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Tor Vergata

Passive Wireless Sensing by *RadioFrequency Identification*

Gaetano Marrocco

Pervasive Electromagnetics Lab

Università di Roma Tor Vergata

Gaetano.marrocco@uniroma2.it

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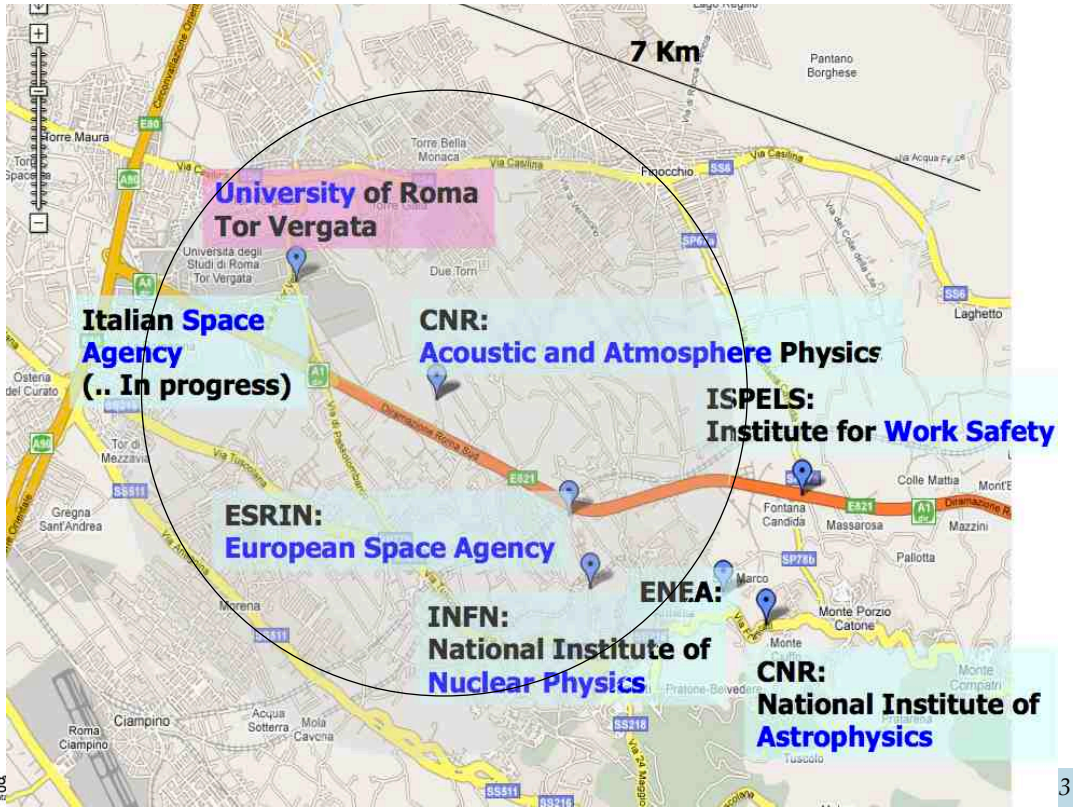
The Research District



Department of Civil Engineering and Computer Science Engineering

Research for the Space, Environment and People

Highly Multi-disciplinary

- Structure Eng.
- Environment Eng.
- Computer Science
- Electromagnetics
- Automatic Controls
- Bio-Engineering
- Remote Sensing
- Optimization

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Pervasive Electromagnetics Lab

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- Positive interaction of the classic Electromagnetics with the Materials Science, Computer Science, Sensors, Medicine, Mechanics and Electronics
- Cross-discipline with the potentiality to provide the very physical layer of the emerging **Internet of Things** that enables the Internet to get into the Real World of physical objects.
- Core research: Radio frequency Identification (RFID) devices and algorithms for **short-range sensing**, ready to be seamlessly embedded into objects, plants, buildings as well as over and even inside the human body with application to **Smart City**, **e-Environment**, and **e-Health**.
- Other Research: **Distributed antenna systems** over naval and satellite Platforms

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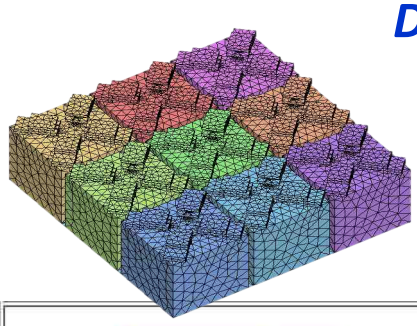
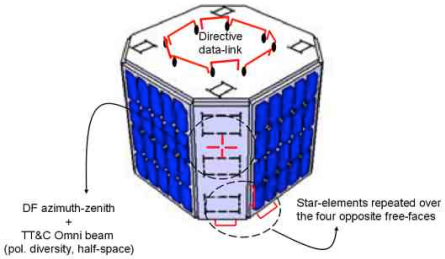
Recent Projects for Estec

Distributed Antennas for Small Sats.



2011-2014 Modular and customisable accomodation friendly antenna system for satellite avionics
funded by ESA-ESTEC



2009-10 Miniaturized Multi-Function Antenna System for Micro/Nano-Satellites
funded by European Space Agency

With **IDS, RUAG, SATIMO**

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Pervasive Electromagnetics Lab

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Gaetano Marrocco
Director

Rossella Lodato

Sabina Manzari

Stefano Caizzone

Sara Amendola

Tullio Musa

Cecilia Occhiuzzi

- **Electronic Engineers**
- **TLC Eng.**
- **Biomdical Eng.**

Cristina Caccami

Carmen Vallese

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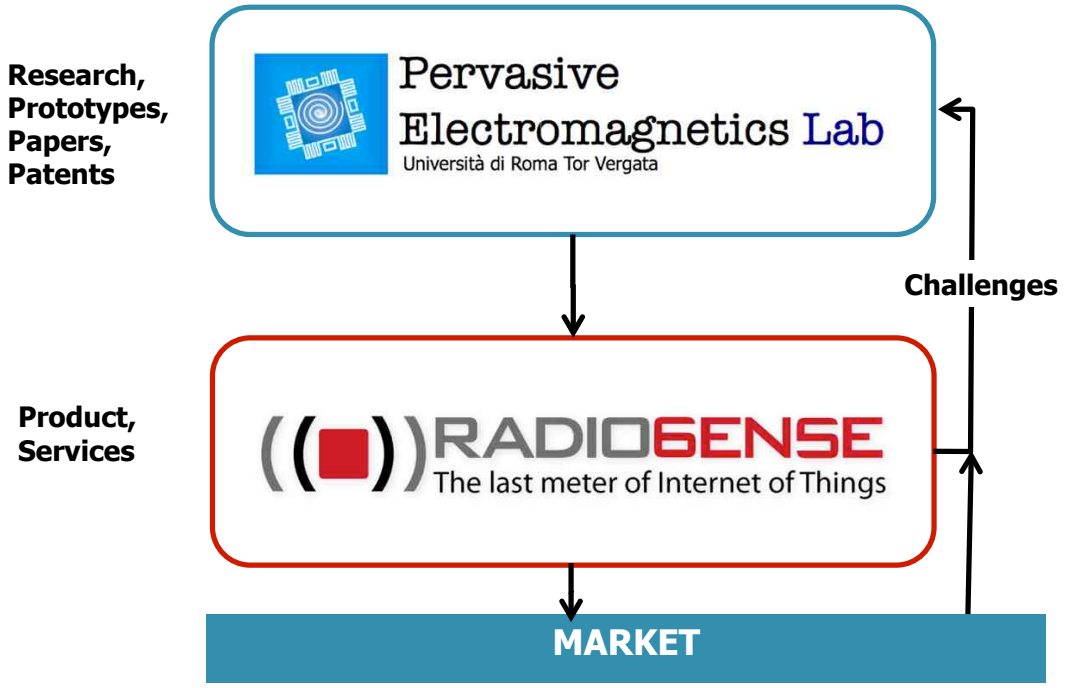
Research & Services



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RFID Basics

Identification of Objects

From visual to Electromagnetic labeling

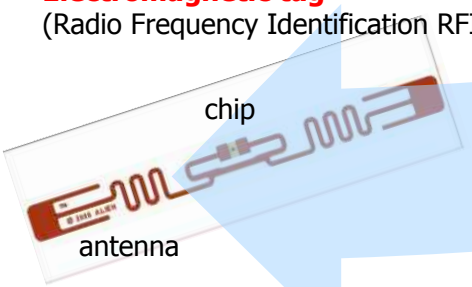
Printed Label

Direct and Visual access to data

Barcode

- Indirect access to data
- Binary coding
- Optical reading by laser scanner
- Reading range: a few cm

Electromagnetic tag
(Radio Frequency Identification RFId)



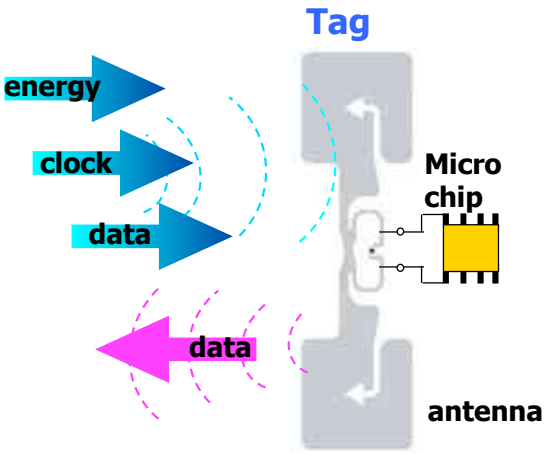
Electromagentic access to data

Electronic tag (Magnetic & Smart Cards)

- Data reading by electrical contact or magnetic induction
- Battery-less devices
- Binary coding

RadioFrequency Identification (RFID)

Reader

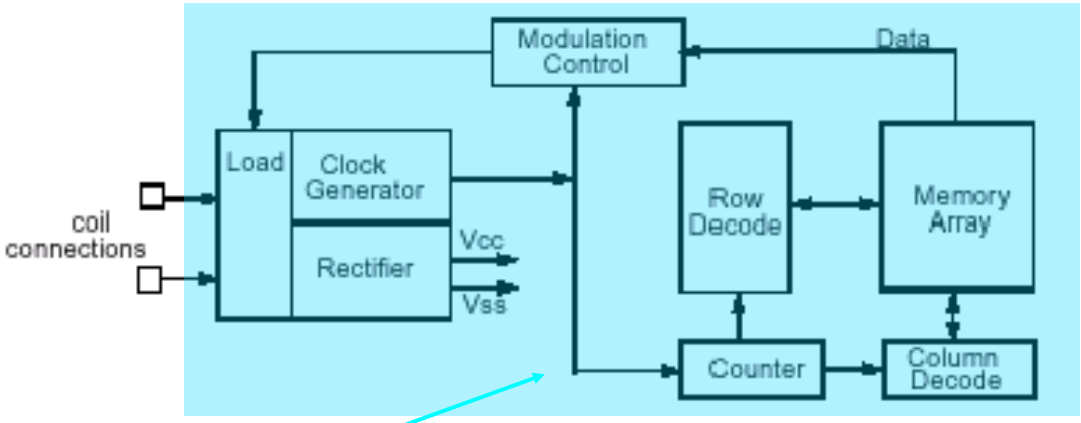


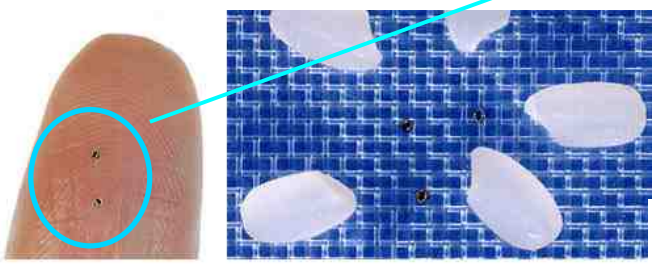
- PASSIVE devices: Tags do not contain a battery; the power is supplied by the reader.
- BACKSCATTERING: Tags reflect the reader's signal right back, modulating the query signal to transmit data.

- Back-scattered data modulation
- **Complex impedance matching**

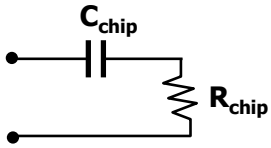
$$Z_A = Z_C^*$$

UHF RFID Microchips





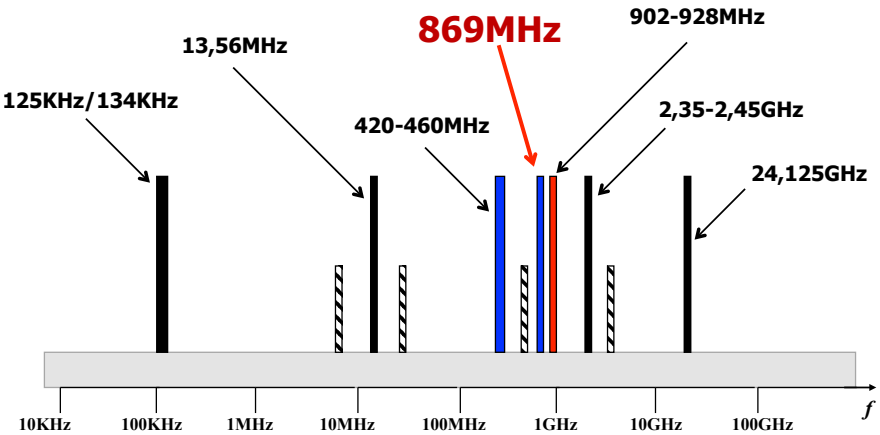
A New RFID with Embedded Antenna μ-Chip



Hitachi µ-chip RFID Technology Compatible with Gamma Sterilization

Tests with MDS Nordion reveal µ-chip can withstand at least 500 kGy gamma ray exposure

Frequency bands



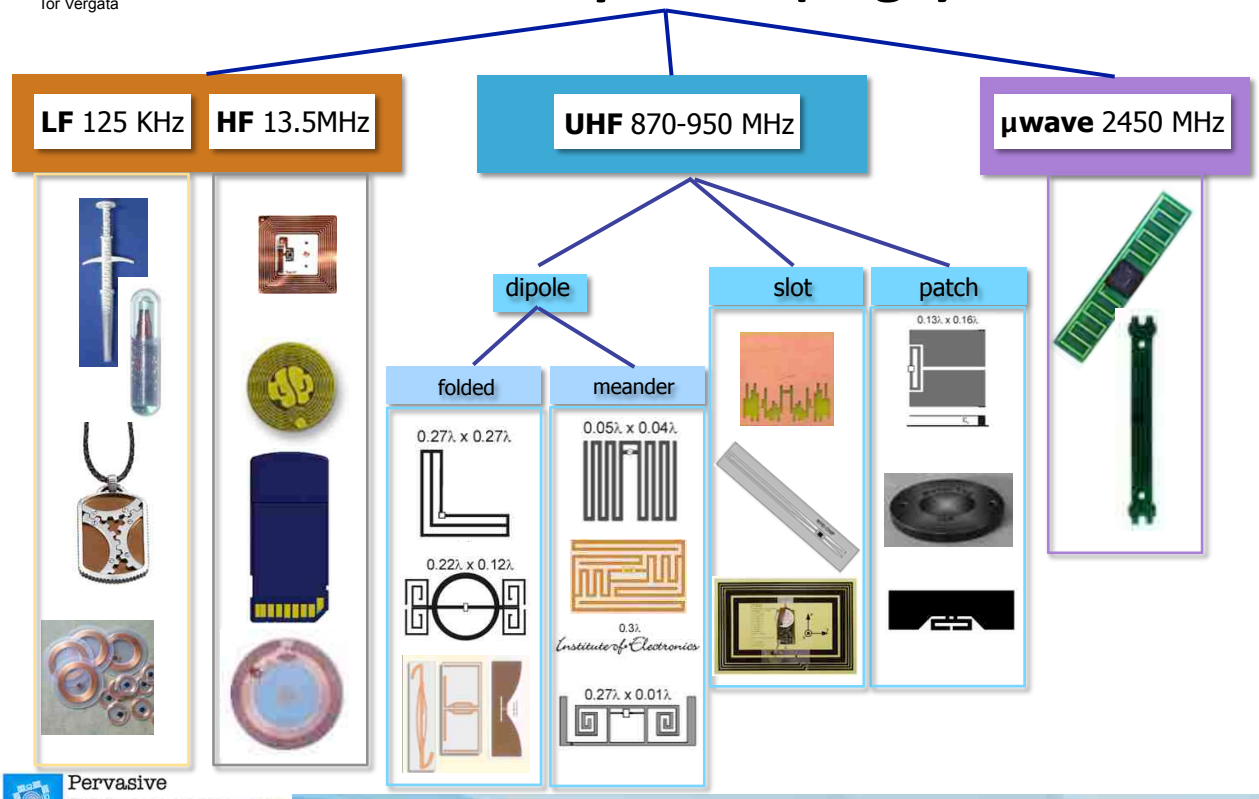
International RFID

European RFID

U.S. RFID

Local RFID

RFID Species (tags)



UHF RFID readers

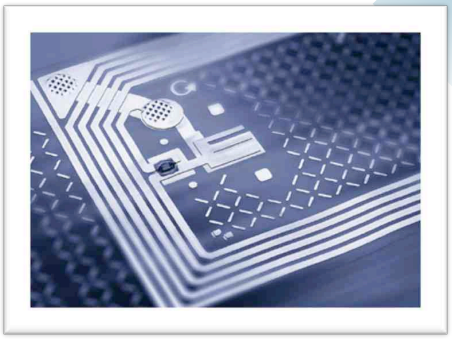
Hand-Held reader

Fixed reader

Embedded module

Bluetooth module

Smartphone dongles



Sensing:
give a "state" to an object

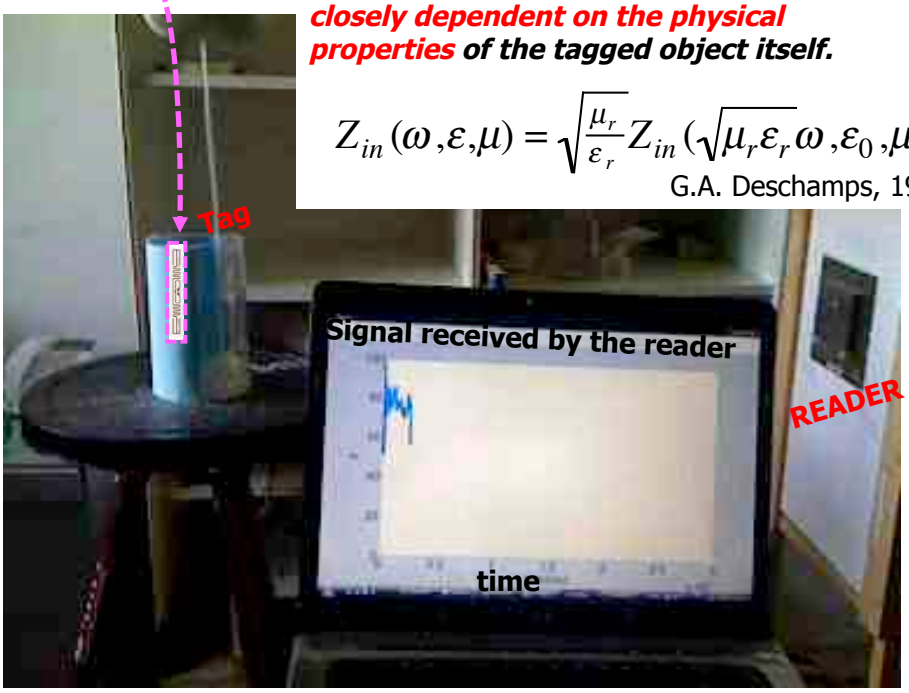
Labeling:
give an ID to an object

Sensing-Antenna Rationale

***The electrical features** of a passive RFID transponder placed on a target **are closely dependent on the physical properties** of the tagged object itself.*

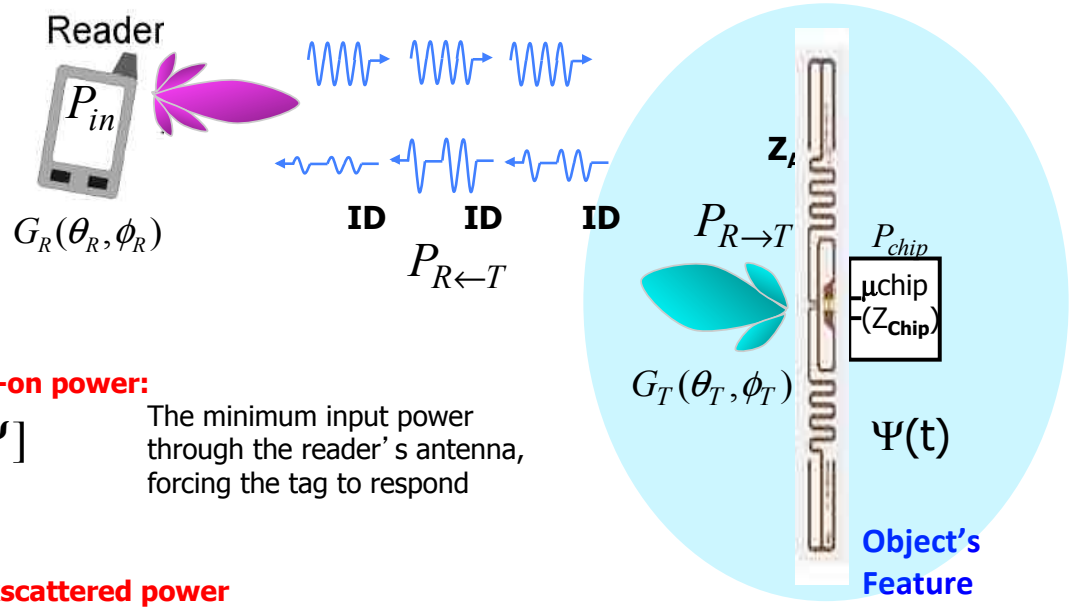
$$Z_{in}(\omega,\varepsilon,\mu)=\sqrt{\frac{\mu_r}{\varepsilon_r}}Z_{in}(\sqrt{\mu_r\varepsilon_r}\,\omega,\varepsilon_0,\mu_0)$$

G.A. Deschamps, 1962



What the Reader may measure

- accessible data



1. Turn-on power:

$P_{in}^{to}[\Psi]$ The minimum input power through the reader's antenna, forcing the tag to respond

2. Backscattered power

$P_{R\leftarrow T}[\Psi]$ (RSSI - received signal strength indication)

Object's Feature

-Geometrical
-Chemical
-physical

The RFID- Sensing Problem

$$P_{in}^{to}(\Psi, d, \theta_{R,T}, \phi_{R,T}, environment)$$
$$P_{R\leftarrow T}(\Psi, d, \theta_{R,T}, \phi_{R,T}, environment)$$

↑ **measurement** ↑ **Reader-tag position**

?

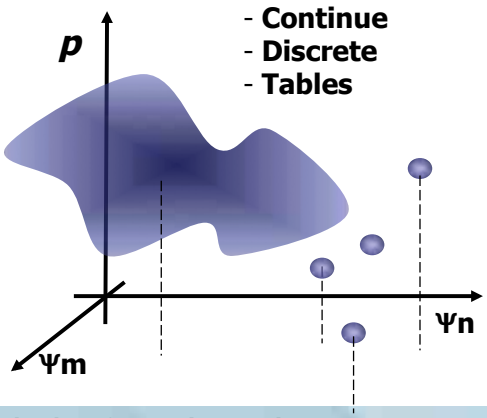
$$\Delta\Psi(t)$$

Unknown

Definition and Shaping of Data Inversion (Calibration) Curves

$$p(P_{R\leftarrow T}, P_{in}^{to}) \leftrightarrow \Psi$$

- **Multidimensional**
- **Continue**
- **Discrete**
- **Tables**



Technology

- Shape Memory Alloys
- Carbon Nanotubes
- Hygroscopic Polymer
- Textile & Elastic Substrates
- Inertial Switches

Environment & Things

- Humidity
- Temperature
- Ammonia
- Deformations
- Cracks

Wearable systems

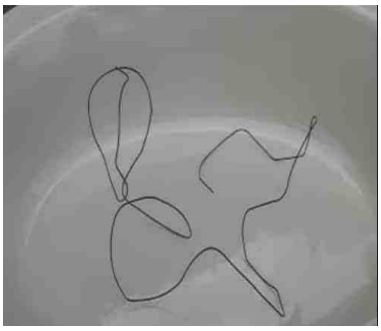
- Motion
- Breath
- Neuropathologies
- Stress
- Edema
- Stenosis

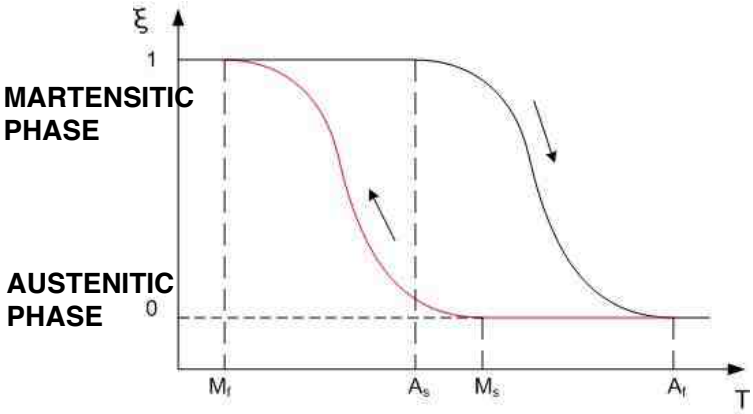
Sensing Temperature

1. Temperature Thresholds

Shape Memory Alloy

A Shape memory alloy is an alloy that "**remembers**" its original forged shape: after being deformed, it returns to that shape, if it is put in a hot environment

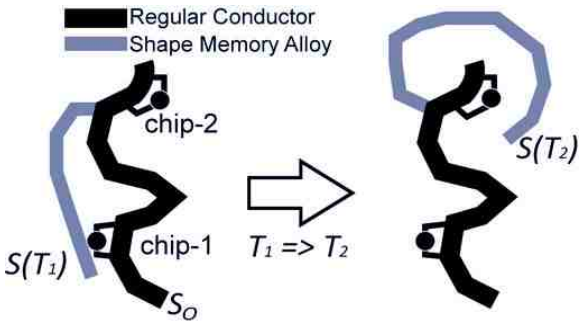




1. Temperature Thresholds

RF-Thermal device

*Antenna which senses the change of the object (or of the environment) through the variation of its **shape***



S_0: parameter-independent Shape

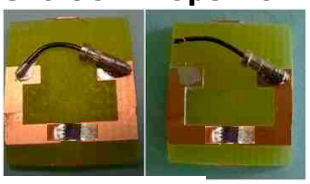
S(T): parameter-dependent Shape

S. Caizzone, C. Occhiuzzi, G. Marrocco, "**Temperature Sensing by Multi-Chip RFID Antenna Integrating Shape-Memory Alloys**", *IEEE Trans. Antennas. Propagat.*, 2011

1. Temperature Thresholds

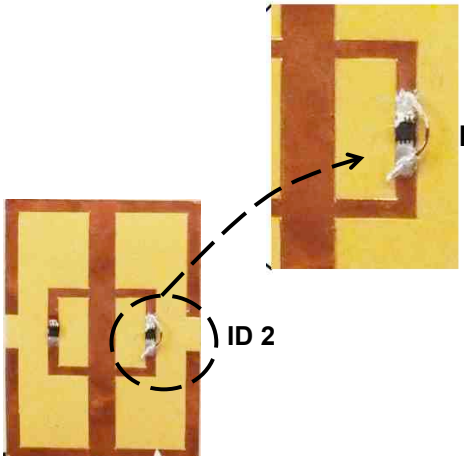
Temperature-controlled Modulation

Short c. **Open .c.**



T<Ta
➔ ID.1

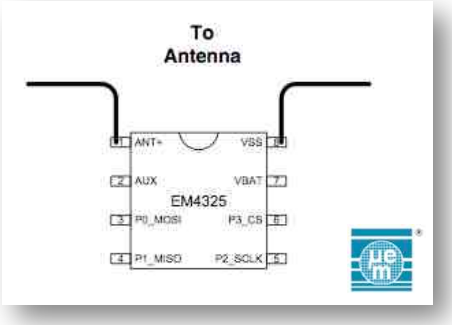
T>Ta
➔ ID.1 + ID.2



When T>Ta the sensor reacts changing **permanently** its state.

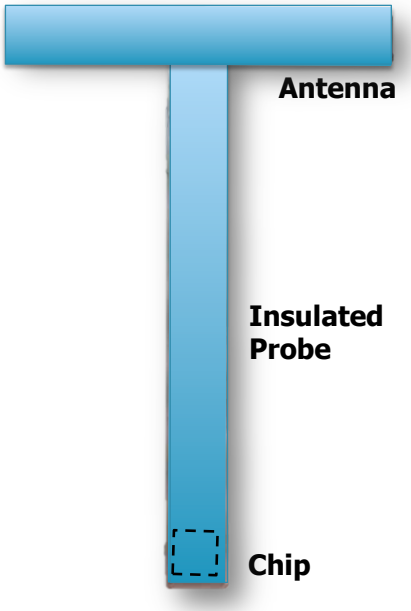
2. Absolute Temperature Logger

- On-chip **integrated** temperature measurement
- Reduced power sensitivity w.r.t. *conventional* microchips
- Price: €.1
- Battery-less and Battery-assisted mode (extended read-range)
- Temperature Range: -40°C - +85°C



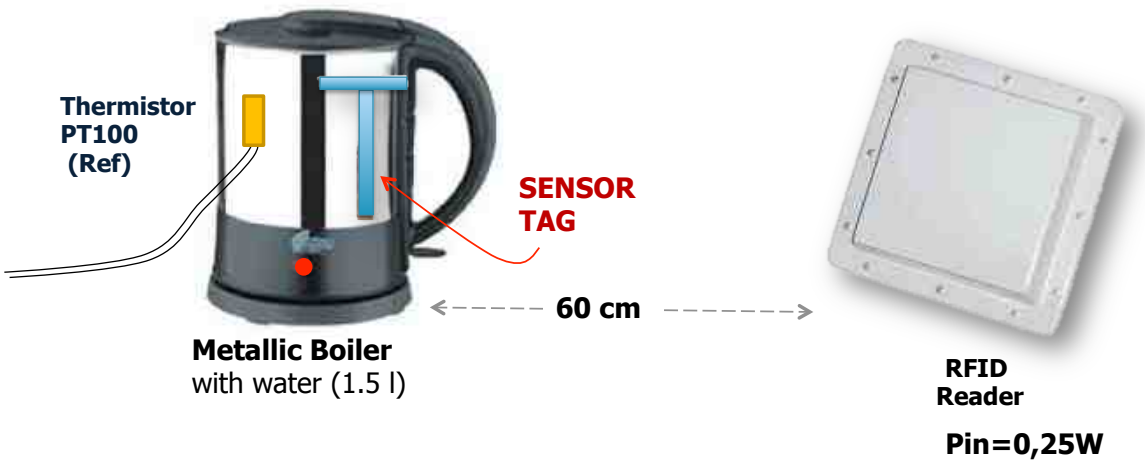
2. Absolute Temperature Logger

Example of implantable tag



2. Absolute Temperature Logger

Experiments



- The thermistor is directly attached over the boiler
- Sensor tag includes a Forex insulator

2. Absolute Temperature Logger

Experiments

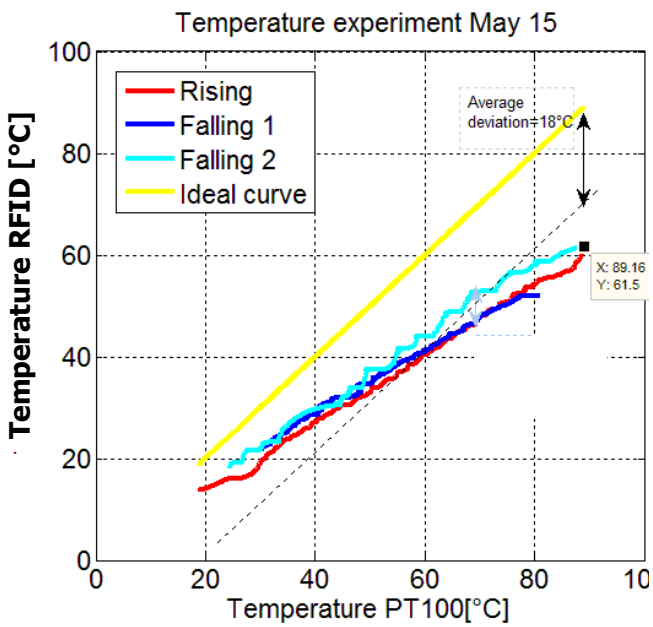
Range: [20 , 94]°C
FSO: [0, 64]°C
Resolution RFID: 0.36°C

Linear response

Stable response

Calibration is required because of the presence of the insulator

$$T=0.7T_{TAG}-0.2$$



2. Absolute Temperature Logger

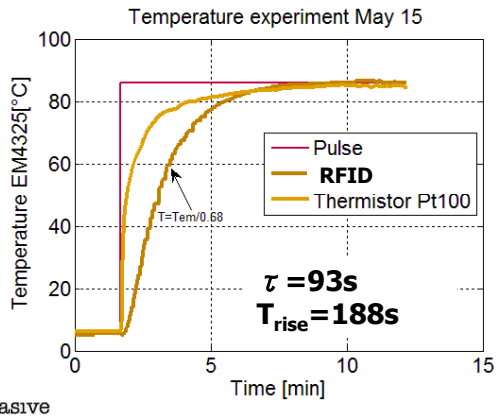
Step Response

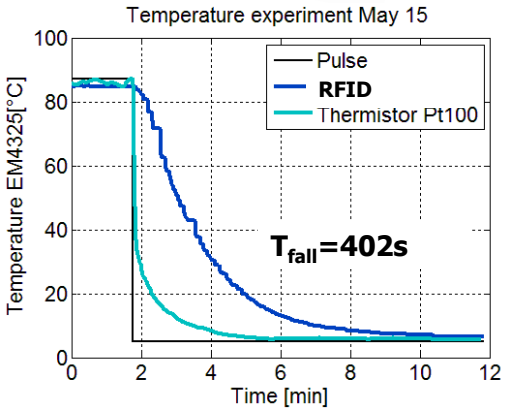
$t_0 < t < t_1$

RISE T

$t_1 < t < t_2$

FALL T

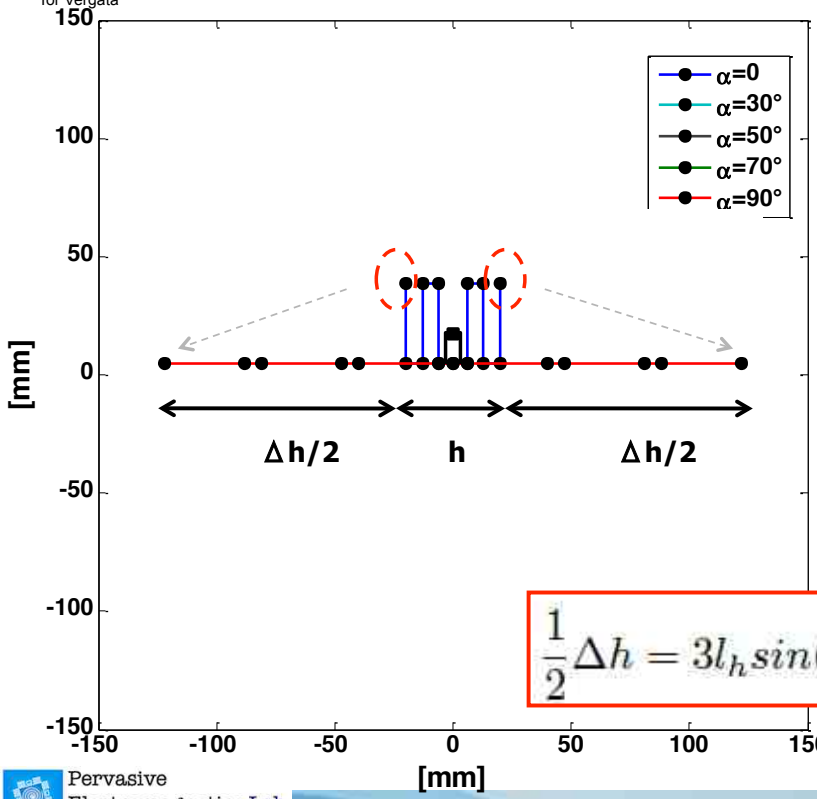




Sensing Deformations

1. RFID Strain-Gauge

Mechanical model



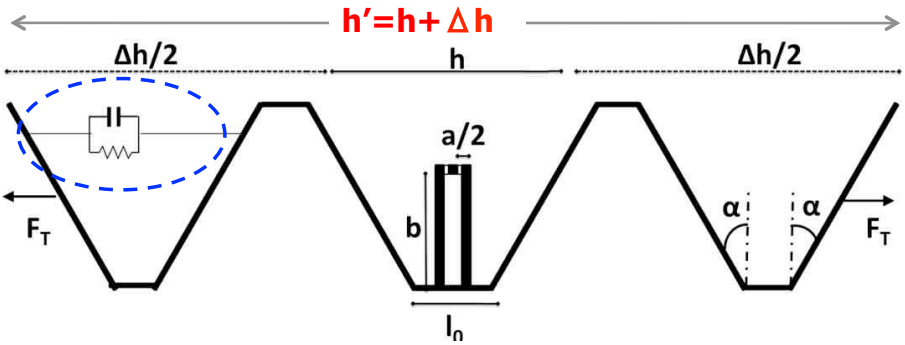
Hypothesis: inextensible wires (rigid structure)

- the external forces act only at the joints,
- rotation of the folding elements
- translation (horizontal and vertical) of the moving nodes of the structure

$$\frac{1}{2}\Delta h = 3l_h sin(\alpha) + 4r_s[1 - cos(\alpha)]$$

1. RFID Strain-Gauge

RF model



The antenna's **shape factor** changes as well as the **distributed loading**, and hence both the input impedance and the antenna gain will be accordingly modified.

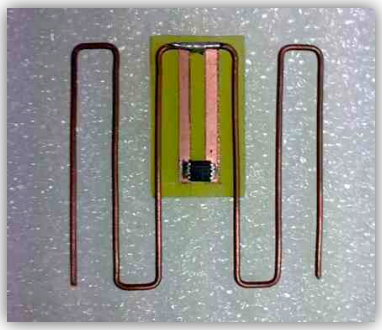
Strain

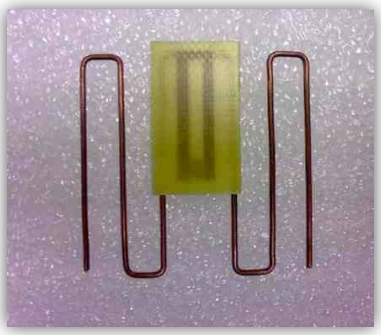
ΔZin **ΔG**

C. Occhiuzzi, C. Paggi, G. Marrocco, "**Passive Strain-Sensor based on Meander-line Antennas**", *IEEE Trans. Antennas and Propagat. 2011*

1. RFID Strain-Gauge

Prototype

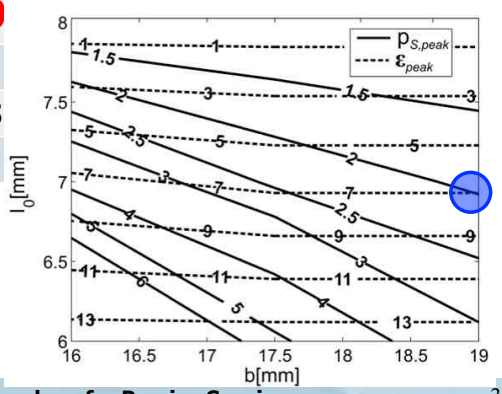




T-match section is printed over a 15x25x0.96 mm FR4 substrate

Parameter	Value [mm]
l_0	7
l_v	7
a	4
b	19
h	36
r_s	0.5
l_h	36

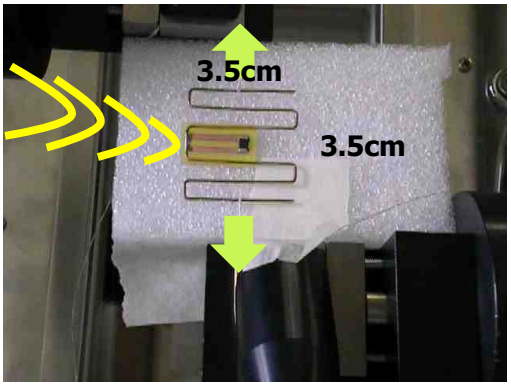
emphasize small deformations

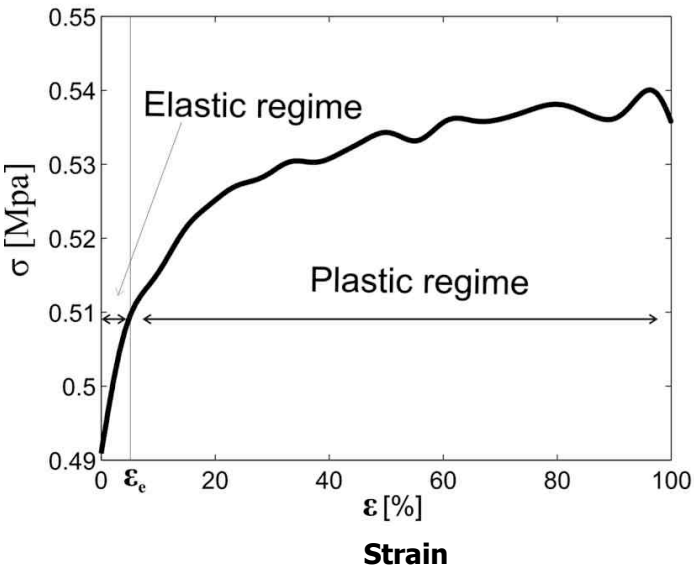


1. RFID Strain-Gauge

Experiments

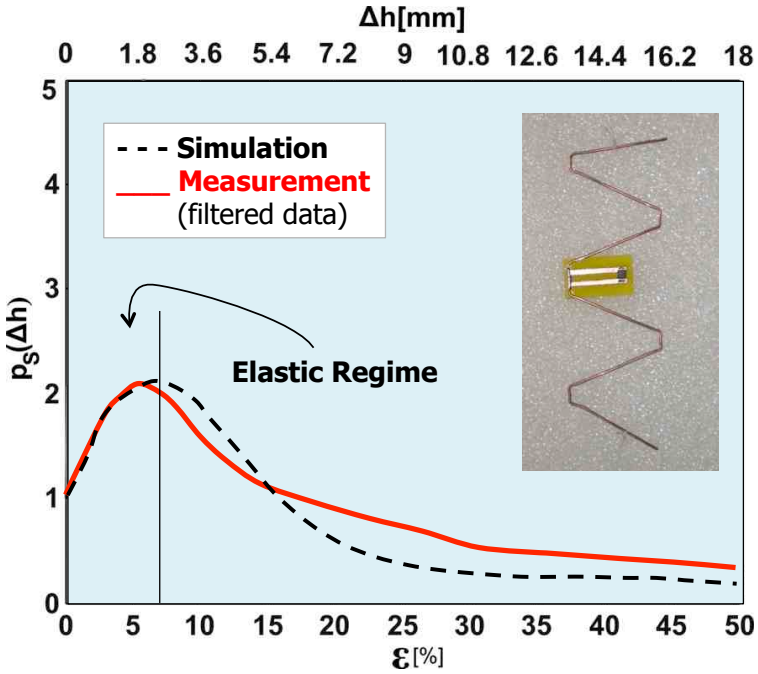
Prototype subjected to controlled **0-3 Newton axial tractive** force for a period of 80s





1. RFID Strain-Gauge

Measurements



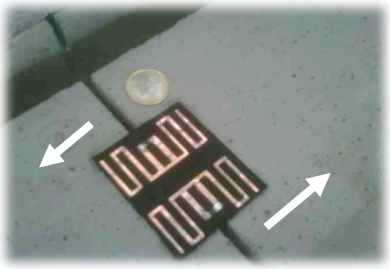
ε_{max}=7% s=20%

Δp_s=10%

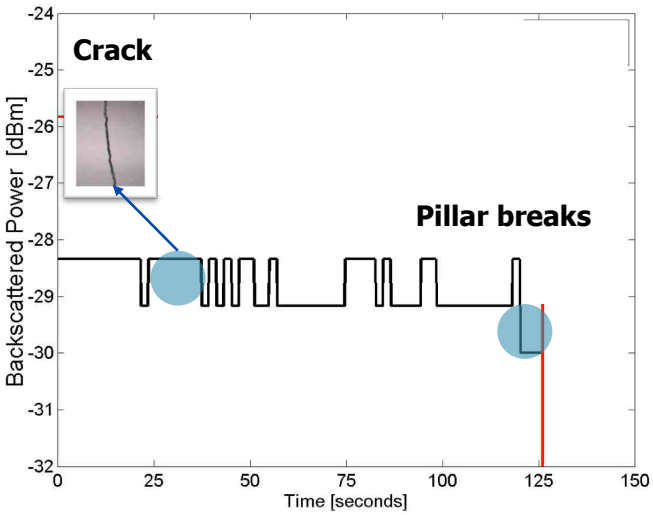
ε =0.7%
Δh=250 μm @870MHz
Δh=85 μm @2450MHz

1. RFID Strain-Gauge

Stress over Pillar

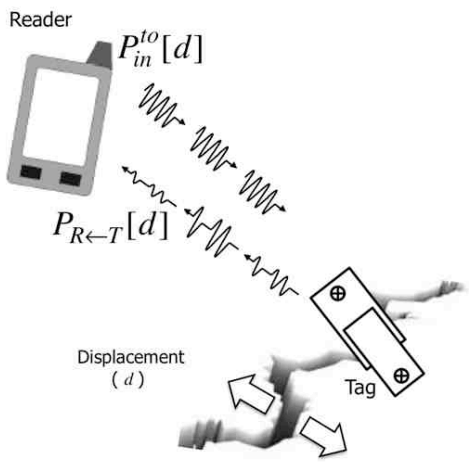


Planar MLA over elastic substrate



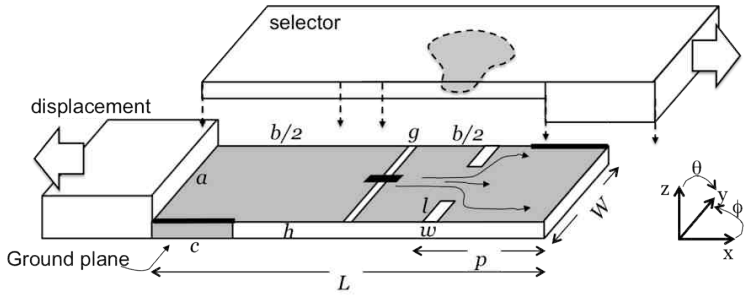
2. RFID Crack-Meter

Model



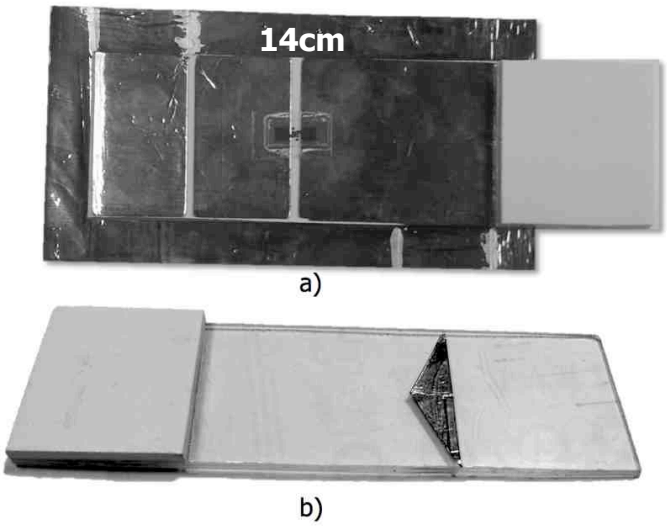
The **mutual shift** of a metallic selector over a **slotted patch** antenna will produce a measurable change of the RF response, corresponding to local displacement

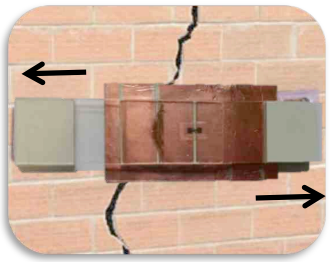
The **sensitivity** and resolution can be fully controlled by means of electromagnetic design



2. RFID Crack-Meter

Prototype

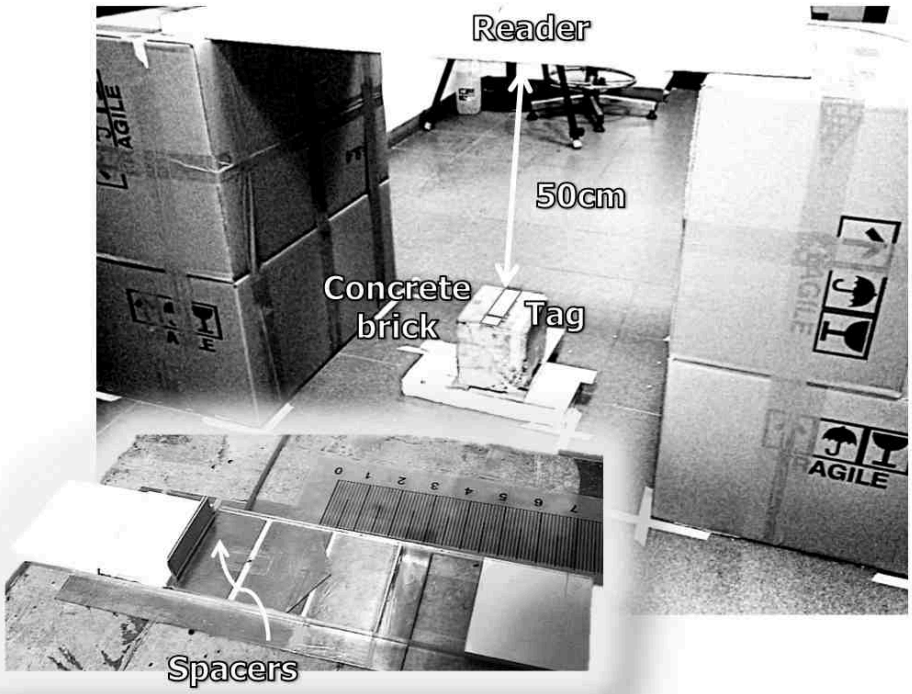




C. Paggi, G. Marrocco, C. Occhiuzzi, "**Submillimeter Displacement sensing by passive UHF RFID Antennas**", Submitted IEEE TAP

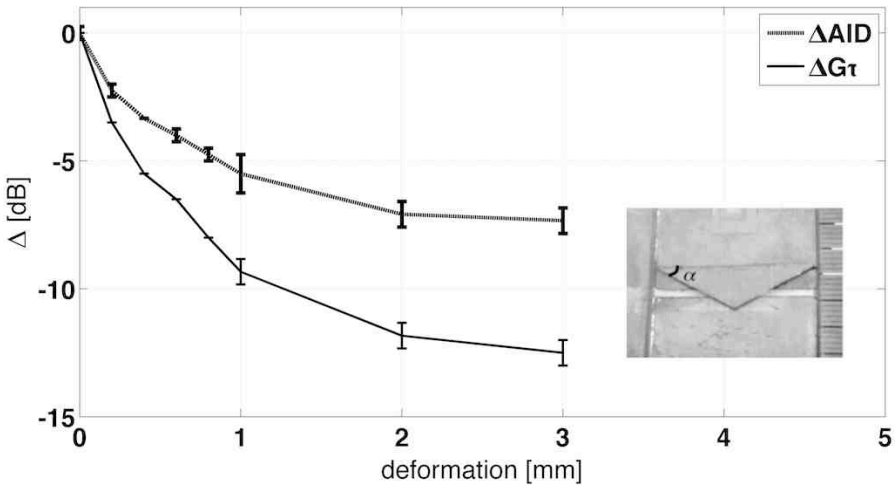
2. RFID Crack-Meter

Measurements



2. RFID Crack-Meter

Measurements



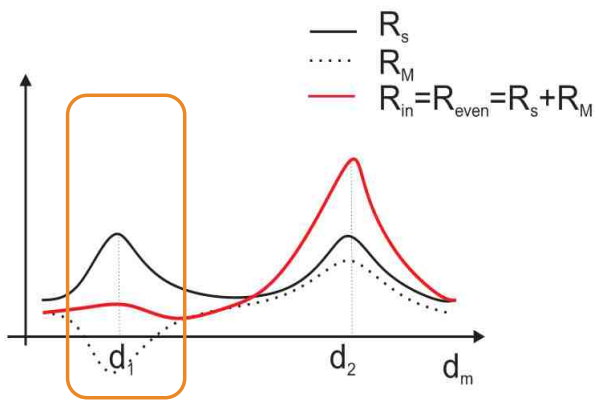
Sensitivity:
4dB/mm (hand-held reader)
9dB/mm (fixed-reader)

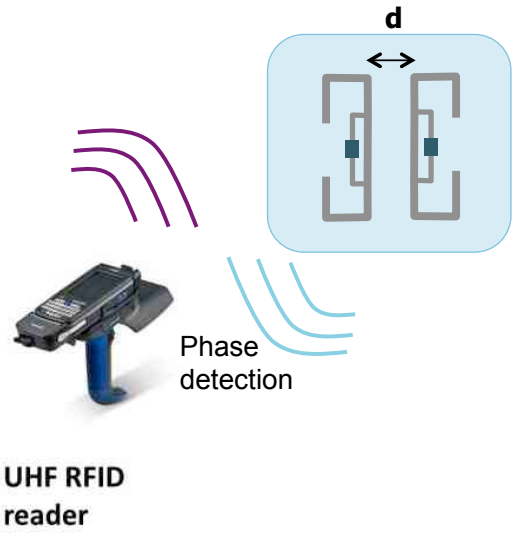
Resolution:
50-100μm (Low-cost COTS reader)
10-20μm (Dedicated COTS reader)

3. Displacement Sensors

Phase sensing

Exploiting the change of mutual coupling between two facing RFID tags

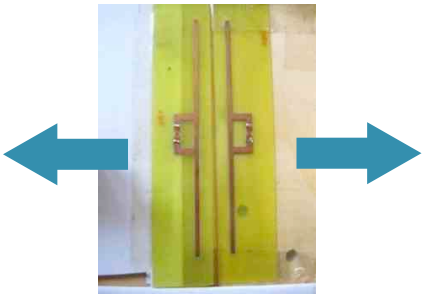


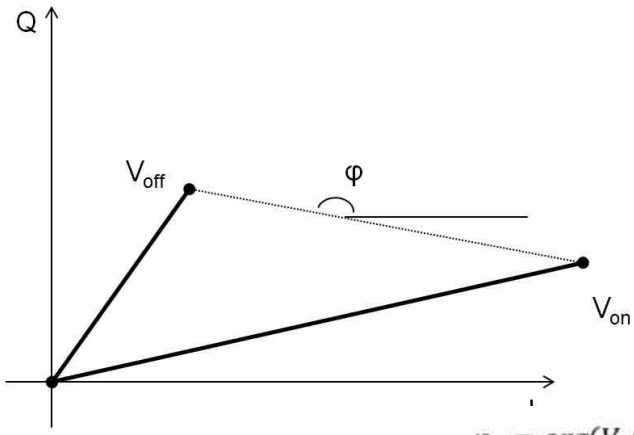


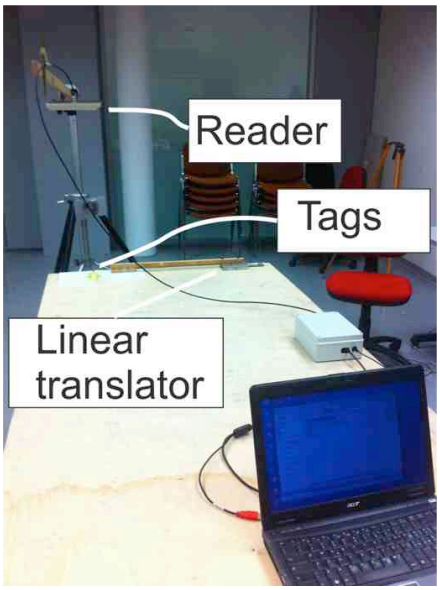
S. Caizzone, G. Marrocco, E. Di Giampaolo, "A novel wireless crack sensor exploiting the phase signal of UHF RFID tags", Eucap 2013

3. Displacement Sensors

Phase measurement



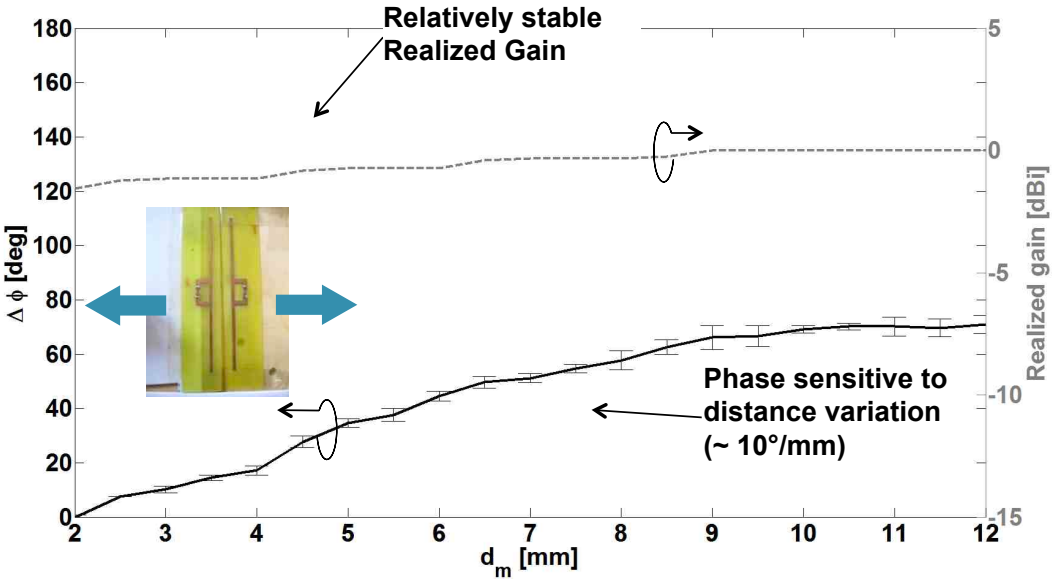




$$\varphi_1 = \arg(V_1(OFF) - V_1(ON)) = \arg\left(\frac{1}{Z_S + Z_C}\right) + \varphi_0$$

3. Displacement Sensors

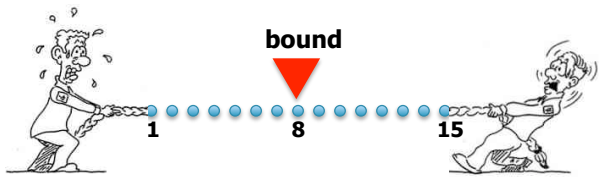
Phase measurement



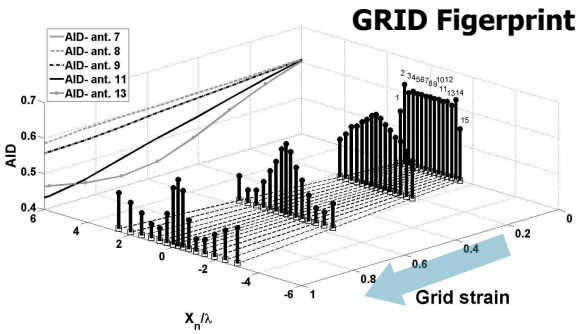
Measured Sensitivity: 10deg/mm
Read-distance: nearly unaffected by change of mutual-distance

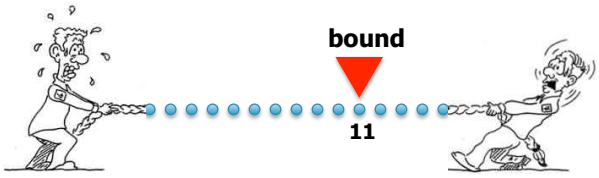
3. Displacement Sensors

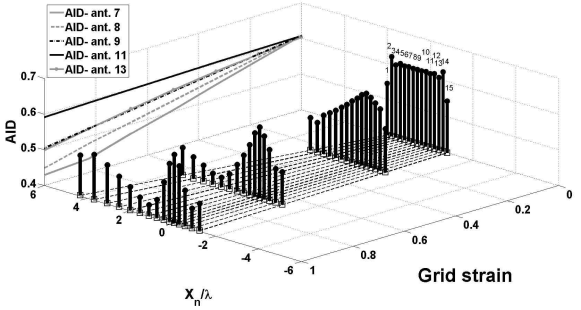
Localizing deformations by RFID Grids



f=870 MHz







Possibility to recognize the position of a crack

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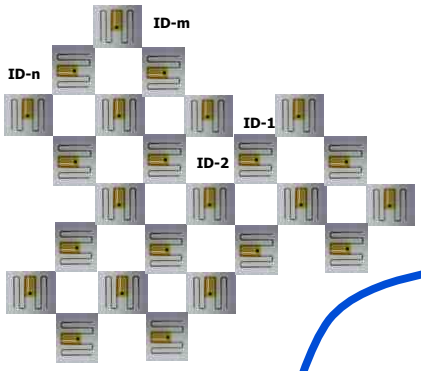
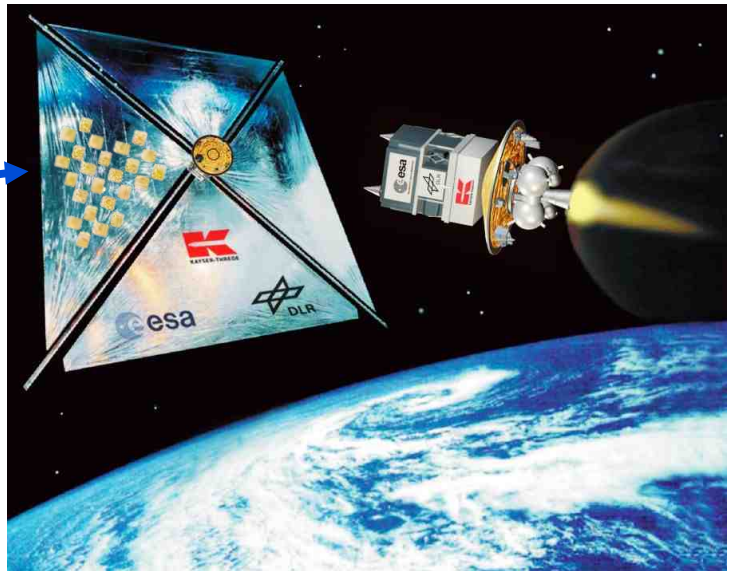
3. Displacement Sensors

Localizing deformations by RFID Grids





S. Caizzone, G. Marrocco, "**RFID-Grids for deformation sensing**", 2012 IEEE-RFID, Orlando

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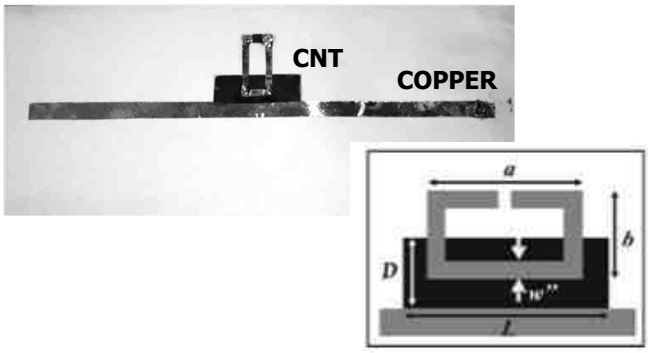
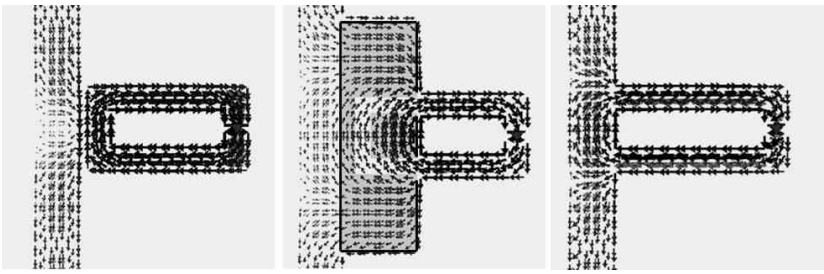
Sensing Chemical Species

1. RFIDs & Carbon NanoTubes

Ammonia radio-sensor



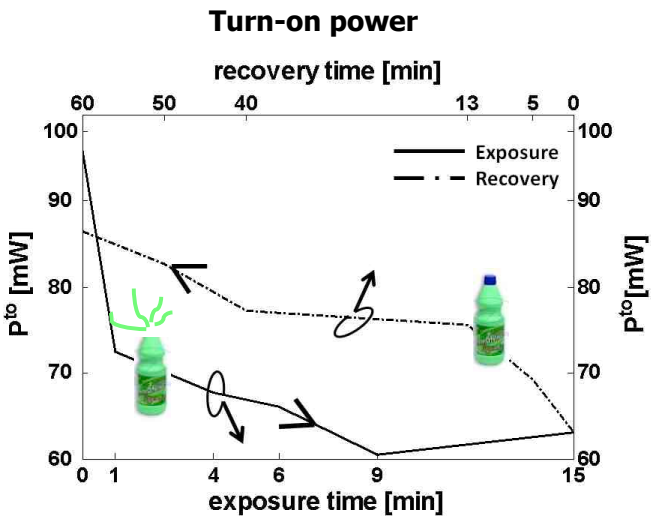
CNT is a partially conductive material, whose conductivity decreases due to the ammonia absorption.
This **gas** plays as a reducing agent that **injects electrons to the nanotubes** (p-type) reducing the number of holes and hence the conductivity.



Loop-feed **CNT** **T-match**

1. RFIDs & Carbon NanoTubes

Ammonia Exposure

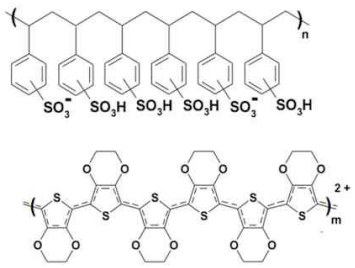


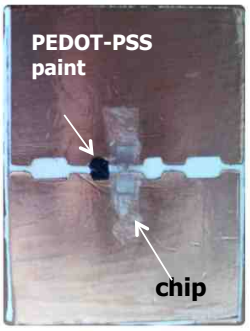
Gas-detection tags for food and environmental monitoring

C. Occhiuzzi, A. Rida, G. Marrocco, M. Tentzeris, "**RFID Passive Gas Sensor Integrating Carbon Nanotubes**", *IEEE Microwave Theory Tech*, 2011

2. Conductive Polymer-doped tag

Chemical Receptors for Humidity Sensing



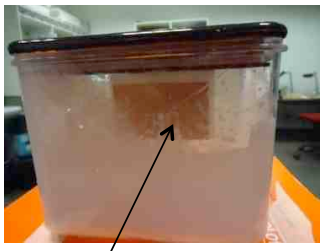


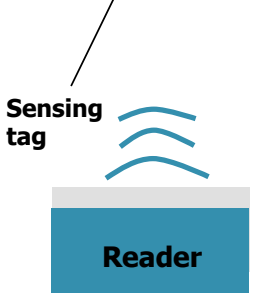
poly (3,4-ethylenedioxythiophene):poly (styrene-sulfonic acid) – **PEDOT:PSS**

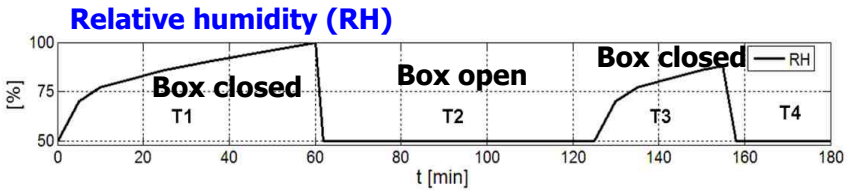
- **Hygroscopic polymer** dispersion which is used to paint the antennas ' slots.
- Change of permittivity/conductivity along with vapor absorption
- Possibility of integration into plaster or **bandages to remotely monitor the healing grade of wounds**

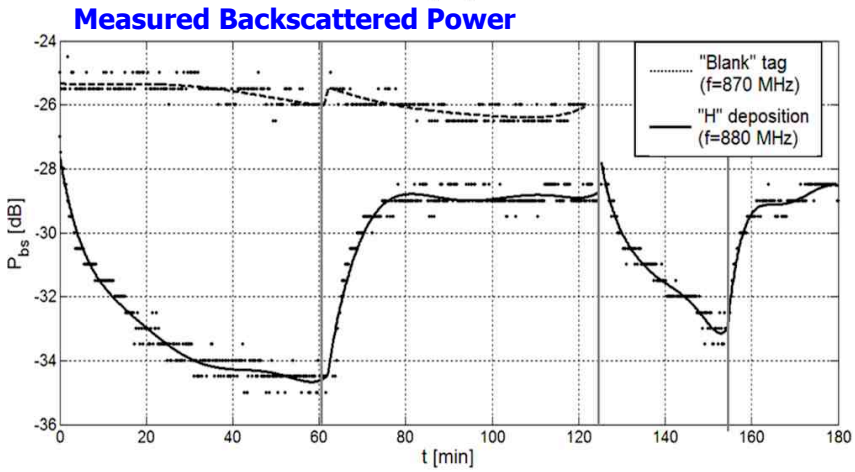
2. Conductive Polymer-doped tag

Exposure to H_2O vapor









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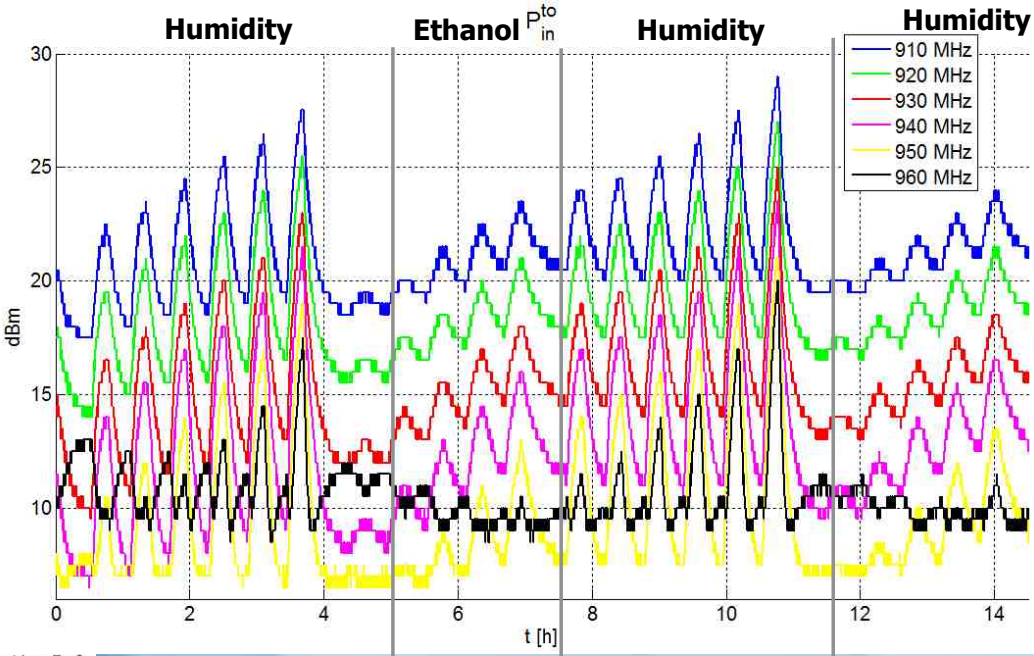
2. Conductive Polymer-doped tag

Humidity and Ethanol

Humidity: 0%-50%-0%-60-0%-70%-0-80%-0%-90%-0%-100%
Ethanol: 0%-10%-0%-20-0%-30%-0-40%-0%-50%-0%



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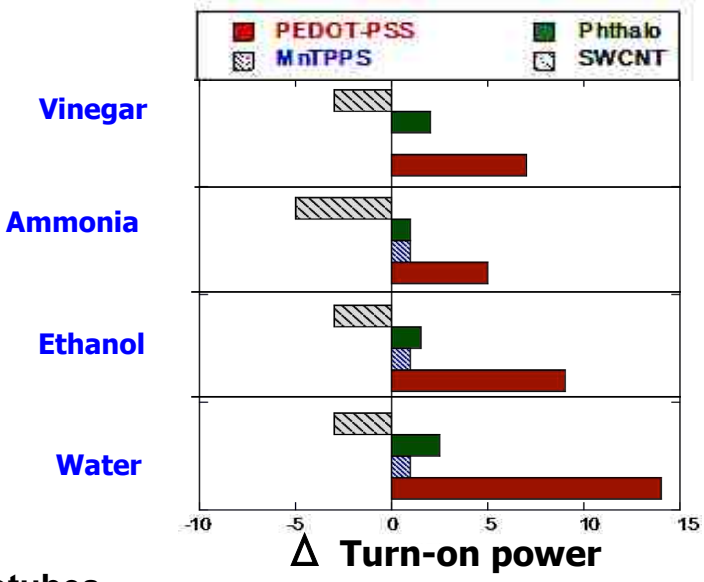
3. RFID Matrix for Moistures

Chemical Lab on tag

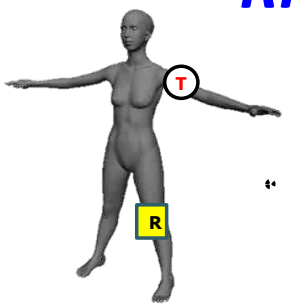


- **Pedot:pss**
- **Single Wall Carbon Nanotubes**
- **Manganese-Tetraphenylporphyrin**
- **Phtalocyanine**

Response Selectivity

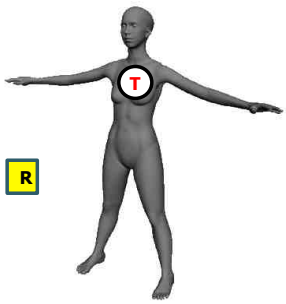
Sensing Human Behavior

RFID-Bodycentric Systems



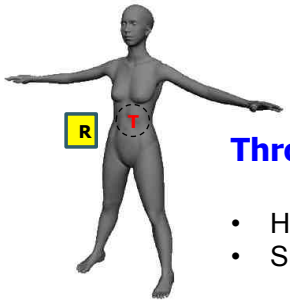
On-Body link: The reader's antenna over the body

- Activity and shadowing effect
- Exposure limit



Off-Body link: The reader placed far from the body

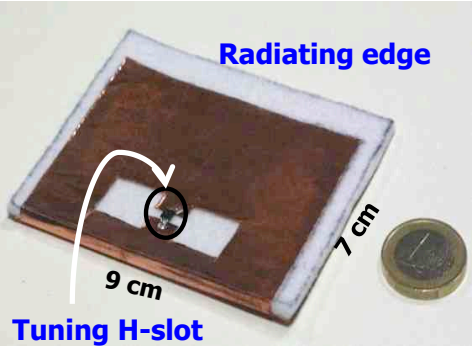
- Reading range in real scenario
- Environmental influence
- Position

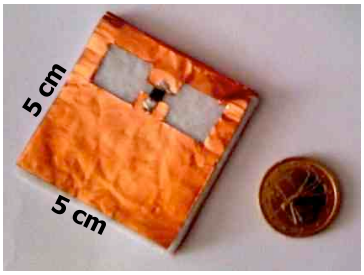


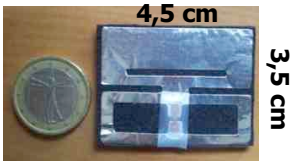
Through-the-Body link: The tag is implanted

- High loss
- Small read ranges

Wearable textile RFID Tags

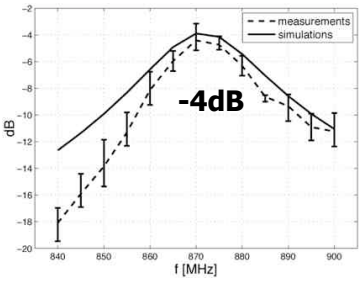


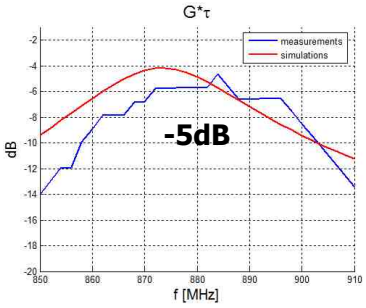


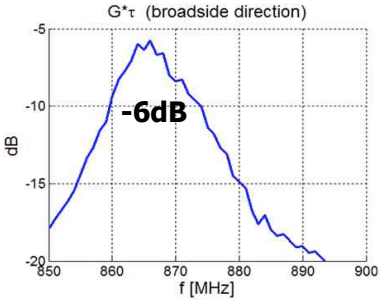


Felt substrate

EPDM (Ethylene-Propylene Diene Monomer)



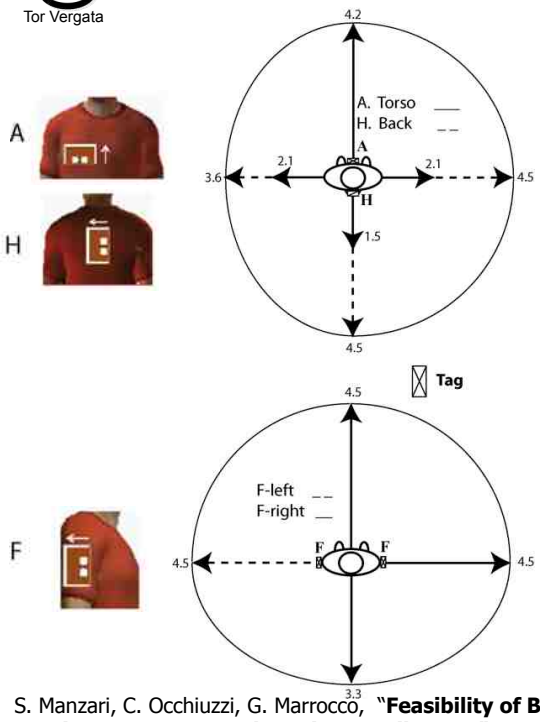




Observation: Normal incidence

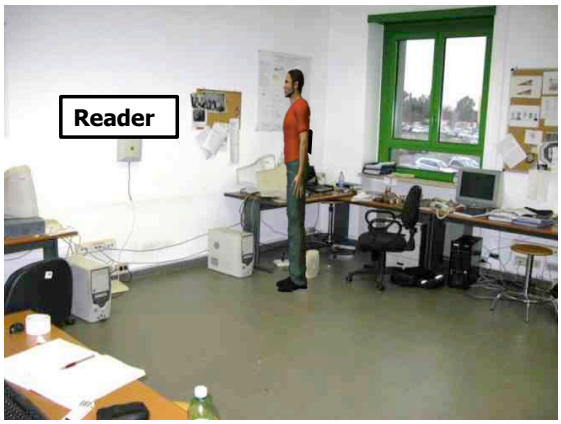
Off-body RFID link

- Real scenario



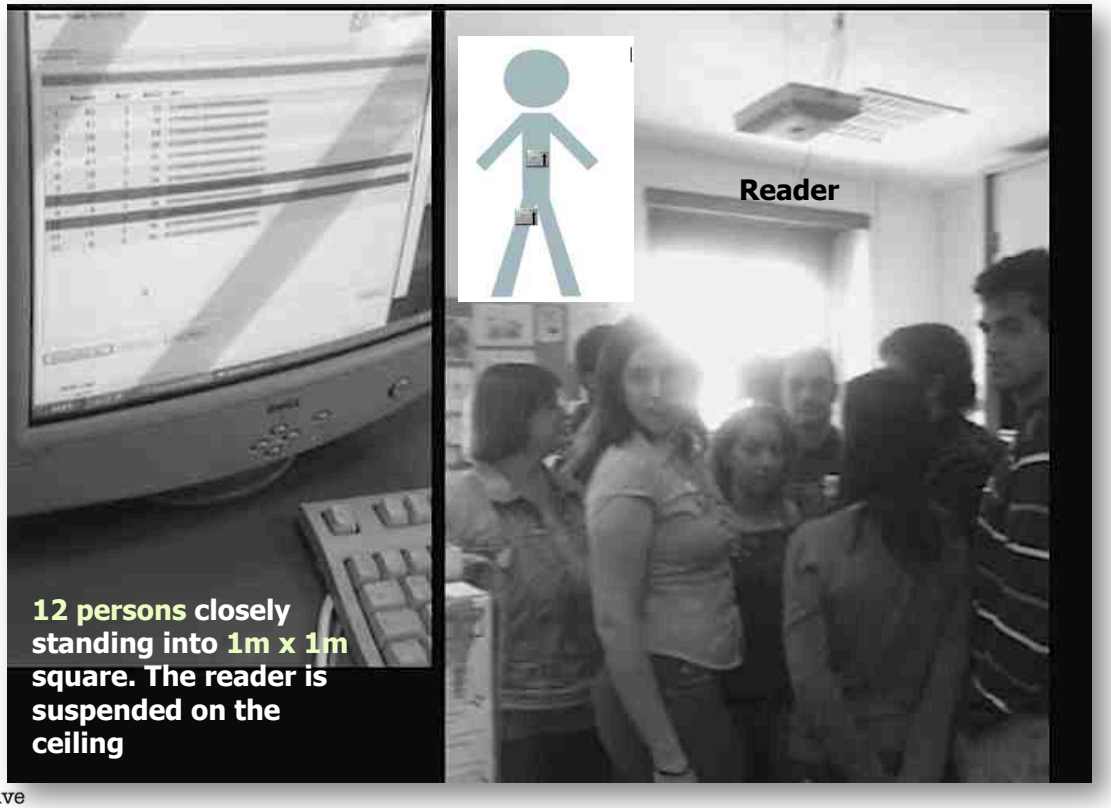
S. Manzari, C. Occhiuzzi, G. Marrocco, **"Feasibility of Bodycentric Passive RFID Systems by Using Textile Tags"** to appear on IEEE Antennas Propagat. Magazine Aug. 2012

5.5m x 5.5m x 3m



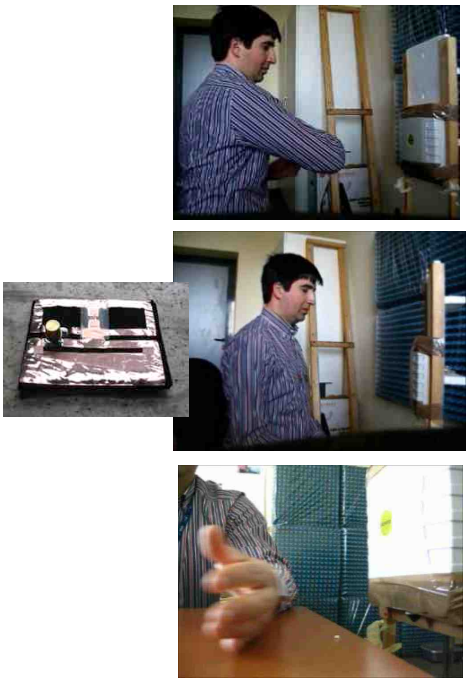
- Two tags properly placed enable a robust monitoring in a 4x3 m room
- **Chip Sensitivity -15dBm**
- No shadowing effects during normal activity

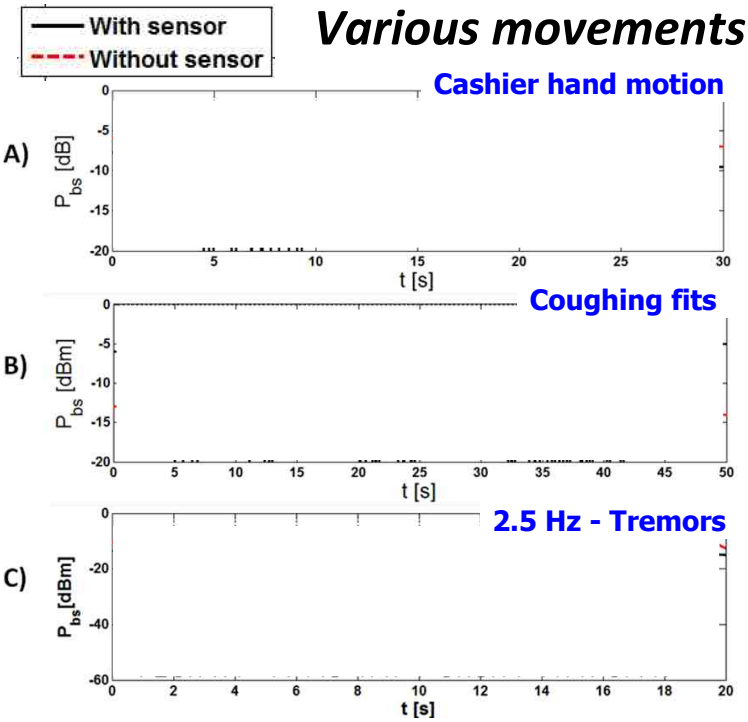
On-body RFID link



Omni-directional Motion Sensing

Various movements





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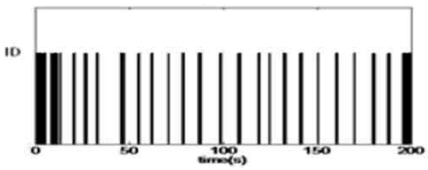
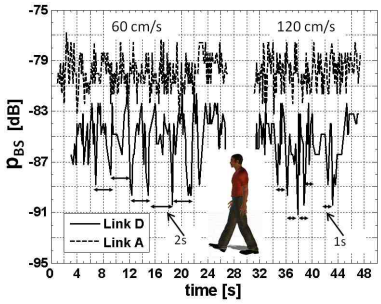
Detection and classification of body motion

Deep Breath

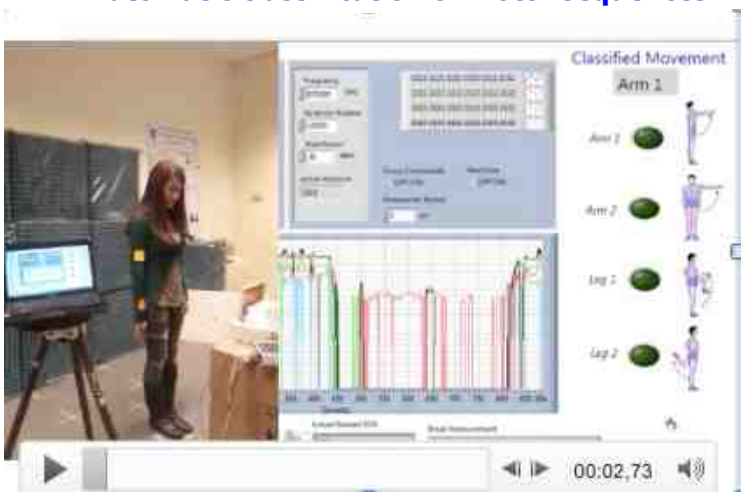


Walking



Application of Machine Learning algorithms

Automatic classification of motor sequences



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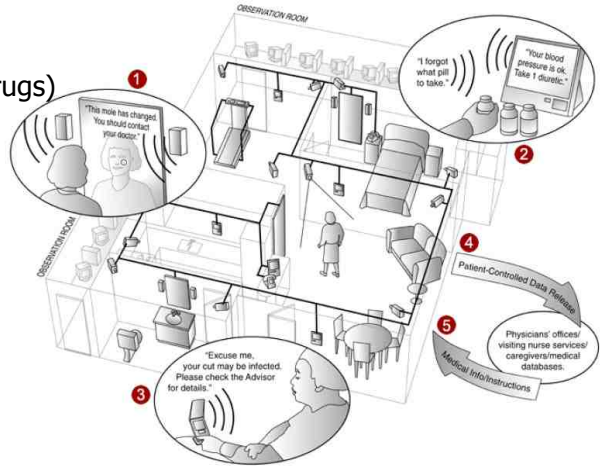
Some Possible Applications

1. Pervasive Healthcare

Ambient Intelligence systems

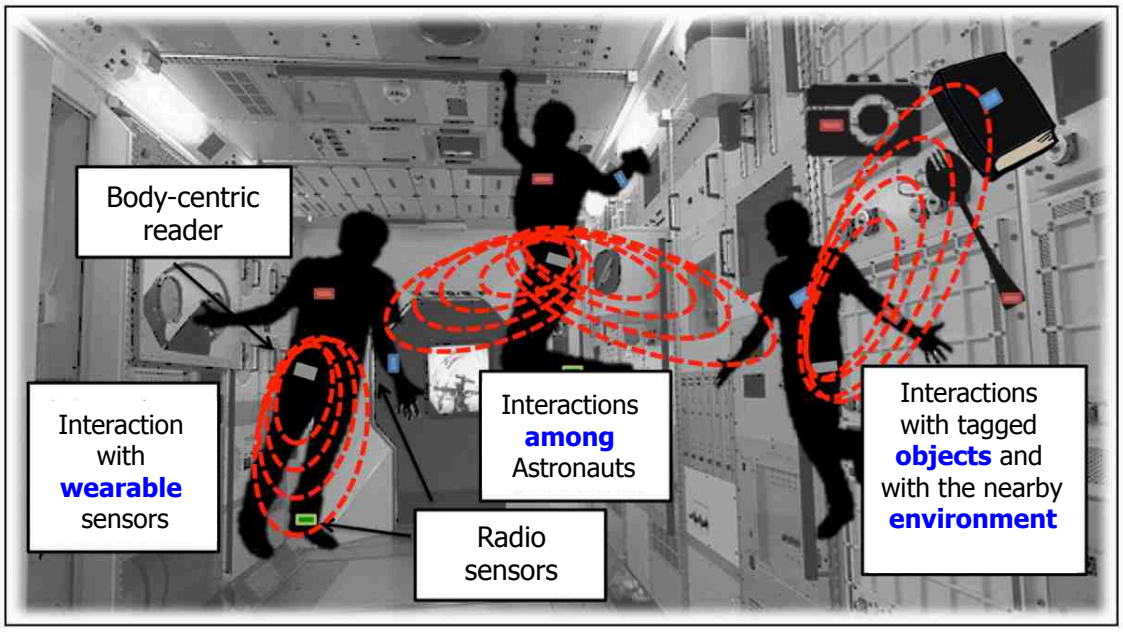
Body sensors
- motion
- ECG
- Evolution of pathologies

Smart Objects
- Localization
- Quality (food, drugs)

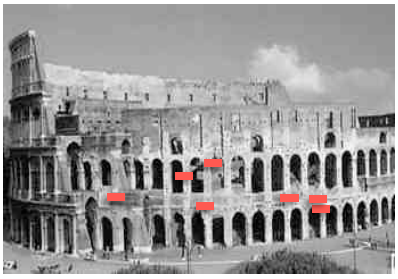


Smart House
- temperature
- Gas
- Structural safety
- localization systems

2. Human relationship in Extreme Spaces

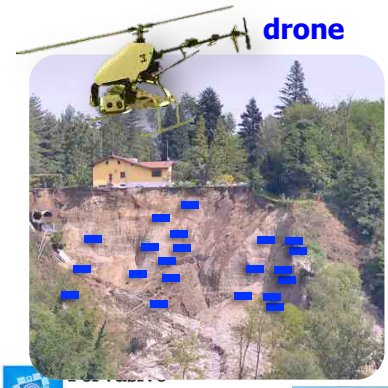


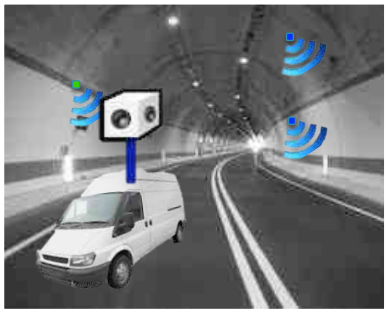
3. Structural Health Monitoring

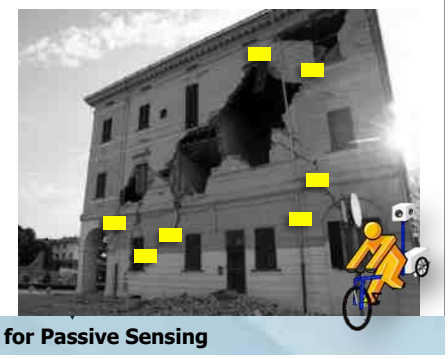


Passive systems to monitor crack, humidity and temperature in concrete walls, pillars and any other structure that need a continuous, distributed and low-cost monitoring of its "health".

- Historical Buildings
- Civil Houses
- Post Disaster Assessment
- Geologic Instability
- Construction Monitoring







An Example of RFID Sensing System

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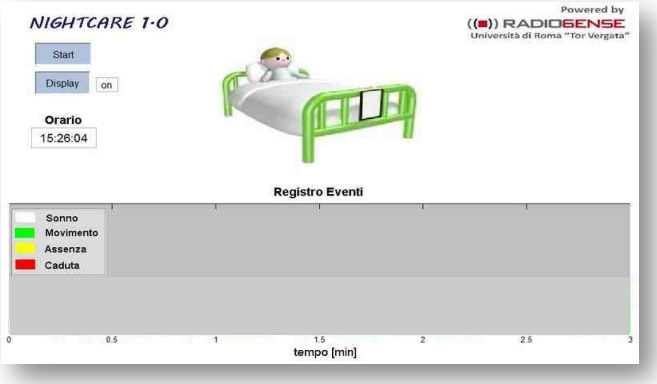
NightCare System

Ambient Intelligence system able to monitor the parameters of sleep quality and to identify anomalous events and **prompt for remote or local assistance**



The system analyzes the interactions of the person with the surrounding environment (bed, carpets, ..) by using our wearable Tags

➔ Video

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Many thanks !!

Gaetano Marrocco
marrocco@disp.uniroma2.it

Pervasive Electromagnetics Lab
Università di Roma Tor Vergata

http://dl.dropbox.com/u/4358070/alab_web/Alab_people_marrocco.htm

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