RFID PLATFORM WITH SENSORS INTEGRATION CAPABILITIES

“One Global Sensing Tag”

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Project objectives:

Develop technologies that make it possible to use the same RFID solutions in logistics and consumer applications.

Radio Frequency Identification (RFID) is a wireless communication technology that uses radio frequency waves to transfer information between tagged objects and readers without line of sight. The objects are numbered, identified, catalogued, and tracked.
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RFID Tag

- Consists of a ASIC/microchip and antenna
- Is a thin, flexible, low cost product
- Can be embedded within a product or applied as a label
- Has an unlimited lifespan
- Type of tags
  - Passive
  - Semi passive
  - Active
## RFID Standards

<table>
<thead>
<tr>
<th>Type</th>
<th>Standards</th>
<th>Applications</th>
<th>Frequency Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID Tags</td>
<td>ISO 18000</td>
<td>Any application</td>
<td>LF: 125/134kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18000-2</td>
<td>18000-3 Mode 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EPC G2</td>
<td>Retail, logistics, healthcare and life sciences (HLS) industry</td>
</tr>
<tr>
<td></td>
<td>ISO/IEC 11784/5</td>
<td>Animal tagging</td>
<td>ISO 14443 Type A TypeB</td>
</tr>
</tbody>
</table>

| RFID Contact less Cards       | ISO/IEC 14443        | Proximity cards, ticketing                       | ISO 14443 Type A TypeB |
| ISO/IEC 15693                 | Vicinity cards, access control |
| ISO/IEC 10536                 | Contact less identificati on cards |
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WP1 RFID Platform Specification

- User requirements
- Technical specifications for the RFID platform with sensor integration capabilities
- Choice of ASIC, sensors, assembly technologies with respect to the RFID platform specifications and compatibility to the modelling and simulation tools and the processing requirements.
- Feasibility study performed to determine the RFID platform implementation aspects: design of the sensors, RF front end electronics, mixed signal interface, communication, protocols and integration issues.
- Critical questions related to the RFID technologies and their impact on design and implementation for wireless sensors was addressed and a trade off was made for the implementation of the RF front end and the protocol implementation.
WP2 Antenna Design and Implementation

*Platform tolerant HF coil and UHF dual-band PIFA Antenna*

- **867/915 MHz**
  - Simulated impedance mismatch and radiation characteristics on a 1.9mm-thick TMM3 substrate

- **13.56 MHz**
  - Simulated input voltage for a 1.9 mm-thick TMM3 antenna on free space (blue) and on metal (red).
  - Input impedance of the RF front-end: RC-circuit with values $R = 2\,\Omega$ and $C = 28.5\,\text{pF}$

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**Multi-band antenna layout**

1.9 mm

<table>
<thead>
<tr>
<th></th>
<th>867 MHz</th>
<th>915 MHz</th>
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</thead>
<tbody>
<tr>
<td>$D_\theta$ [dBi]</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>$D_\phi$ [dBi]</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>$D_{RHCP}$ [dBi]</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>$D_{LHCP}$ [dBi]</td>
<td>-0.7</td>
<td>0.0</td>
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<tr>
<td>rad. eff. [%]</td>
<td>35</td>
<td>23</td>
</tr>
</tbody>
</table>
WP2 Antenna Design and Implementation

*Fractal Antenna*

- **Objectives:**
  - UHF band + 2.45GHz
  - 1.9 mm thick TMM substrate

- **Features**
  - Multi-band antenna.
  - Small size.
  - Trial-and-error design

![Graph showing measured and simulated S11 values](chart.png)

- **Optimized for 2.45GHz**
- **Measured S11**
- **Simulated S11**
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**WP3 High Data Rate Communication**

- Goal of achieving 10Mb/s at a few cms with RFID technique
- Air interface specifications
  - Dual mode operation
  - Tag powering using UHF
  - Communication at ISM band (2.45GHz or 5.8 GHz)
  - Protocol elaboration
- Power budget links
  - Reader architecture: 10 cms achievable (oscillator phase noise limiting)
  - Tag powering:
    - At UHF for $d=\lambda/2$ (17cm), power available at the tag: $P_t = 14\text{dBm}$ (5mW)
    - Rectifier efficiency of 50 %
    - Memory bank of 64Mb: 1.25 mW
Multi-band front end: designed and optimized for 100 µA load. Current consumption: 40 µA
At HF, available input voltage: 5V
At UHF: matching of 0.96 for data "0" and 0.86 for data "1" with an antenna input impedance of
9.5+259.4j
Achievable distance: d = 1.28m

Testing:
At HF: ISO 14443-A logic implementation
At UHF: EPC Gen 2 logic implementation

Implementation:
UMC 0.18µ - 02/26/2007
WP4 RF Front End Design

First phase: block testing: UMC 0.18 mixed mode
Submitted February 26, 2007

Multi-band front end
1000 µm × 1200 µm

ISO 14443-A
300 µm × 300 µm

EPC Gen2
500 µm × 500 µm
Scenarios evaluated for implementation:

- Passive operation without battery. The tag can be read and written and use its sensor interfaces when powered by a reader.
- Semi-passive operation with battery assistance. In addition to the functionality for the passive operation the tag can be programmed to use its sensors and store the results in memory at regular intervals even when there is no reader in the vicinity.
- Semi-passive operation with battery assistance and external microcontroller. This allows for more programmability as the external microcontroller can implement more complicated behaviour and even add new sensor interfaces. Results can still be communicated via an RF reader.
- Active operation with external microcontroller.
Architecture – example from investigated design

**Digital RX front end (EPC2 and ISO 1443-A)**

Detection of bits is measurement of pulse length

- Tari = 25us “0”
- 1.5-2 Tari = 37.5-50 us “1”

- Pulses shorter than 31us = “0”, longer pulses = “1”, preamble RTcal is detected as more than 56 us.

- Gate count = 194 (when synthesized for Xilinx FPGA)

**Control logic. Designed with no continuously toggling elements.**

**Event pulse**

**Ripple counter (4 bits + overflow shown).**

Uses less power than synchronous counter. Real implementation will have more bits and some may be prescaler bits without latch or clear.

**Output latch. Uses less power than FF.**

Module has been implemented in VHDL and simulated (e_front_end.vhd and t_front_end.vhd).

Gate count = 194 (when synthesized for Xilinx FPGA)
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WP5 Digital Control Communication Protocol Design

- **Main state diagram for digital control**

  - Waiting while external I2C access
  - Waiting while RF access
  - Measurement by RF command
  - Auto mode measurement (at regular intervals)
  - Auto Adc
  - Auto I2C-Clr
  - Auto I2C-WriteWait
  - Auto I2C-ClrWait
  - Read Auto-command from memory
  - (Clearing next memory location)
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WP6 Mixed Signal Generic Interface

Objective:

- Specify and implement a generic mixed signal interface to access different sensors and transfer the information using the common RFID platform with sensor integration capabilities.
- Low power consumption
- Low voltage operation
  - Supply voltage: 1-1.2V
  - Current consumption: 40µA
  - Resolution: 8-10 bit
  - Sampling rate: 10kHz
  - Process: 0.18µm CMOS
  - Capacitance range 10±2pF
The research is focused on achieving system level integration. The main drivers for this effort are cost and size reduction.

The goal is to find a cost efficient way of integrating all the devices that are part of the RFID platform (digital core, RF front end, and non volatile memory, mixed signal interface).

Two approaches are used for integration:
- System on chip (SOC) for the active circuitry
- System in package (SIP) for the integration of the active circuitry with the passive substrate, antenna, sensors

2D Embedded microelectronics
- Micro vias
- Short interconnect between chips and substrate
- Compact and thin chip
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WP8 Sensors Design and Fabrication

**Pressure and Temperature Sensors**

- The designed pressure/temperature sensor chip size is 1.0 x 1.0 mm²
- The complete pressure/temperature sensor is constructed of an array of surface micromechanical, capacitive sensor elements
- The base capacitance of the pressure sensor is 8.7 pF and the sensitivity is 1.3 pF / bar within 0.1-1.1 bar
- The base capacitance of the temperature sensor is 9.88 pF at 100°C and the simulated sensitivity is -1.2 fF/°C within 0-100°C (real sensitivity expected to be larger)
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**WP8 Sensors Design and Fabrication**

**Humidity and pH Sensors**

- Same geometry for both sensors: interdigitated microelectrodes with the specific polymer onto them.
- Microelectrodes of Au on glass substrate, 250nm – 3μm wide electrodes, with area 0.2 mm\(^2\) – 5mm\(^2\), polymer thickness 1 μm – 5μm; 0.5mm total sensor thickness.
- Humidity sensor and its reference: measured based capacitance 6-7pF, variation 1-2pF for 30%RH to 80%RH, sensitivity 0.04pF/%RH at 0.1V.
  - Design improvement for nominal voltage (1.2-1.8V)
- pH sensor: base capacitance in dry state 13-17pF, in liquid >60pF. Needs improvements for design, polymer quality, voltage.

*Sketch of interdigitated capacitor structure: (left) top view, (right) cross-section*
WP8 Sensors Design and Fabrication

**Humidity and pH Sensors**

- Same geometry for both sensors: interdigitated microelectrodes with the specific polymer onto them.
- Sensing area 0.8 mm².

*SEM, 500nm interdigitated capacitor structure*

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**%RH measurements**

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**pH 6 - pH 7 - pH 8 sweep**

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WP9 Assembly Design

- Objectives:
  - Development of packaging and assembly solutions for the RF wireless sensor platform prototype.

- Implementation:
  - In the first phase, all individual functional blocks will be put together on a carrier by flip-chip, providing wire bonding for electrical interconnection.
WP10 Testing and Characterization

- The functionality of the building blocks (antenna, RF front end, digital control, mixed signal interface, and the sensor) will be tested individually in other work packages.
- Necessary digital filters will be developed that are needed to decode the backscattered signal, modulated by the RFID sensor.
- The sensor test bench will be used to characterize the performance of RFID sensors.
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WP11 Dissemination


- The project web-site (www.intellisenserfid.com) presenting the project results was setup (December 2006).

An active contact with the EU and the groups involved in the EU initiatives related to RFID was established. Participation to the Workshops organized by EU in Brussels:

- “From RFID to the Internet of Things” March 6-7th, 2006.
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WP11 Dissemination

IntelliSense RFID project expands the technical and market potential of RFID technology by developing multi-protocol devices with sensing capabilities that are able to sense the environment and communicate at different frequency bands.
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Project Advisory Committee

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<th>NOKIA</th>
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<th>UPM</th>
<th>VTI TECHNOLOGIES</th>
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"There is nothing more powerful than an idea whose time has come."
Victor Hugo