RFID UHF pour l'identification et la traçabilité des objets

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Agenda

- Generalities and Principles
- HF versus UHF
- UHF Spectrum regulations
- Back Scattering Modulation and Maximum Read Range
- UHF antennas (860-960 MHz)
- Propagation, absorption, detuning issues
- EPC Gen2 protocol
  - Integrated circuit – Memory
  - Coding and Modulation
  - Anticollision algorithms
RFID Principles

Radio Frequency IDentification

HF Tag

UHF Tag

antenna

chip

antenna

chip
RFID Principles

- **Data** is stored in a **chip** connected to an antenna.

- Uses radio frequency transmission in either, inductive **near field** or radiating **far field**.

- Ability to automatically identify **multiple objects without line of sight**.

- Tags can be **passive**, semi-passive or **active**, **with** or **without security**.
Different Frequencies are used: LF, HF, UHF…..

Could replace the bar code !!!
- Simultaneous reading of a large number of tags
- Tag does not need to be within line of sight of the reader
- Tag may be embedded in the tracked object

Used for many applications in a growing number of markets world-wide.
RFID Applications

- Real-time inventory and stock control
- Supply chain management (fashion, retail, pharmaceuticals)
- Libraries
- Rental
- Animal ID
Les métiers de la RFID

- Chip manufacturer / designer
- Inlay manufacturer
- Label manufacturer
- LF/HF/UHF readers
- Infrastructure, RFID stations
- Supervision, Communication, Installation, Maintenance
Market Potential

Estimated value share of RFID market in 2010, by region

Global forecast of RFID hardware, middleware and IT market
HF versus UHF
Inductive Coupling - Propagation coupling

**Near field (HF)**

- Inductive coupling
- Frequencies: LF (125 kHz) and HF (13.56 MHz)
- Impedance variation
- Loop antennas

![Near field](image1)

**Far field (UHF)**

- Propagation Coupling
- Frequencies: UHF (900 MHz) and MW (2.45 GHz)
- Backscattered modulation
- Dipole antennas

![Far field](image2)
UHF vs HF (1)

**UHF**
- Based on electromagnetic waves
  - Electric Field
  - Magnetic Field
  - Best Performances in “Far-Field” (FF)
- Long Range
  - E and H field in FF decrease with 1/r
- Performances in presence of dielectrics
  - bad

**Dipole antenna**

**Loop antenna**

**HF**
- Based on Magnetic Field
  - in “Near-Field” (NF)
- “Short” Range
  - H field in NF decrease with 1/r^3
- Performances in presence of high dielectrics
  - good
Low Frequency (LF): ~125 kHz
- Inductive coupling
- Data rate 10 kbits/s
- RW distances: 1m
- Metal: low perturbations
- Water: no perturbations

High Frequency (HF): 13,56 MHz
- Inductive coupling
- Data rate >=100 kbits/s
- RW distances: Max: 1m
- Metal: high perturbations
- Water: no perturbations

Ultra High Frequency (UHF): ~900 MHz
- E-field coupling
- Data rate >= 256 kbits/s
- RW distances: up to 10 m
- Metal: high perturbations
- Water: med. perturbations

Micro Wave (MW): ~2,45 GHz
- E-field coupling
- Data rate >= 256 kbits/s
- RW distances: >10m
- Metal: high perturbations
- Water: high perturbations
Security

People
- Access Control
- Security
- Payment
- Passport/Visas
- Transport ticketing

Short Range
- Identification
- Authentication
- Data Security

Long Range
- Identification

Objects
- Laundry
- Library
- Supply Chain
- Logistics
- Luggage
- Apparel
- Traceability

Limited Security

Smart cards, key fobs,...
UHF Spectrum regulations
### UHF regulation overview

#### EU
- Frequency: 865 MHz to 869.5 MHz
- Radiated power: 2 Werp

#### US
- Frequency: 902 MHz to 928 MHz
- Radiated power: 2,4 Werp

#### Japan
- Frequency: 952 MHz to 955 MHz
- Radiated power: 2,4 Werp (high power)

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<table>
<thead>
<tr>
<th>Channel band width</th>
<th>EU (200 kHz)</th>
<th>US (500 kHz)</th>
<th>Japan (200 kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel nb</td>
<td>15</td>
<td>52</td>
<td>9 for (high power) / 14 for (low power)</td>
</tr>
<tr>
<td>Synchronization</td>
<td>LBT</td>
<td>Frequency Hopping</td>
<td>LBT</td>
</tr>
<tr>
<td>Radiated power</td>
<td>2 Werp</td>
<td>2,4 Werp</td>
<td>2,4 Werp (high power) / 12 mWerp (low power)</td>
</tr>
</tbody>
</table>

#### Important Points
- **Listen Before Talk technique**: Interrogators are only permitted where they employ frequency agile techniques.
- **Only 10 sub-bands** – likely to be many more readers than that in same radio ‘space’ ⇒ Real risk of system degradation and data loss if these sub-bands are not used responsibly.

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ETSI EN 300 208 limitations

1. Very low listen threshold (-96 dBm)
   ► in free space, a reader transmitting at 2W will be detected by another reader at a range of 78 km!
   ► sharing channel is thus almost impossible in a same area

2. The Transmit spectrum mask defines spurious emissions at -36 dBm
   ► this spurious level is not compatible with the listen level of -96 dBm
   ► readers in 2 adjacent channels must be spaced by 30 m

3. The channel spacing is reduced to 200 kHz limiting the uplink data rate

Conclusions
► performances with the current 302 208 regulation are very limited
► a task group (TG34) is updating the regulations
   ● Limitation of 4 to 5 readers transmitting at the same time
   ● Time multiplexing by “global listen” or by “radio communication” between readers
Back Scattering Modulation and Maximum Read Range
Reader/tag data exchange (UHF)

- The reader sends commands & energy to the tag via pulse amplitude modulation.
- The tag sends responses to the reader via backscatter modulation.

The chip in the tag is powered
The tag changes its impedance by switching on and off a resistor (or a capacitor). This impedance variation will change the tag reflections seen by the reader antenna, i.e., the tag RCS=Radar Cross Section.

\[
\Delta \text{RCS} = \frac{\lambda^2}{4 \cdot \pi} \cdot G_{\text{Tag}} \cdot (|\Gamma_{\text{mod}}|^2 - |\Gamma_{\text{unmod}}|^2)
\]
Reader with linear polarized antenna

With linear polarized antennas:

- A tag’s performance depends on its orientation with respect to a linear polarized antenna.
Reader with circular polarized antenna

With circular polarized antennas, tag orientation is less critical.

- The helical nature of the field from a circular polarized antenna allows it to read tags in more than one orientation.

- The down side of circular polarized antennas is that their output is less than linear antennas (approximately 1/3 down).
FRIIS Formula applied to RFID

- Transferred power from a reader antenna to the chip

\[ P_{Chip} = P_{EIRP} \cdot \frac{\lambda^2}{(4 \cdot \pi \cdot R)^2} \cdot G_{Label} \]

- Peirp = Pe * Ge (dBi)
Read Range of an UHF/GHz Chip

- Example III (UHF)

- under EN 302 208 European regulation:
  \( P_{ERP} = 2 \text{ W equals } P_{EIRP} = 3.28 \text{W} \); \( G_{Label} = 1.64 \)
  \( f = 869 \text{MHz}; \ P_{CHIP} = 35 \mu \text{W} \)
  \( G_{\text{Matching}} = 0.8 ; \ G_{\text{Polarisation}} = 1 ; \ G_{\text{Antenna}} = 0.5 \)

\[
R_{max} = \sqrt{\frac{3.28W \cdot 1.64 \cdot 0.35m^2}{(4 \cdot \pi)^2 \cdot 35 \cdot 10^{-6} W \cdot 0.8 \cdot 1 \cdot 0.5}} = 6.90m
\]
Active vs passive

Passive tag
- RF Chip powering + backscattering
- Battery for chip powering only, RF transmission from tag to reader is backscattering
- Up to 10 m!

Semi-passive = Battery assisted
- Battery for chip powering & RF Transmission
- Emits its own signal.
- Up to 50 m!

Active tag
- Battery for chip powering & RF Transmission
- Up to 200 m!

Price ↗ with reading distance
UHF antennas (860-960 MHz)
Chip equivalent circuit

\[ Z_C = R + jX_C \]

\[ X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C} \]

......capacitive reactance
Example of UHF RFID chip: Monza 4 Impinj

<table>
<thead>
<tr>
<th>Chip Load Model</th>
<th>Single-port connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conjugate Match Impedance</td>
<td>866 MHz</td>
</tr>
<tr>
<td></td>
<td>13 + j151 Ω</td>
</tr>
<tr>
<td></td>
<td>1650 Ω</td>
</tr>
</tbody>
</table>
Impedance matching

\[ \Gamma = \frac{Z_a - Z^*_c}{Z_a + Z_c} \]

- Know impedance behavior of the Antenna
- The chip input
  - Know impedance behavior of the Chip
  - Match it!

- To ensure maximum power transfer from the antenna to the reader, the required output impedance should be
  \( \approx 22 + j\ 195 \ \Omega \) for 915 Mhz.
- This means a inductive (coil-like properties) antenna impedance
Connexion directe de la puce à l’antenne

Adaptation de l’impédance IC à l’impédance antenne via un transformateur d’impédance associant inductance série et inductance parallèle
Principe de l’adaptation

On veut: \( Z_A \text{ ramené} = Z_{ic}^* \)

- \( Z_A = \) résonance série du dipôle (quelques dizaines d’ohms et réactance faible)
  - A priori à l’INTERIEUR du cercle \( \text{Re}(Z_{ic})=\)constante car valeur faible
  - validité du transformateur d’impédance proposé.
Near-field and far-field elements
Examples de tags UHF à connexion directe

<table>
<thead>
<tr>
<th>Antenna Design</th>
<th>Layout</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range: Far Field</strong></td>
<td></td>
<td>Dimension: 98mm x 10mm</td>
</tr>
<tr>
<td><strong>Name: FF98-4</strong></td>
<td></td>
<td>Works best up to Epsilon r = 4</td>
</tr>
<tr>
<td><strong>Range: Far Field</strong></td>
<td></td>
<td>Dimension: 95mm x 10mm</td>
</tr>
<tr>
<td><strong>Name: FF95-8</strong></td>
<td></td>
<td>Works best up to Epsilon r = 8</td>
</tr>
<tr>
<td><strong>Range: General Purpose</strong></td>
<td></td>
<td>Dimension: 33mm x 24mm</td>
</tr>
<tr>
<td><strong>Name: GP33</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Range: Mid Range</strong></td>
<td></td>
<td>Dimension: 34mm x 15mm</td>
</tr>
<tr>
<td><strong>Name: MR34</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Application: Fashion / airport baggage tagging</strong></td>
<td></td>
<td>Dimension: 50mm x 30mm</td>
</tr>
<tr>
<td><strong>Name: OmniDir50</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Read range (in meters)

Loop resonance

Dipole resonance
Propagation, absorption, detuning issues
Multipath effects (1)

At UHF frequencies multi-path RF waves, caused by reflections from the floor and other obstructions, may combine constructively or destructively.
Multipath effects (2)
Dynamic reading

Tags detected

- 100%
- 90%
- 0%
Standard UHF Tag tuned at 900 MHZ placed in water. Range: $\approx 0$ m

Attenuation $\approx -40$ dB
Detuning: [900→750] MHZ
UHF RFID Inlay: Material Detuning Effect

Table E: Permittivity Values of the Reference Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>PTFE</th>
<th>PMMA</th>
<th>PC</th>
<th>PET</th>
<th>PU/PUR</th>
<th>KITE</th>
<th>CARP</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Figure 7: UHF Reference Materials
Label position

It may not be possible to read labels on cartons in the center of a pallet.

- It depends on a number of factors:
  - Output power of the reader antennas
  - The distance from the antennas
  - The material in the cartons

- If at all possible, position the labels on the outside of the pallet load.

- One situation that **must** be avoided is overlapping labels
  - Labels that overlap are the same as placing each label close to metal. They de-tune each other and performance is lost.
EPC Gen2 protocol
• **EPC Global**

  - *Not-for-profit organization entrusted by industry to establish and support the Electronic Product Code (ePC).*

  - *Develop a global standard for immediate, automatic, and accurate identification of any single item in the supply chain of any company, in any industry, anywhere in the world. The tag is only a token to access distributed and replicated databases.*

  - **EPC Global Generation 2 (new global protocol available since December 2004)**

• **ISO 18000 – Part 6 (International Standard Organization)**

  *Information technology - Radio frequency identification (RFID) for item management Type C (same as EPC Global Gen2, RTF protocol)*
EPC Gen2 protocol
Integrated circuit - Memory
Gen2 Block Diagram

+ data encoder
+ clock extractor
Memory types and Gen2 operations

**Read Only (RO)**
Data (ID) are burned into the tag at factory ⇒ can never be changed

**Write Once Read Many (WORM)**
Data generally written into tag at point of application ⇒ when encoded, cannot be reprogrammed

**Read Write (RW)**
Data may be written, erased and rewritten into memory in field

<table>
<thead>
<tr>
<th>Operation</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inventory</strong></td>
<td>Singulate tags and receive their EPCs</td>
</tr>
<tr>
<td><strong>Read</strong></td>
<td>Read tag memory</td>
</tr>
<tr>
<td><strong>Write</strong></td>
<td>Write tag memory</td>
</tr>
<tr>
<td><strong>Lock</strong></td>
<td>Permalock, lock, or unlock tag memory</td>
</tr>
<tr>
<td><strong>Kill</strong></td>
<td>Render a tag permanently inoperative</td>
</tr>
</tbody>
</table>
Not everything below is implemented usually:

- **UID = Unique ID**
  Unique ID, usually read only similar to the MAC address of a network card.

- **EPC memory = Electronic Product Code**
  Writable 96 bits EPC code similar to barcode

- **EAS = Electronic Article Surveillance**
  Security bit implemented on some chips

- **AFI = Application Family Identifier**
  Byte used to categorize the tag by application

- **Write access**
  Byte used to store the ACL (Access Control List) of the user memory

- **Passwords to kill the tag or read/write**
  Different 32 bits passwords used by the tag. If unused, bits are zero

- **User memory**
  Structure and size depends on the chip - up to a few kb
Delivery types

Bumped Wafer on Film Frame Carrier
UCODE HSL, UCODE EPC 1.19, UCODE EPC G2

Standard Package TSSOP8
UCODE HSL, UCODE EPC G2

I-Connect Flip Chip Package
UCODE EPC G2

NXP Ucode
Flip Chip Assembly

Assembling process adds parasitic Capacitances

\[
C_{\text{parasit}} = C_{\text{chip}} = R \]

\[
C_{\text{tot}} = C_{\text{parasit}} + C_{\text{chip}}
\]
EPC Gen2 protocol
Coding and Modulation
Reader-to-Tag communications

Modulation
ASK: can be detected with a simple envelope detector

- Double-sideband amplitude shift keying (DSB-ASK)
  - Simple, but not spectrally efficient
- Single-sideband amplitude shift keying (SSB-ASK),
  - More complex (requires a IQ modulator)
  - More spectrally efficient
- Phase-reversed amplitude shift keying (PR-ASK)
  - Reduces the width of the spectrum

Data Coding
Pulse interval encoding (PIE)
- Ensures a constant RF energy from the reader to power the tag chip.
Reader-to-Tag: PIE encoding

Tari = reference time interval (duration of a data-0)

Data rates according with local radio regulations:
- 6.25μs = 160kbps
- 12.5μs = 80kbps
- 25μs = 40kbps

<table>
<thead>
<tr>
<th>Tari Value</th>
<th>Tari-Value Tolerance</th>
<th>Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.25 μs</td>
<td>+/- 1%</td>
<td>DSB-ASK, SSB-ASK, or PR-ASK</td>
</tr>
<tr>
<td>12.5 μs</td>
<td>+/- 1%</td>
<td></td>
</tr>
<tr>
<td>25 μs</td>
<td>+/- 1%</td>
<td></td>
</tr>
</tbody>
</table>
Tag-to-Reader: FM0 or Miller

FM0 inverts the baseband phase at every symbol Boundary.

A data-0 has an additional mid-symbol phase inversion.

Baseband Miller inverts its phase between two data 0s in sequence, or in the middle of a data-1 symbol.
### Subcarrier spectral allocation

<table>
<thead>
<tr>
<th>Region</th>
<th>Link</th>
<th>Rates / Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Forward</td>
<td>Tari=25µs SSB-ASK</td>
</tr>
<tr>
<td></td>
<td>Backscatter</td>
<td>53.3 kbps at 213.3 kHz subcarrier</td>
</tr>
</tbody>
</table>

**B: Subcarrier Spectral Allocation (CEPT: Multiple Channels)**

- Reader CW (during backscatter)
- Reader Modulation (SSB ASK shown)
- Tag Response
- Primary Sidebands

Note: Reader modulation may also use PR-ASK

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Frequency (kHz)
## Read rate - Bit rate

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Read rate</strong></td>
<td>600 tags/sec</td>
<td>Read rate: 1600 tags/sec</td>
</tr>
<tr>
<td><strong>T→R Bit rate</strong></td>
<td>from 16 kbits/sec (dense reader) to 160 kbits/sec (Maximum throughput)</td>
<td>from 64 kbits/sec (dense reader) to 640 kbits/sec (Maximum throughput)</td>
</tr>
<tr>
<td><strong>R→T Bit rate</strong></td>
<td>from 40 kbits/sec (Nominal) to 80 kbits/sec (Maximum throughput)</td>
<td>from 40 kbits/sec (Nominal) to 128 kbits/sec (Maximum throughput)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
<th>Communication speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noisy</td>
<td>Need to talk slowly and carefully</td>
</tr>
<tr>
<td>Europe</td>
<td></td>
</tr>
<tr>
<td>Many readers</td>
<td></td>
</tr>
<tr>
<td>Quiet</td>
<td>Can talk fast</td>
</tr>
<tr>
<td>North America</td>
<td></td>
</tr>
<tr>
<td>Few readers</td>
<td></td>
</tr>
</tbody>
</table>

- Gen2 sometimes needs fast tag reads (Pallets moving through a dock door)
- Gen2 sometimes needs slow tag reads (Noisy environments)
- Solution: Variable read rates
EPC Gen2 protocol
Anticollision algorithms
Protocol: *Reader Talk First* vs *Tag Talk First*

**RTF**

1. Tag power up
2. Wait for the reader cmd
3. Receive the reader cmd
4. Response to the reader

**TTF**

1. Tag power up
2. Send ID and data
Collisions and Anticollision Algorithm

**Origine of the collision:**
A collision occurs when two or more transponders send their data at the same time.

**Anticollision algorithm in EPC Gen2 protocol:**
Slotted Aloha-based probabilistic algorithm
Simplified Aloha algorithm

1. Everybody pick a small number and a nickname (alias).
2. Is anybody’s number = 0?
   - Nobody: Everybody subtract 1
   - 1 person: Tell me your alias
     - I hear you. Can you hear me?
       - Tell me your full name
         - Go to sleep
     - Wait for now, we’ll try again
       - Everybody else subtract 1
   - 2 or more people: Wait for now, we’ll try again
Slotted Aloha-based probabilistic algorithm

- Reader issues a Query command with a parameter $Q$
  - Starting the inventory round
- Tags load a $Q$-bit random value into their slot counter
  - If a tag loads a zero it replies immediately, backscattering an RN16
- Reader acknowledges the tag by sending an ACK containing this same RN16
- Acknowledged tag backscatters its PC, EPC, CRC-16
- Reader issues a QueryRep command
  - Tag toggles the state of its inventoried flag and leaves the round
  - All other tags decrement their slot counters
  - If any tag decrements to zero, it replies with an RN16

RN16 (16 bits random number) ≠ $Q$-bit random value (length $L = 2^Q - 1$)
• Slot number of each tag is independently chosen
  ⇒ collisions happen

• If $2^Q - 1 = \text{number of tags in the read area}$
  ⇒ minimize collision rate
  ⇒ maximum system efficiency

• **The application can optionally set the starting point**
  – Application can optimize inventory, based on a priori knowledge of the population size, by setting the starting $Q$ value

• **Real-time $Q$ adjustment is handled by the reader**
  – At any given time instant, peak inventory efficiency requires:
    • Allocated slots = Number of remaining (uncounted) tags
    – Real-time visibility into the physical layer metrics is critical
    • Number of single, collided, and empty slots
Typical read rate

Preliminary Stress Test Results

- 325 tag hard to read pallet
- Portal configuration
- Pallet moving at 1.8 m/s