Electromagnetic Analysis of UWB RFID Tag Backscattering

Francesco Guidi

In a joint PhD program between Ecole Polytechnique ParisTech and University of Bologna

Supervisors: Prof. Alain Sibille, Prof. Marco Chiani
Co-Supervisor: Prof. Davide Dardari
Activity carried out during the PhD

Context: EU Project SELECT

- UWB backscattered signals analysis (with Ecole Polytechnique):
  - interaction UWB RFID tags-environment
  - UWB backscattering principle analysis

- Communication System aspects (with University of Bologna) for passive UWB RFID:
  - elimination of clutter
  - interference mitigation
  - ....
The UWB Technology

MAIN FEATURES

- Pulse with a short duration (\([\text{ns}], [\text{ps}]\))
- Bandwidth > 500[MHz]

ADVANTAGES

- Reduced fading due to finer multipath resolution
- Easier material penetration
- Multiple access capability through Spread Spectrum techniques
- Underlay and covert communications due to low PSD

[Diagram showing frequency spectrum with categories: Narrowband (KHz), Wideband (MHz), Ultra-Wideband (GHz)]
◆ **Structural Mode Scattering:**

It involves the antenna itself and any other structure part such as the antenna support

◆ **Antenna Mode Scattering:**

it stems from the capability of the antenna to radiate when excited at its ports
Interaction of UWB RFID tag with the close environment

- RFID Tags are usually attached to objects which may drastically affect the backscattered energy;

- For Passive UHF RFID many studies have already been conducted showing how often the performance is degraded by the presence of nearby objects;

- Metallic reflectors usually represent the most detrimental object close to the tag;

What about metallic reflectors for UWB RFID backscattering?
Interaction UWB tag – Metallic reflector

✓ measurements of the round trip channel transfer in the 2-12GHz BW

✓ simulations of the RFID tag backscattered electric fields and of its RCS

\[
|H_{\text{tag}}|^2 = \left(\frac{4\pi r}{\lambda}\right)^2 \frac{|E_{\text{sc}}|^2}{|E_{\text{inc}}|^2} = \frac{4\pi\sigma}{\lambda^2}
\]

\[
\Gamma_{IN} = \frac{b_2}{a_1} = H_{\text{read}}^T \left[ -j \left(\frac{\lambda}{4\pi r}\right)^2 e^{\frac{2\pi kr}{\lambda}} \right] \cdot H_{\text{tag}}
\]
Comparison Simulations/Measurements

- The RFID system is associated to a two port network

![Network Diagram]

- With simple manipulations of the S-matrix it is possible to connect any load to the simulated tag antenna, such as the «measured» charge

- In this way, a good agreement between measurements and simulations can be achieved
Characterization of UWB antennas backscattering in the presence of nearby metallic reflectors

**Top:** Measured Antenna mode scattering with $10\times10\text{cm}^2$ metal placed 1 cm behind the MDFS

**Bottom:** isolated MDFS

Simulated antenna mode scattering for the planar dipole
Top: Simulated average energy over the azimuth plane for the dipole.
Bottom: Measured Average energy over the azimuth plane for the dipole.

Measured Average energy over the azimuth plane for the MDFS antenna.
Analysis of the RFID backscattered signal (ideal scenario)

- the superposition principle is used to reconstruct the full tag backscattering signal from the one way radio channel

The complete response in A can be separated into 2 contributions:

B: the reader transmits towards the short-circuited tag
C: the tag radiates towards the reader in what we can call the antenna mode
Using Reciprocity theorem:

We can express the antenna tag effective height as a function of the own tag parameters (antenna impedance $Z_a$ and radiated field $E_{ant}$)

$$h = \frac{\lambda Z_a}{60\pi} \frac{r}{\exp(-jkr)} \frac{E_{ant}}{e}$$

Antenna tag induced Electromotive Force as a function of the incident electric field $E$:

$$EMF = hE$$

Thus the voltage at tag terminals induced by the $EMF$ can be generally written as

$$V_{tag} = EMF \frac{Z_C}{(Z_C + Z_{ant})}$$
Methods to compute backscattering from CAD tools 1/2

**METHOD 1**

Computation of:
1a) response of tag connected to 0Ω
1b) response of tag connected to another load (i.e. 50Ω)
1c) tag radiation pattern

1d) From 1a and 1b evaluation of the EMF and of the tag excitation
1e) the pattern provides the monostatic/bistatic backscattering from the new impedance

**METHOD 2**

Computation of:
2a) response of tag connected to 0Ω
2b) incident electric field to the tag
2c) tag radiation pattern

2d) evaluation of the tag excitation from the tag effective height
2e) the pattern provides the monostatic/bistatic backscattering from the new impedance

**DS**
(Direct Simulations)

Computation of:
3) response of tag connected directly to the relevant loads (0Ω and another load)

**KNOWLEDGE OF THE ANTENNA MODE BACKSCATTERING**
Example: simulation of a simple dipole

**DS:** results obtained by simulating directly the antenna mode scattering with the CAD tool WIPL-D

**CASE 1:** antenna mode scattering reconstructed by means of the antenna effective height

**CASE 2:** antenna mode scattering reconstructed by a differential scattering method
The backscattered signal in the antenna mode depends on the tag antenna impedance, the tag radiation pattern and the propagation channel.

We have the product (in the frequency domain) or the convolution (in the time domain) of the two channel responses.

\[
e_0' = Z_0 \left( \frac{\lambda}{60\pi} \right)^2 \frac{Z_a Z_C}{(Z_C + Z_a)} e \sum_{i,j} E_i E_j |A_i| |A_j| \exp\left( -j\omega \left( d_i + d_j \right)/c \right)
\]
Measurement Analysis

◆ The previous EMF expression can be calculated only if we know all the multi-paths directions of the electric field backscattered by the tag

◆ Alternative Solution:

✓ Expression of the received wave which contains only the antenna mode contribution

\[ b_{1L} - b_{1S} = S_{12}S_{21} \left( \frac{\Gamma_L}{1 - \Gamma_L S_{22}} + \frac{1}{1 + S_{22}} \right) a_1 = S_{12}S_{21} \frac{1 + \Gamma_L}{1 - \Gamma_L S_{22}} \frac{1}{1 + S_{22}} a_1 = \frac{S_{12}}{\sqrt{Z_0} (1 + S_{22})} (V_{2L}) \]

✓ Expression of the excitation voltage at tag terminals

\[ V_{2L} = (a_{2L} + b_{2L}) \sqrt{Z_0} = (\Gamma_L + 1) b_{2L} \sqrt{Z_0} = \sqrt{Z_0} \frac{1 + \Gamma_L}{1 - \Gamma_L S_{22}} S_{21} a_1 \]
Considerations about measurements

- We obtained the similarity between the proposed methodology and the direct measurements of the backscattering response.

- Some differences in measurements can be ascribed to the manual changes of the load impedance and some movement of cables.

- There is a clear advantage in having a single (one way channel) measurement by this method, when only the antenna mode backscattering is of interest, which is precisely the case as regards load modulated backscattering for RFID.

- A single measurement provides a better reliability, is less time consuming and easier to perform.
Full Electromagnetic Simulations

![Diagram of electromagnetic simulation setup]

- Reader (V1) connected to Tag (Z) with distances d = 1m and d = 0.8m.
- Graphs showing the intensity of electromagnetic waves over time (t [s])
  - Direct simulations
  - Superposition principle

Francesco Guidi                                Seminari fine II anno, XXV ciclo
Considerations about simulations

◆ Total agreement between the proposed method and the direct simulations of the backscattering for different tag loads

◆ Convolution between the channel from the reader to tag with the vice-versa

◆ We only need to simulate once the S-matrix to have the response for any load connected to the tag

◆ Results are in accord with previous considerations
Ongoing Activities

- With Ecole Polytechnique (ENSTA-ParisTech, Télécom-ParisTech)
  - Analysis of UWB RFID Backscattering in presence of perturbators with different permittivity (with Ecole Polytechnique)
  - Statistical Analysis of the UWB RFID backscattering

- With University of Bologna
  - Performance evaluation of Passive UWB RFID systems in multi-tag scenario, using data collected from both simulations and measurements (with University of Bologna)
Conférence Papiers


Journal Papiers

Dissemination 2/2

Deliverables for EU Project SELECT

- D2.1.1: Backscatter propagation modelling
- D2.2.1: Signal processing techniques
- D2.3.1: Multi-functional network design
Grazie