
- Experimental results
- Conclusion

Introduction

- **Stationary depolarizing chipless tags**

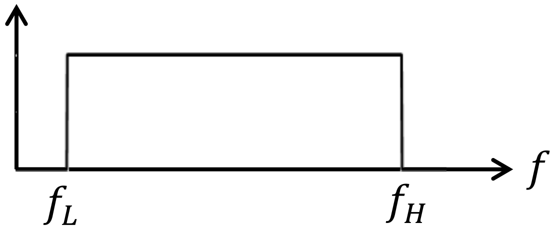
Stationary depolarizing tag (Linear Time-Invariant)	Stationary non-depolarizing object and environment (Linear Time-Invariant)

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 61, NO. 8, AUGUST 2013

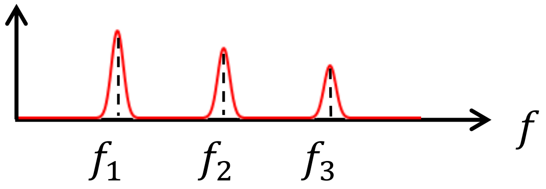
A Depolarizing Chipless RFID Tag for Robust Detection and Its FCC Compliant UWB Reading System

Arnaud Vena, *Member, IEEE*, Etienne Perret, *Member, IEEE*, and Smail Tedjni, *Senior Member, IEEE*

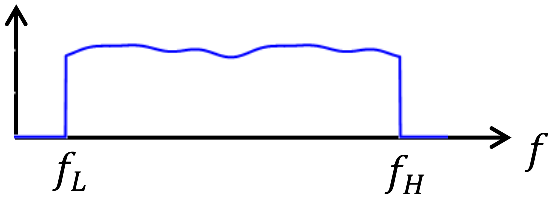
TX signal (V pol.)



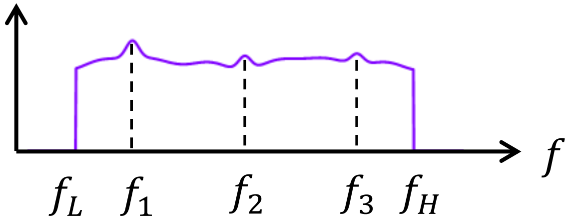
Tag response (V and H pol.)

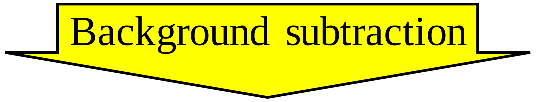


Env. + Obj. Response (V pol.)

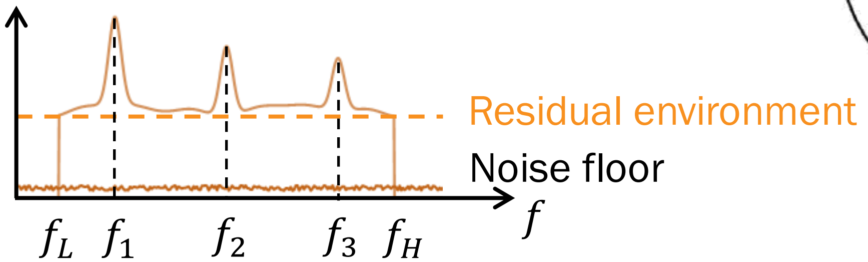


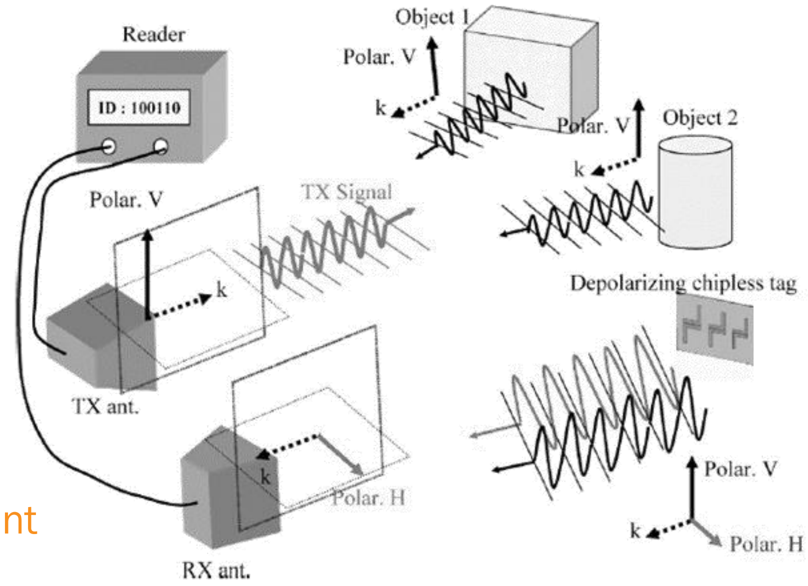
RX Signal (H pol.)





Measured Cross-RCS (σ^{VH})





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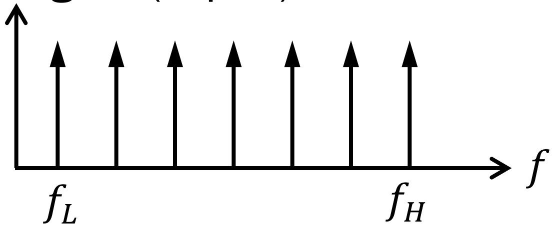
Introduction

The Coolest Ideas Under the Sun
SAN DIEGO 2023

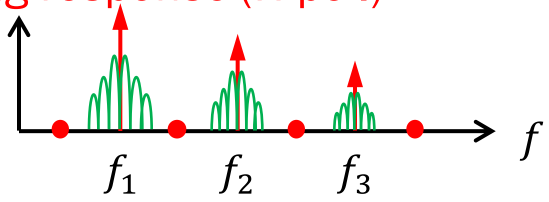
- Rotating non-depolarizing chipless tags

Rotating non-depolarizing tag (Linear Time-Variant)	Rotating non-depolarizing object* (Linear Time-Variant)	Stationary non-depolarizing environment (Linear Time-Invariant)

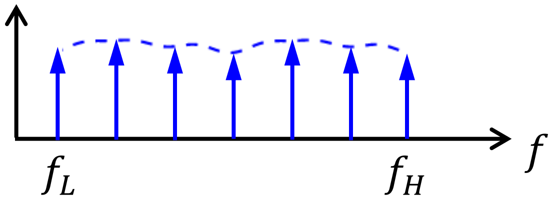
TX signal (H pol.)



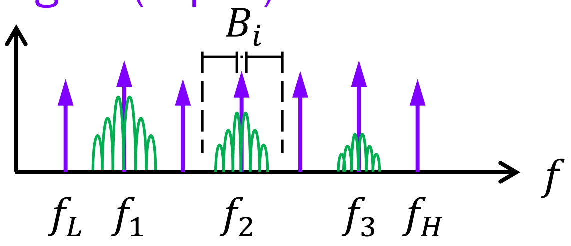
Tag response (H pol.)

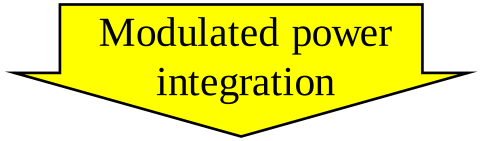


Env. + Obj. response (H pol.)

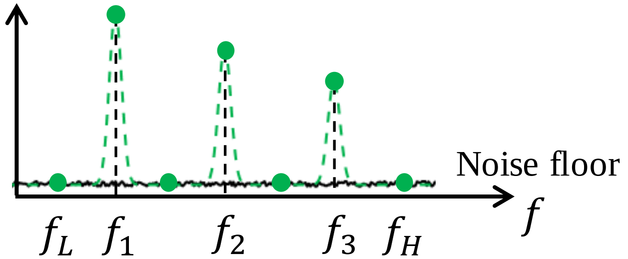


RX signal (H pol.)





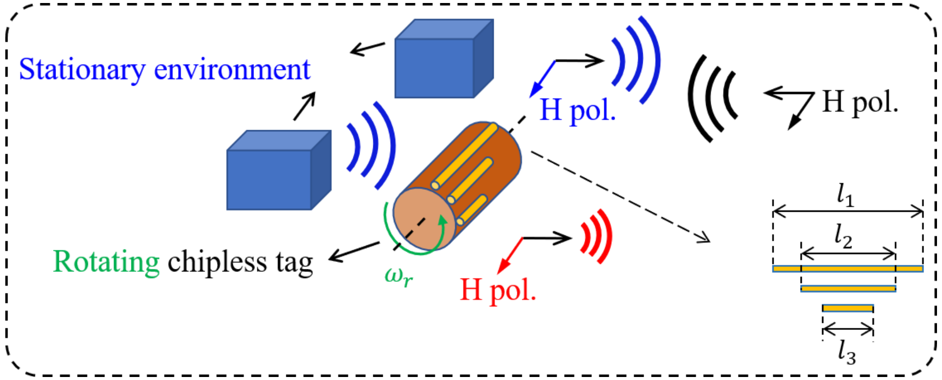
Measured differential Co-RCS (σ_d^{HH})



766 IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 70, NO. 1, JANUARY 2022

Chipless RFID Based on Micro-Doppler Effect

Ashkan Azarfar, Member, IEEE, Nicolas Barbot, Member, IEEE, and Etienne Perret, Senior Member, IEEE



* The cylindrical object considered here does not generate micro-Doppler due to its full rotational symmetry.

Introduction

- Stationary depolarizing vs. rotating non-depolarizing tags

Stationary depolarizing chipless tag

- Stationary tag and object responses are decomposed in polarization domain.
- Stationary tag, object, and environment responses are superimposed in frequency domain.

✓ Tag and object isolation
X Tag and environment isolation
X Read range < 1 meter

Rotating non-depolarizing chipless tag

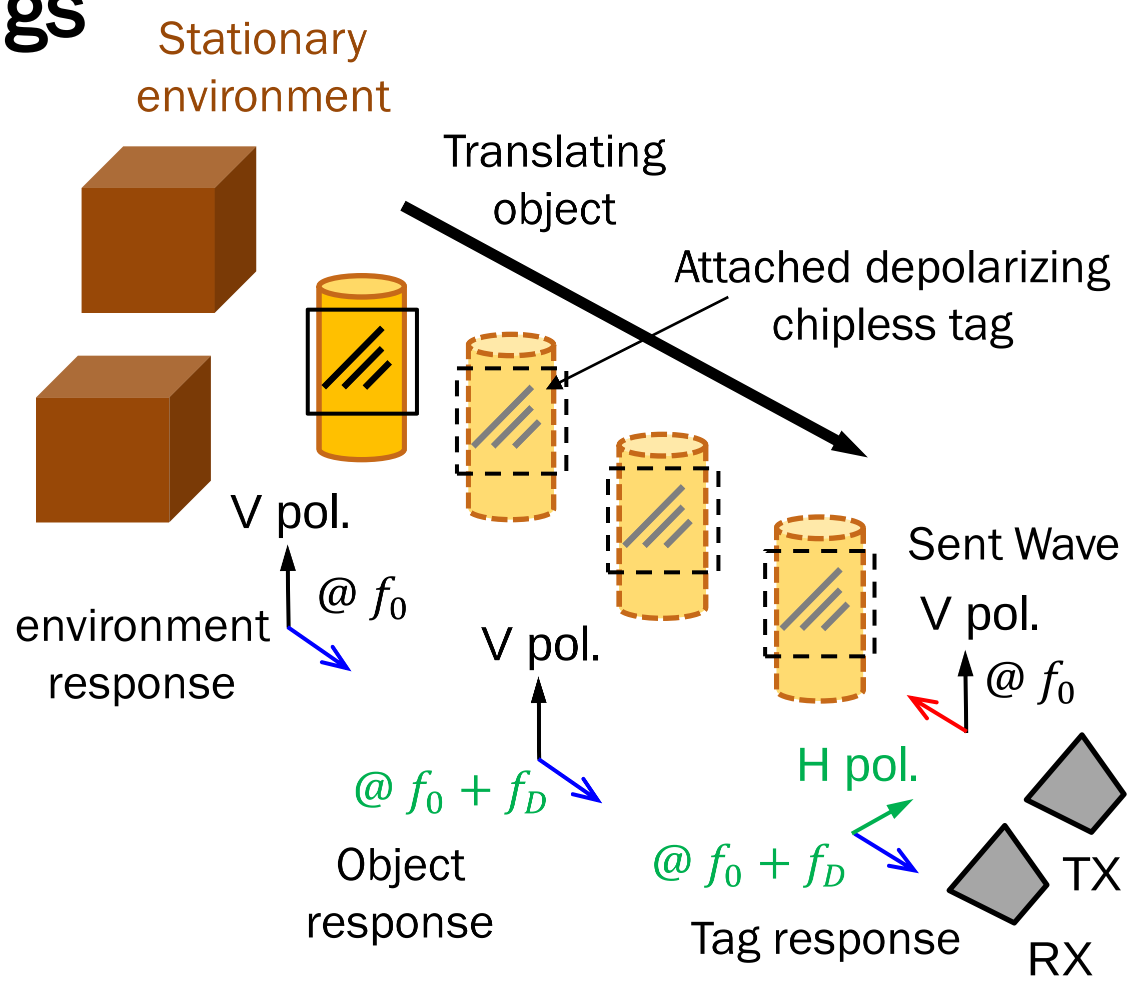
- Rotating tag and object responses are not decomposed in polarization domain.
- Rotating tag and stationary environment responses are decomposed in frequency domain.
- Rotation is not practical in real applications

X Tag and object isolation
✓ Tag and environment isolation
✓ Read range up to 10 meter
X Not feasible in application

Motivation

- **Translating depolarizing chipless tags**
  - Translating tag and object responses are decompose in polarization domain.
  - Translating tag and stationary environment responses are decompose in frequency domain.
  - Translation is practical in real applications.
  - Differential RCS should be redefined since the range of the tag is varying during time.

✓ Tag and object isolation
✓ Tag and environment isolation
✓ Read range up to several meters
✓ Feasible in application



Model

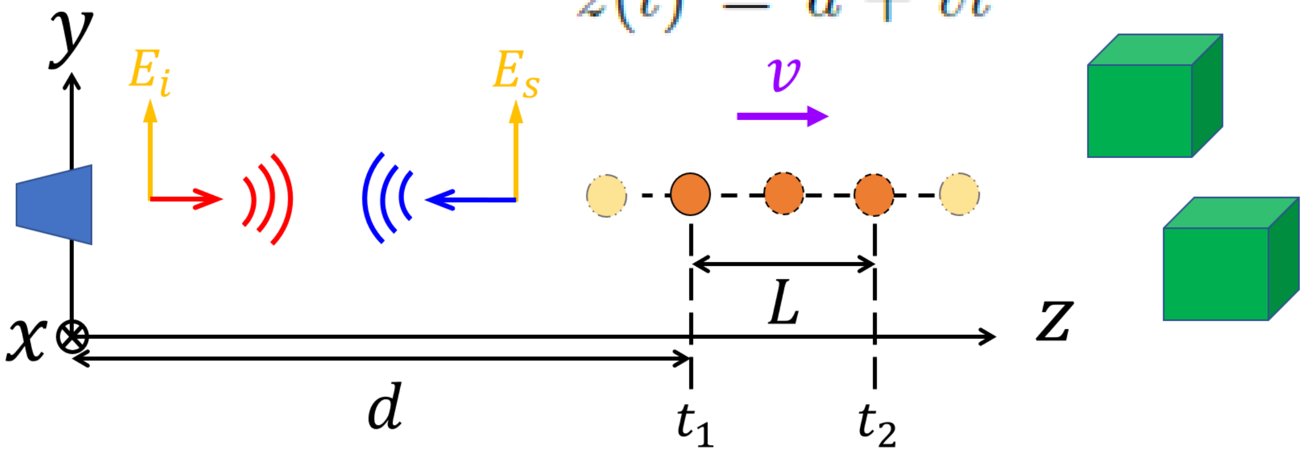
- **Backscattering from translating scatterer**

$$L = v(t_2 - t_1)$$

$$z(t) = d + vt$$

$$\begin{bmatrix} E_x^s \\ E_y^s \end{bmatrix} = \begin{bmatrix} S_{xx} & S_{xy} \\ S_{yx} & S_{yy} \end{bmatrix} \begin{bmatrix} E_x^i \\ E_y^i \end{bmatrix}$$

$$\vec{E}_i(t) = \frac{E_0}{d + vt} e^{-jk(d+vt)} \hat{y}$$

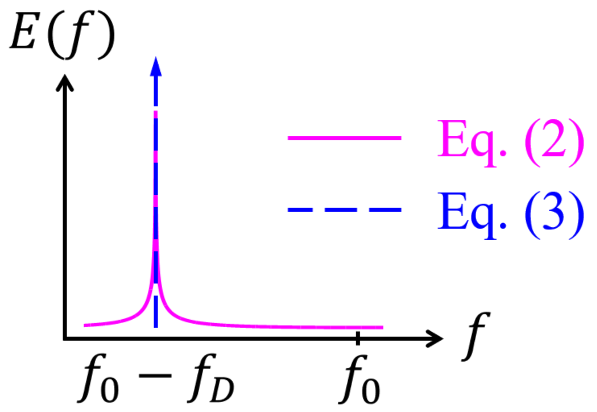


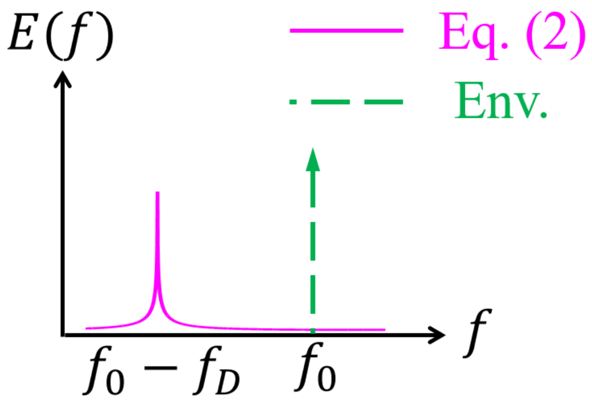
Depolarization

Phase (Doppler) modulation

$$\vec{E}_s(t) = \frac{E_0 S_{yx}(f_0)}{(z - d - vt)(d + vt)} e^{-j2k(d+vt)} e^{jkz} \hat{x} \qquad (2)$$

Amplitude modulation





- Classical radar targets

$d \gg L$

$$\vec{E}_s(t) = \left[-E_0 S_{yx}(f_0)/d^2\right] e^{-2jk(d+vt)} \qquad (3)$$

Model

6128 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 69, NO. 9, SEPTEMBER 2021

Communication

Differential RCS of Modulated Tag

Nicolas Barbot, Olivier Rance, and Etienne Perret

- **Differential RCS**

✓ Definition in the time and frequency domain based on the modulated backscattered field

✓ The differential RCS of the tag is independent of the range

X In the definition, the range of the tag is supposed to not vary with time

– **Differential RCS of the translating chipless tag**

- Magnitude of the backscattered field is significantly affected by the time-varying range of the tag for $L \sim d$.

$$\vec{E}_s(t) = \frac{E_0 S_{yx}(f_0)}{(z-d-vt)(d+vt)} e^{-j2k(d+vt)} e^{jkz}\hat{x}$$

- The time-varying magnitude of the backscattered filed is compensated to have the final differential RCS value independent of the range.

Classical form

$$\sigma_d^{HH}(f_0) = 4\pi d^2 \frac{\overline{|E_s(t)|^2}\Big|_{t_1}^{t_2} - \left|\overline{E_s(t)}\Big|_{t_1}^{t_2}\right|^2}{\overline{|E_i(t)|^2}\Big|_{t_1}^{t_2}}$$

$$\overline{(\cdot)}\Big|_{t_1}^{t_2} = \frac{1}{\Delta t}\int_{t_1}^{t_2} (\cdot)\, dt$$

Modified form

$$\sigma_d^{VH}(f_0) = 4\pi \frac{\overline{(d+vt)^4|E_s(t)|^2}\Big|_{t_1}^{t_2} - \left|\overline{(d+vt)^2 E_s(t)}\Big|_{t_1}^{t_2}\right|^2}{\overline{(d+vt)^2|E_i(t)|^2}\Big|_{t_1}^{t_2}}$$

Model

- Differential RCS

Rotating non-depolarizing chipless tag

Classical form

$$\sigma_d^{HH}(f_0) = 4\pi d^2 \frac{\overline{|E_s(t)|^2}\Big|_{t_1}^{t_2} - |\overline{E_s(t)}\Big|_{t_1}^{t_2}|^2}{\overline{|E_i(t)|^2}\Big|_{t_1}^{t_2}}$$

$$\sigma_d^{HH}(f_0) = \sigma^{HH}(f_0)[1 - J_0^2(\beta)] \quad \beta = \frac{4\pi R}{\lambda}$$

Modulation efficiency depends on the rotation radius R

Translating depolarizing chipless tag

Modified form

$$\sigma_d^{VH}(f_0) = 4\pi \frac{\overline{(d+vt)^4 |E_s(t)|^2}\Big|_{t_1}^{t_2} - |\overline{(d+vt)^2 E_s(t)}\Big|_{t_1}^{t_2}|^2}{\overline{(d+vt)^2 |E_i(t)|^2}\Big|_{t_1}^{t_2}}$$

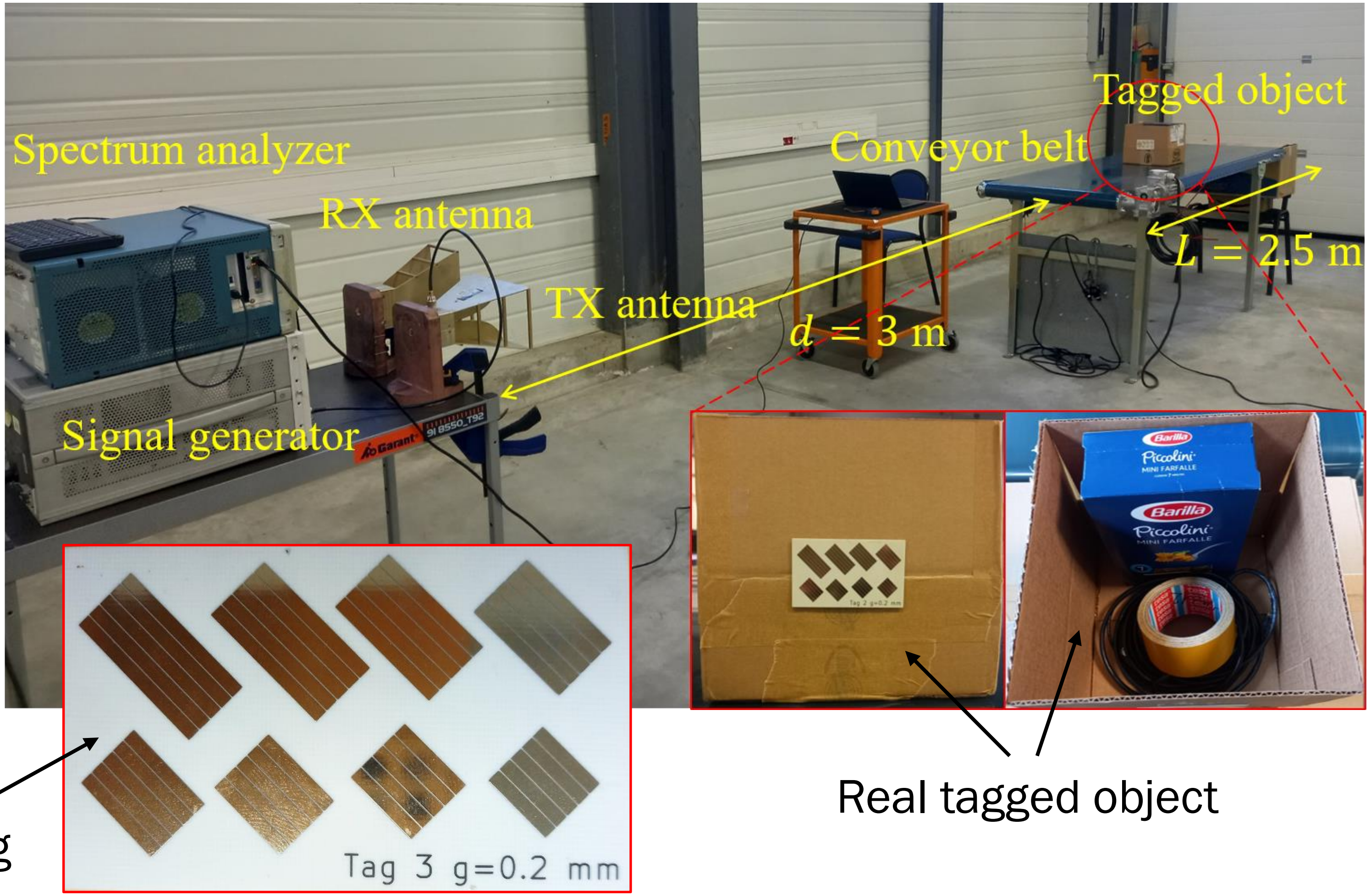
$$\sigma_d^{VH}(f_0) = 4\pi |S_{yx}(f_0)|^2 = \sigma^{VH}(f_0)$$

Modulation efficiency is almost 100 % independent of the translation velocity

Experimental Results

- **Measurement with a conveyor belt**

- Cross-polarized TX and RX ant
- $3.2 < f_0 < 3.8$ GHz
- $P_t = 5$ dBm
- $L = 2.5$ m
- $v = 0.19$ m/s
- $1 < d < 3$ m
- Acquisition time 11 seconds
- Sample rate: 256 S/s

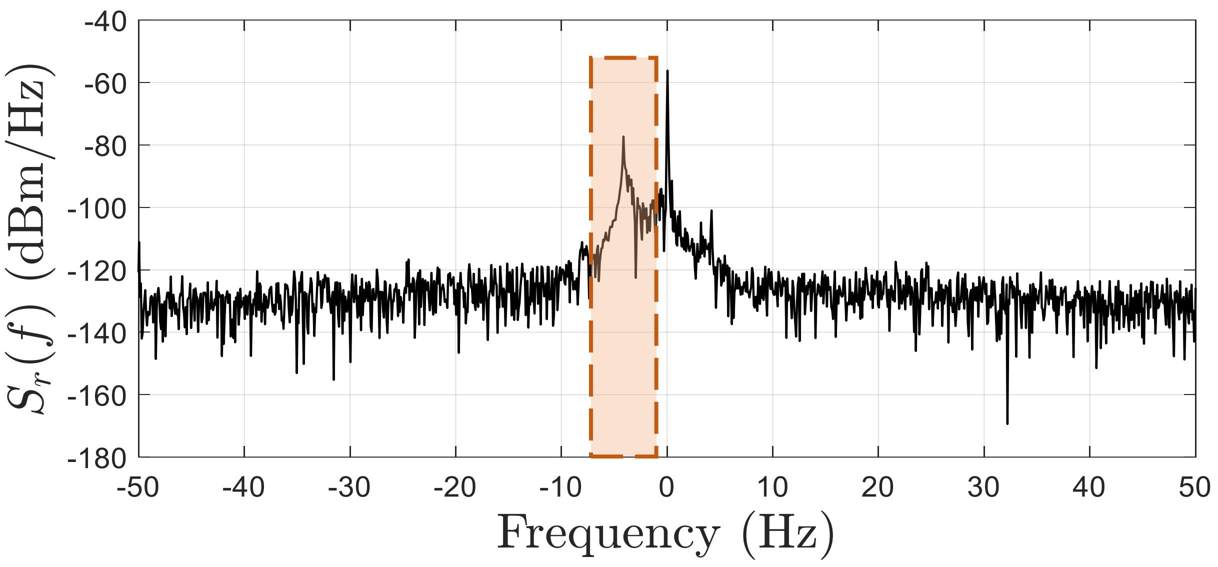


Depolarizing chipless tag

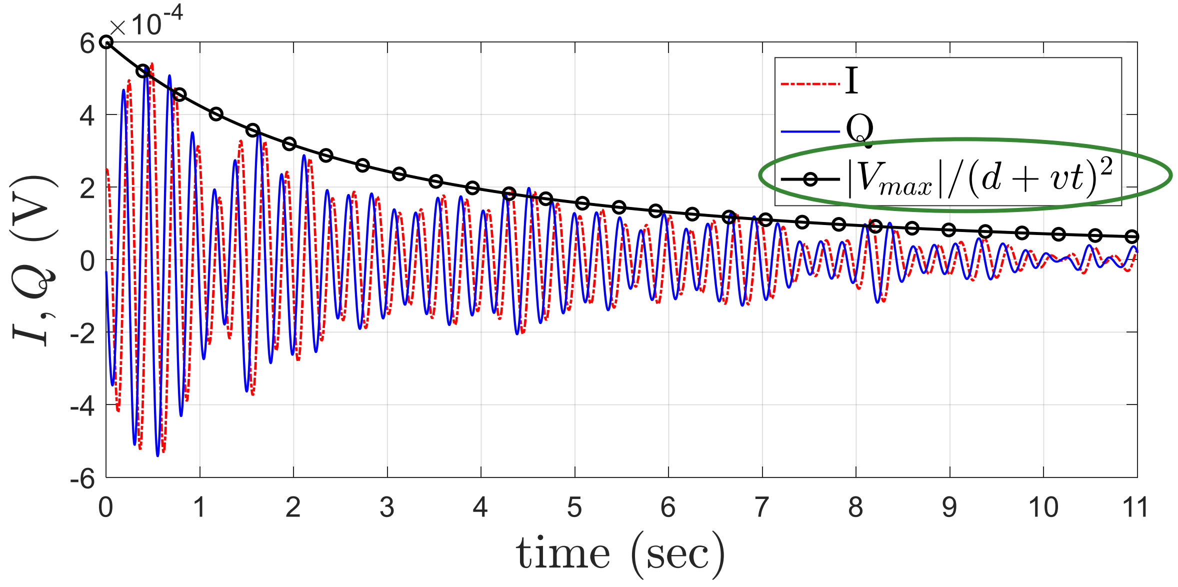
Real tagged object

Experimental Results

- **Backscattered signal in time and frequency**
  - At the second resonance of the chipless tag $f_0 = 3.59$ GHz



$f_D = \frac{2v}{\lambda} = \frac{2 \times 0.19 \text{ m/s}}{0.08 \text{ m}} = 4.5$ Hz



$v = 0.19$ m/s
$d = 1.2$ m

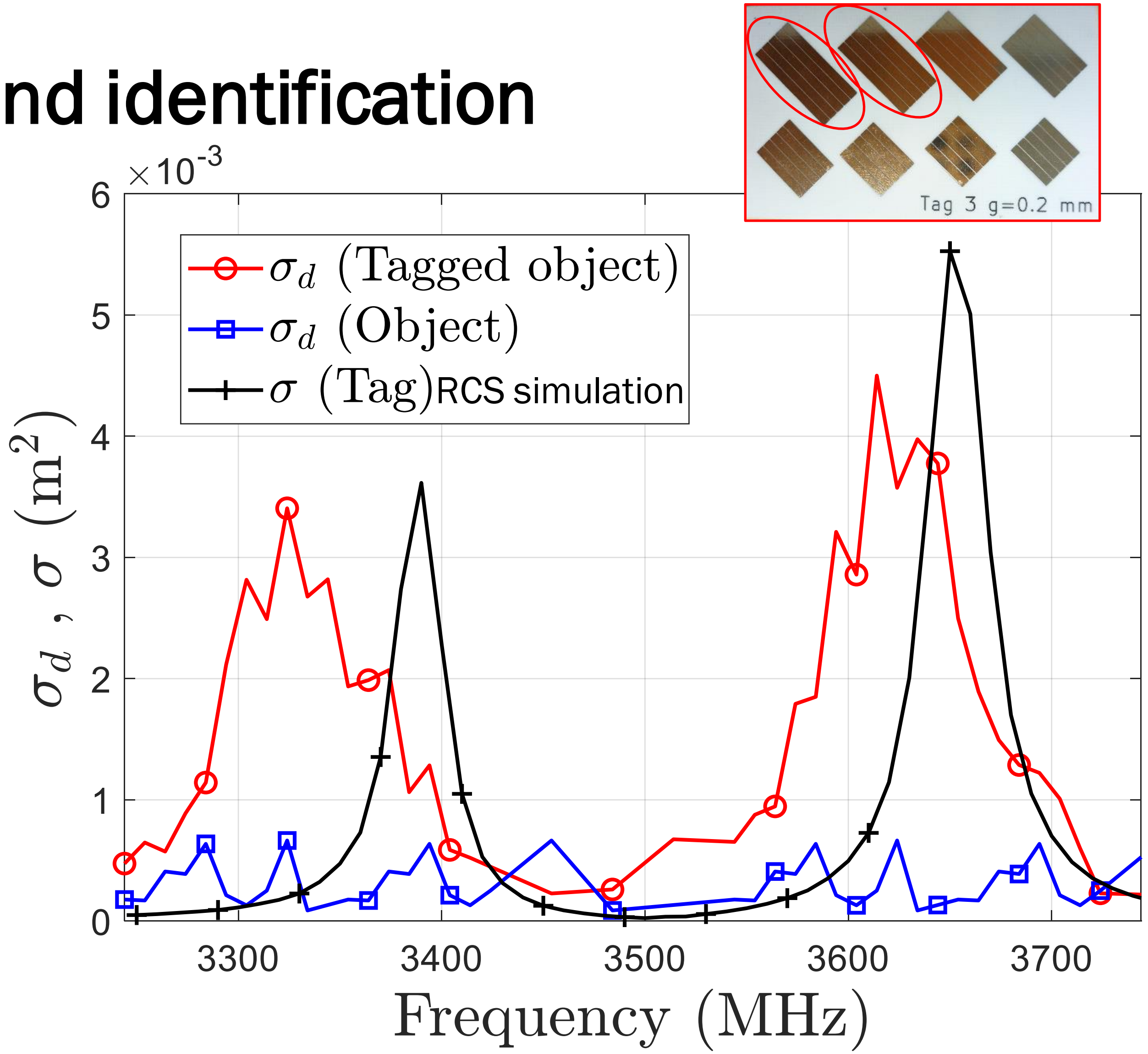
Experimental Results

- **Measured differential RCS and identification**

$$\sigma_d(f_0)=4\pi\frac{\overline{(d+vt)^4|E_s(t)|^2}\Big|_{t_1}^{t_2}-\left|\overline{(d+vt)^2E_s(t)}\Big|_{t_1}^{t_2}\right|^2}{\overline{(d+vt)^2|E_i(t)|^2}\Big|_{t_1}^{t_2}}$$

$$\overline{(\cdot)}\Big|_{t_1}^{t_2}=\frac{1}{\Delta t}\int_{t_1}^{t_2}(\cdot)\,dt$$

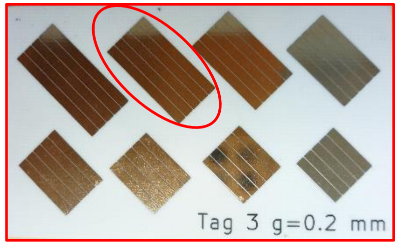
- $d = 1.2$ m
- $v = 0.19$ m/s
- $\Delta t = t_2 - t_1 = 11$ sec
- $V_r(t) = I_r(t) + jQ_r(t)$
- $E_s(t) = \sqrt{4\pi/Z_0 G\lambda^2}\, V_r(t)$
- $E_0 = \sqrt{2\eta P_t G/4\pi}$



Experimental Results

- **Read range**
  - **Differential backscattered power as a function of distance**

@ $f_0 = 3.59$ GHz



- Real measurement

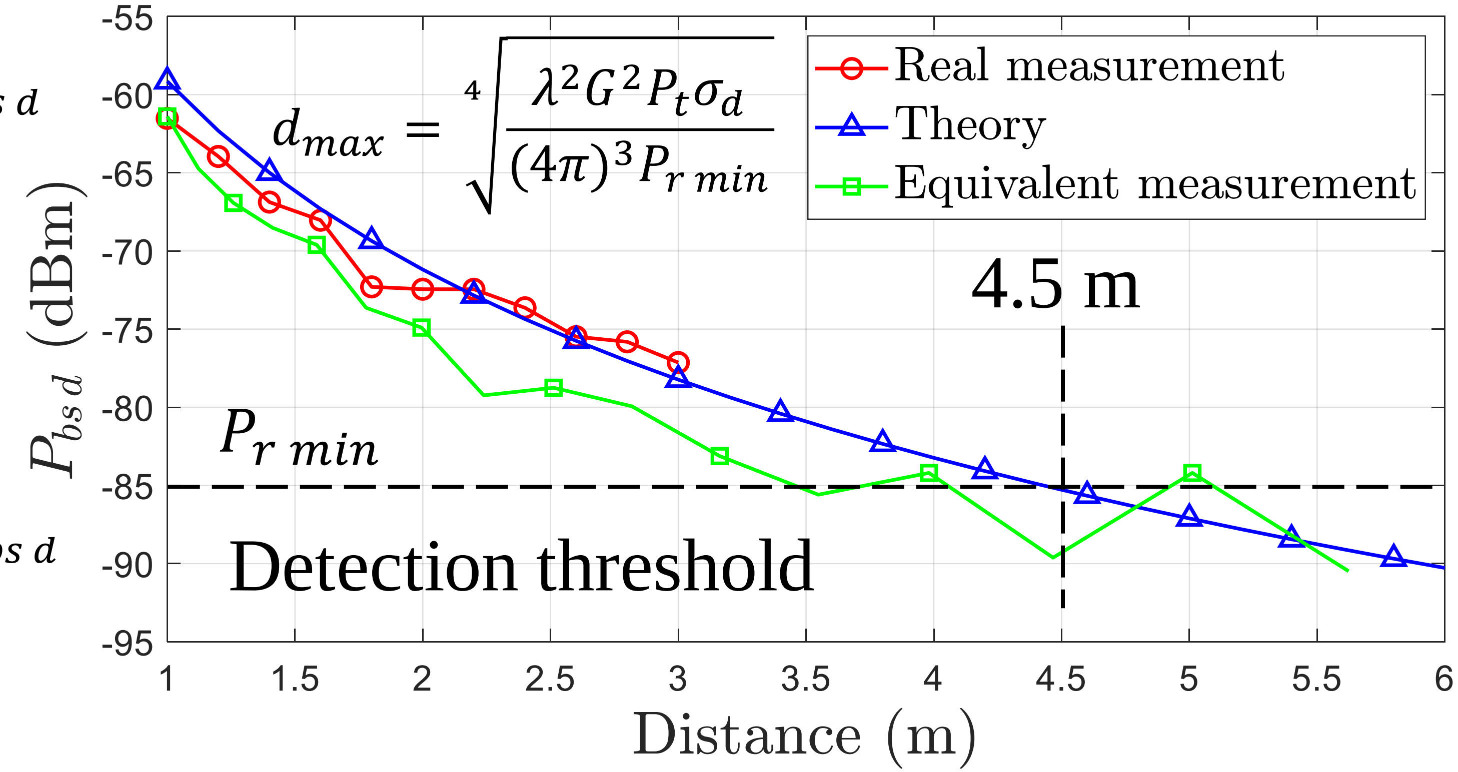
$P_t = 5$ dBm ➡ $d \nearrow 1:0.2:3$ m ➡ $P_{bs\,d}$

- Theory (radar equation)

$\sigma_d = 4.5 \times 10^{-3}$
$P_t = 5$ dBm ➡ $P_{bs\,d} = \frac{P_t G}{4\pi d^2}\sigma_d$

- Equivalent measurement

d = 1 m ➡ $P_t \searrow 5:-1:-25$ dBm ➡ $P_{bs\,d}$



Conclusion

- Translating Doppler-modulated depolarizing chipless tags
- Response of the tagged object and the environment are decomposed based on Doppler modulation
- Response of the tag and the object are decomposed based depolarizing property of the chipless tag
- Range-independent definition of the differential RCS is developed
- Robust and long-range chipless RFID for real applications with conveyor belts
- Read range up to 5 meter

Thank you for your attention !

Question time …