RFID Technology for IoT-based Personal Healthcare in Smart Spaces

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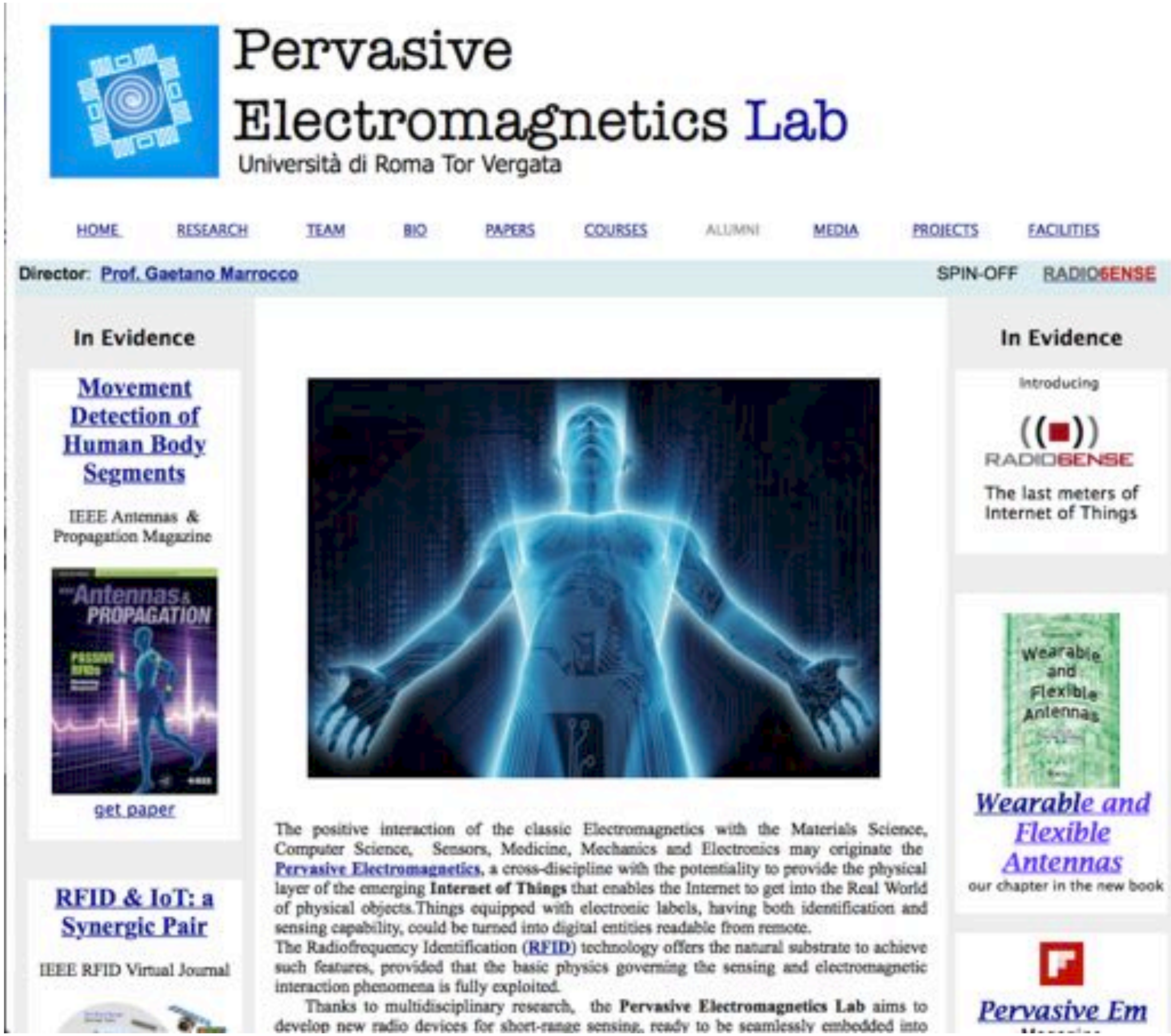
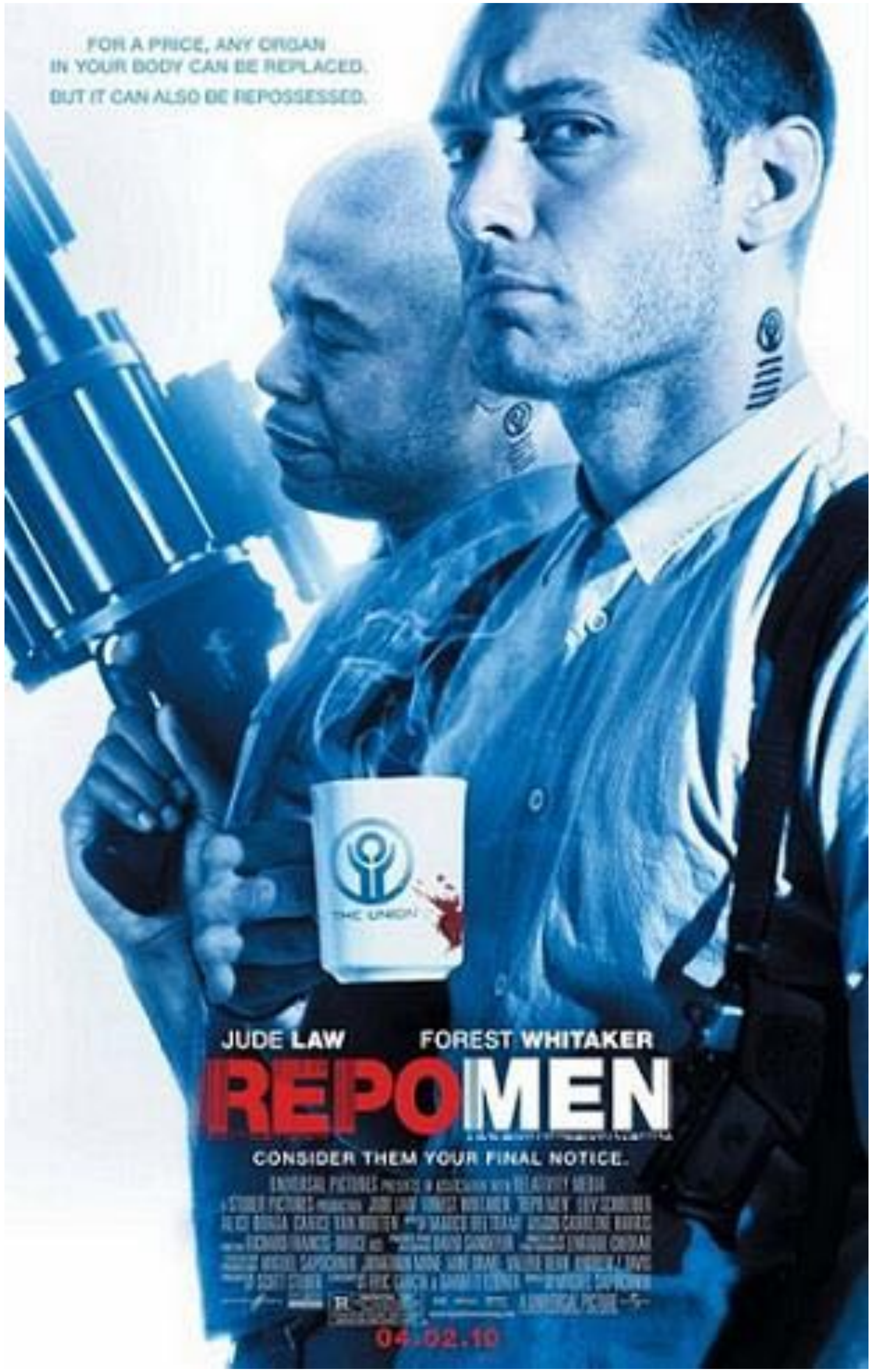


From REPOman (2009)



[VIDEO ITA]

[VIDEO ENG.]

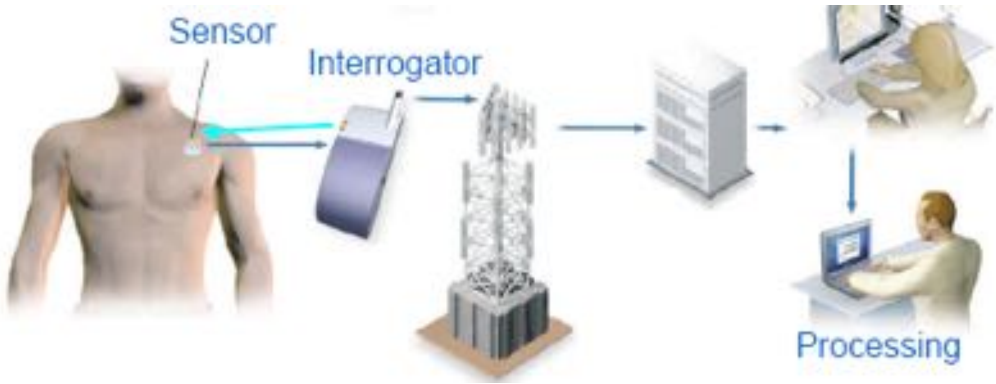
Logan's Run (1976)

Self tracking (I-health)

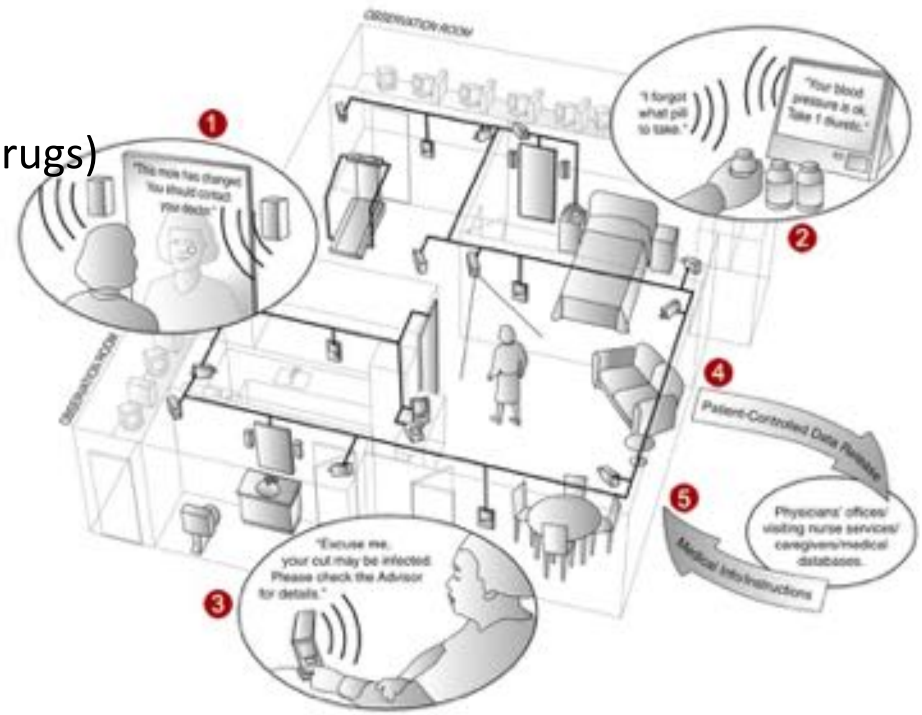
Pervasive Healthcare systems
(Smart home)

Context-aware systems

Body sensors
- motion
- ECG
- Evolution of pathologies



Smart Objects
- Localization
- Quality (food, drugs)

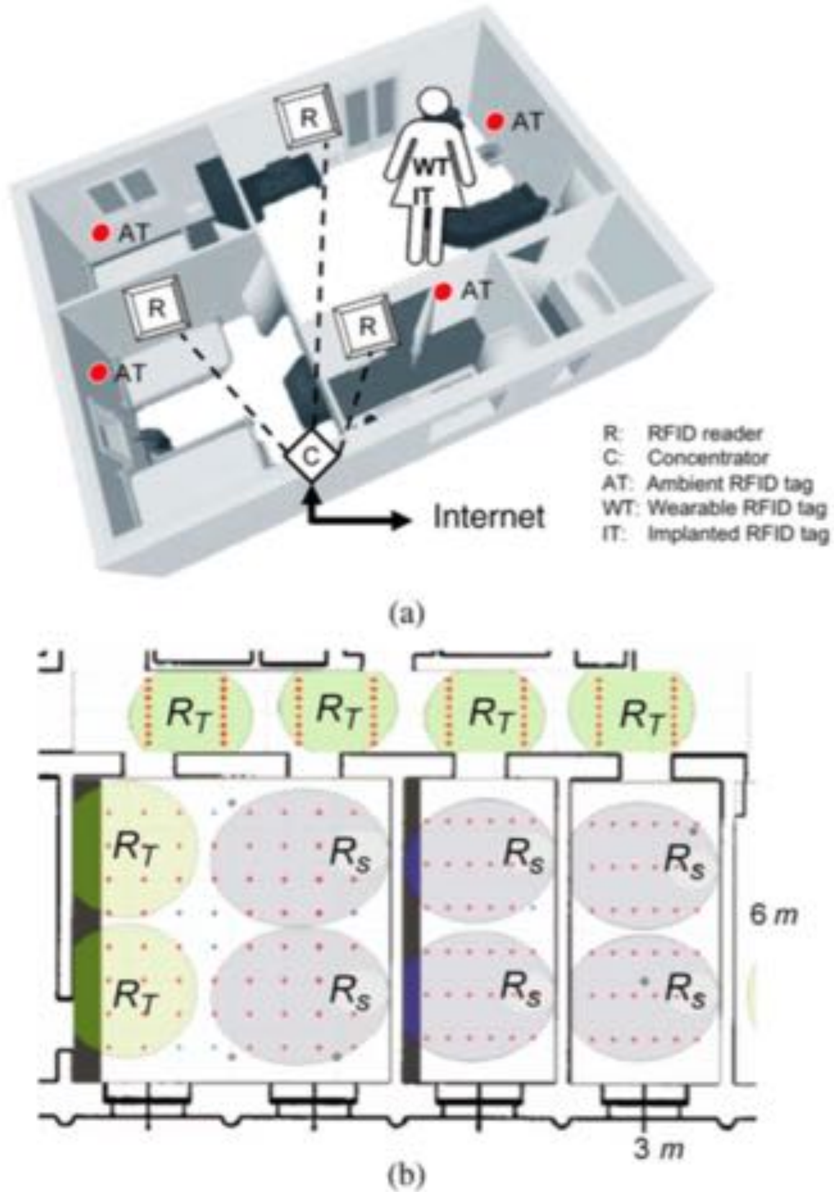


Smart House
- temperature
- Gas
- Structural safety
- localization systems

Human-environment interactions

(a) Sketch of an RFID-powered habitat with ambient tags (AT) attached over the walls and objects, wearable tags (WT), and implanted tags (IT) placed over and inside the human body, one or more RFID readers (R) scanning the rooms and a wireless concentrator (C) capable to pack the collected data for in-house processing and/or for internet streaming.

(b) Example of RFID coverage [2] of a home-portion by a multiplicity of readers' antennas placed at the walls' side (R_S) and over the top ceiling (R_T).



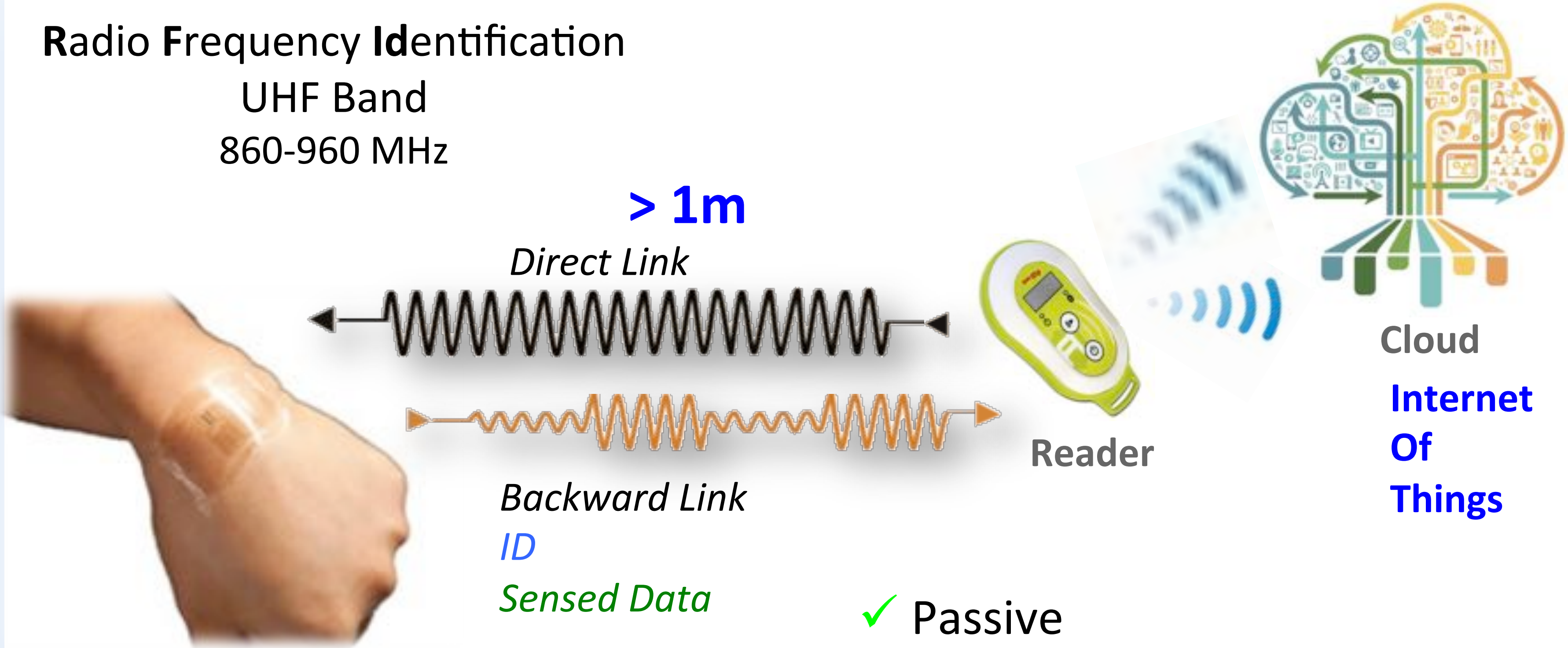
Batteryless ..

- Sensors could be requested to operate for months or even years
- Battery replacement or recharging needed
- Additional man-power
- Pollution
- **Energy-Harvesting required**

Wireless remote powering by electromagnetic waves

UHF-RFID Technology

Radio **F**requency **Id**entification
UHF Band
860-960 MHz



Bodycentric Sensor-Tags

UHF Antenna

IC

- ✓ Passive
- ✓ Remote Reading
- ✓ Easy integration
- ✓ Communication & Sensing

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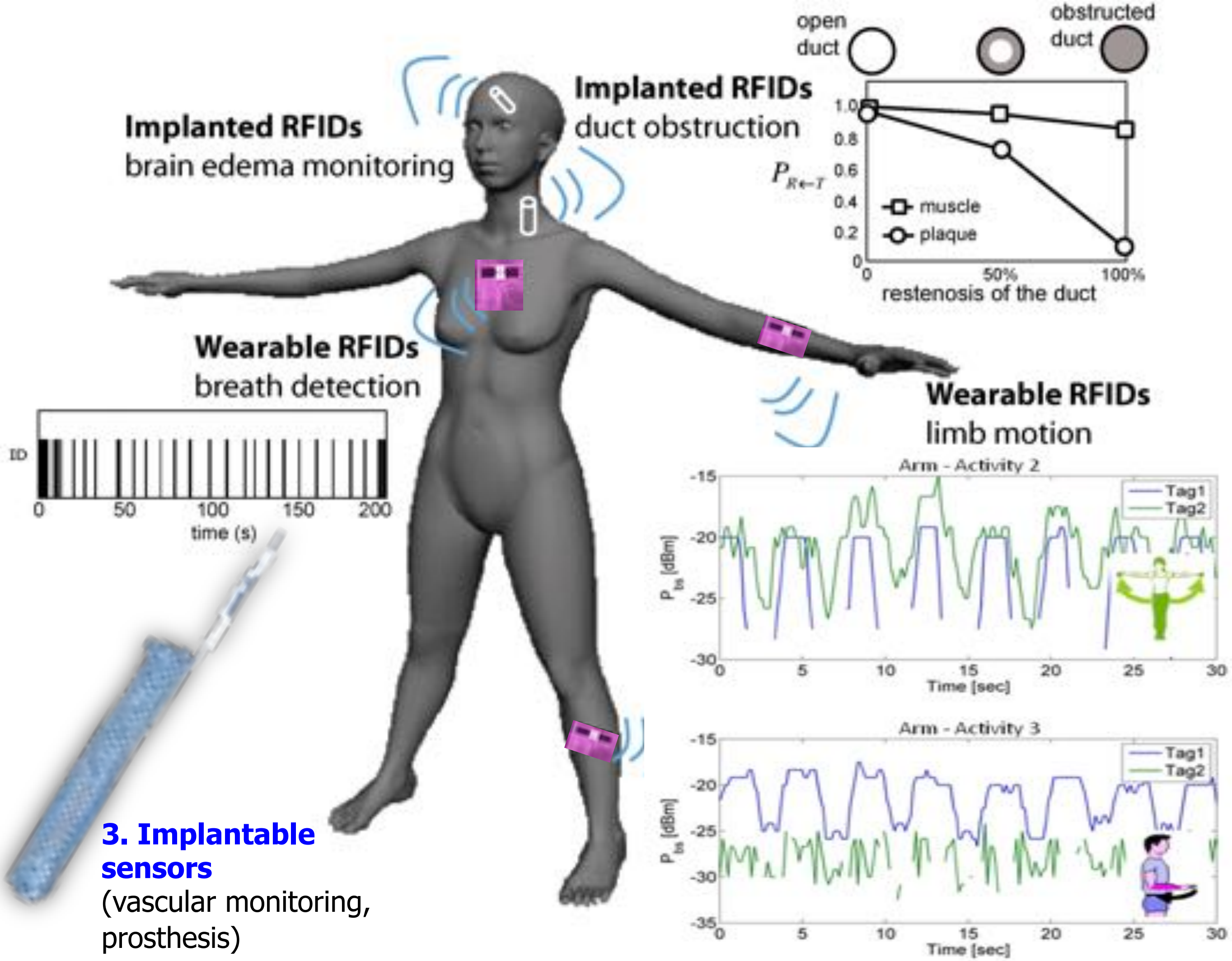
Power-less Sensors for Pervasive Healthcare

1. Wearable sensors
(motion and stress)

2. Epidermal sensors
(temperature monitoring))



3. Implantable sensors
(vascular monitoring, prosthesis)

Outline

Bodycentric RFID Devices

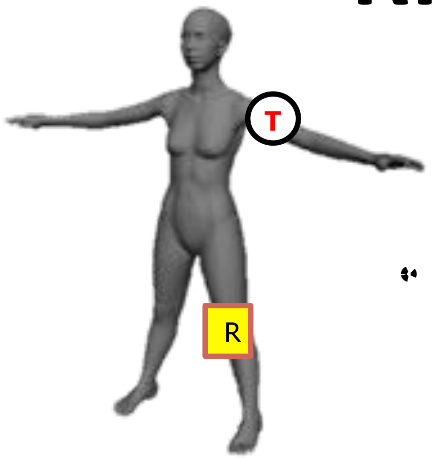
- wearable
- epidermal
- implantable

RFID-IoT Systems

- Motion detection and gesture recognition
- Continuous and on-flight temperature monitoring
- Human-things interactions

Bodycentric RFIDs

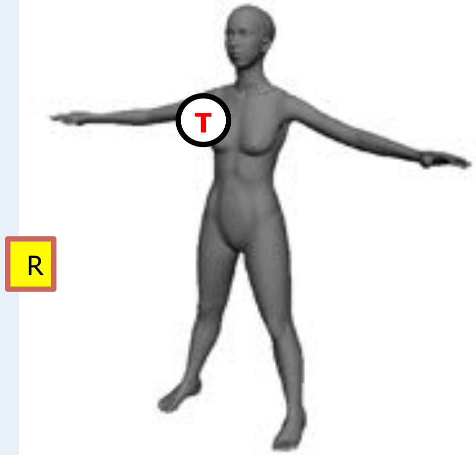
RFID-Bodycentric Systems



On-Body link

The reader's antenna is placed over the body

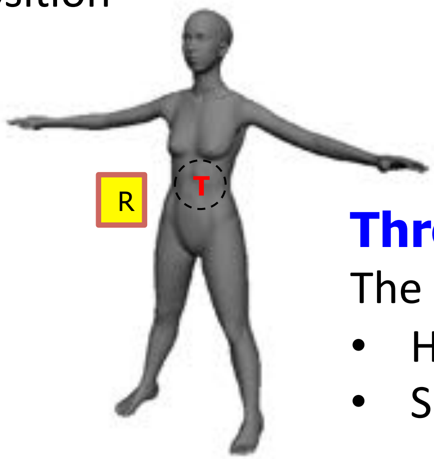
- Activity and shadowing effect
- Exposure limit



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

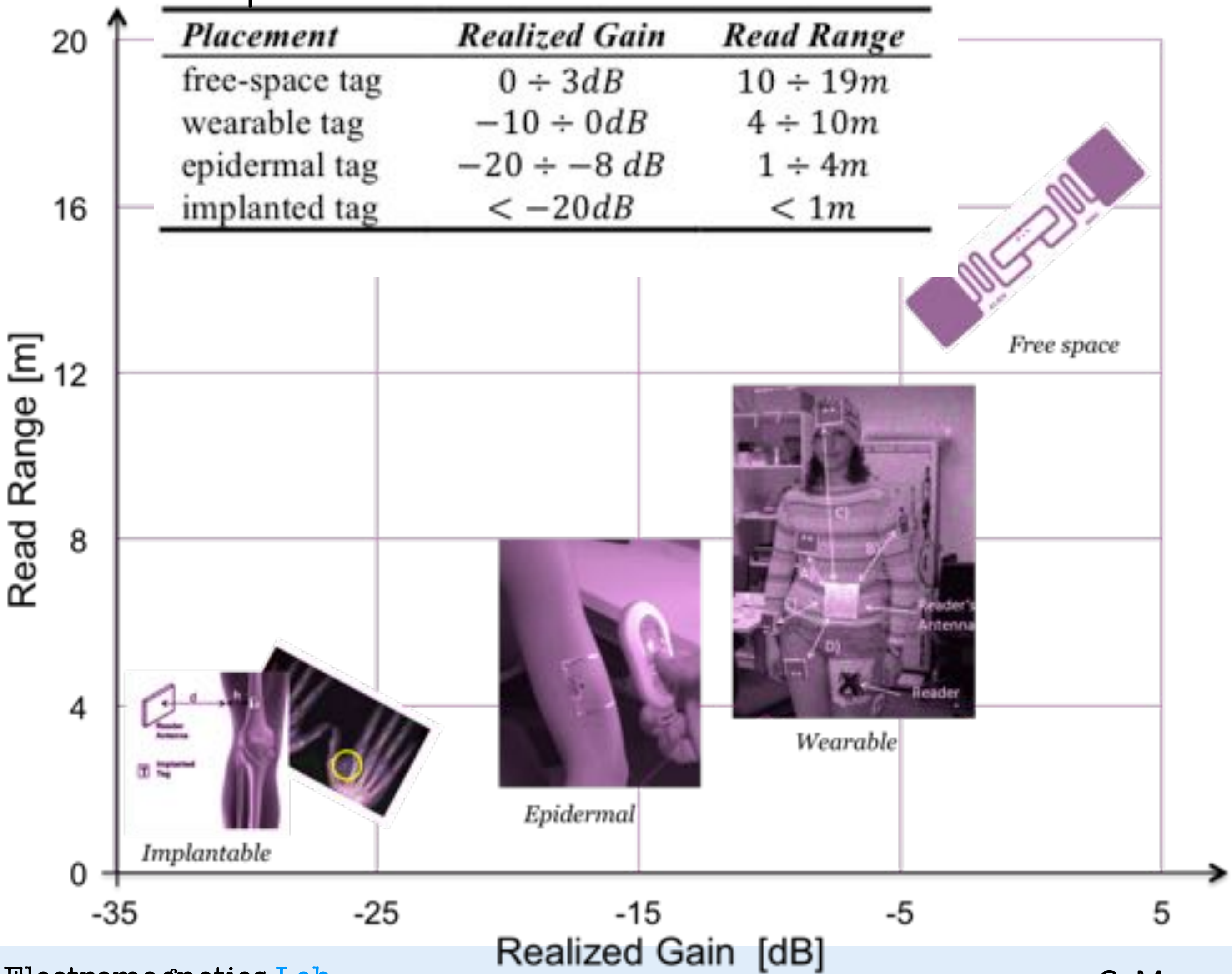
- High loss
- Small read ranges

RFID-Bodycentric Systems

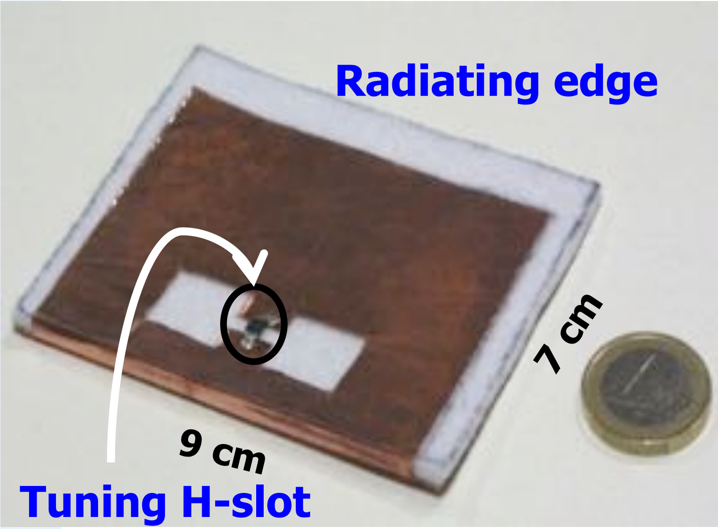
- Read ranges

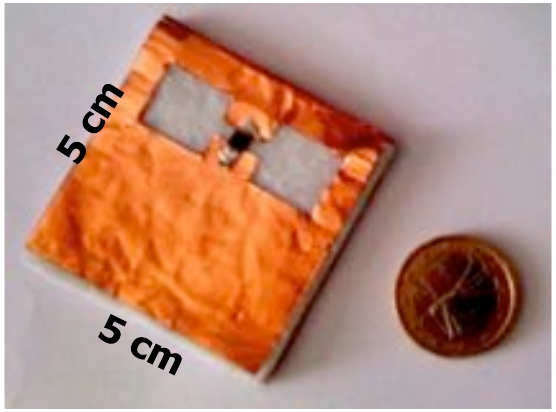
Pchip=-22dBm

Placement	*Realized Gain*	*Read Range*
free-space tag	$0 \div 3dB$	$10 \div 19m$
wearable tag	$-10 \div 0dB$	$4 \div 10m$
epidermal tag	$-20 \div -8\ dB$	$1 \div 4m$
implanted tag	$< -20dB$	$< 1m$

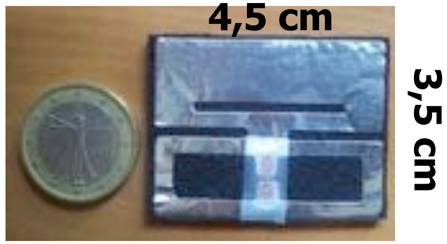


Wearable textile RFID Tags

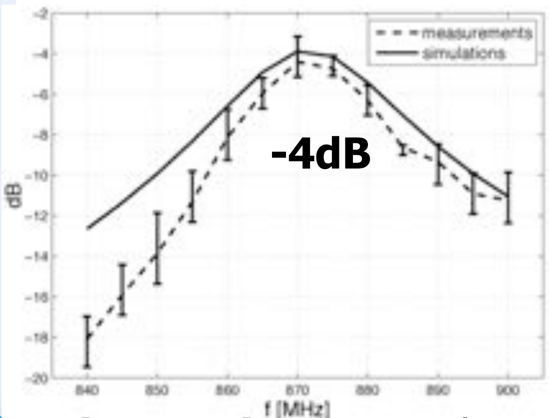


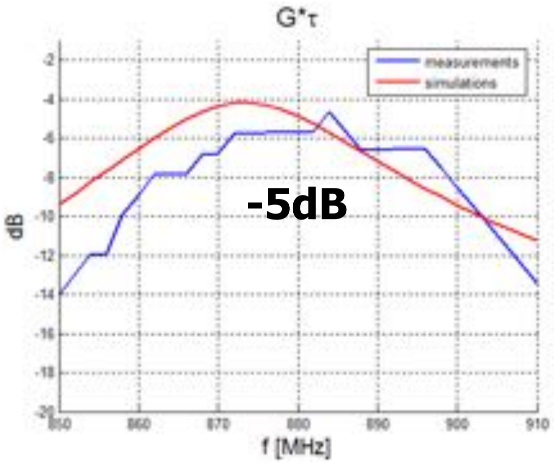


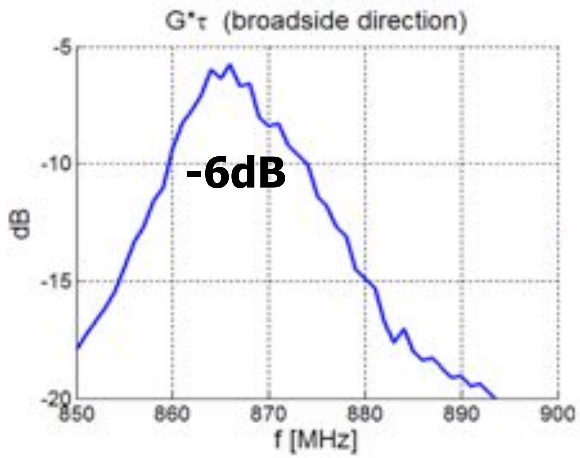
Felt substrate



EPDM (Ethylene-Propylene Diene Monomer)



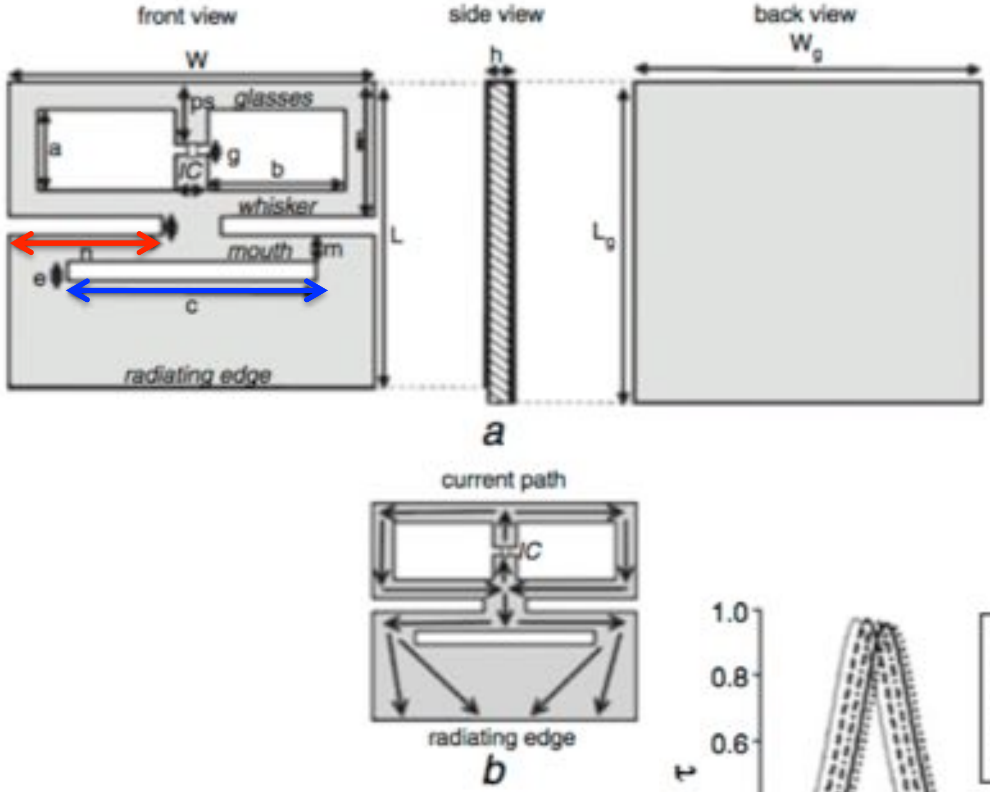


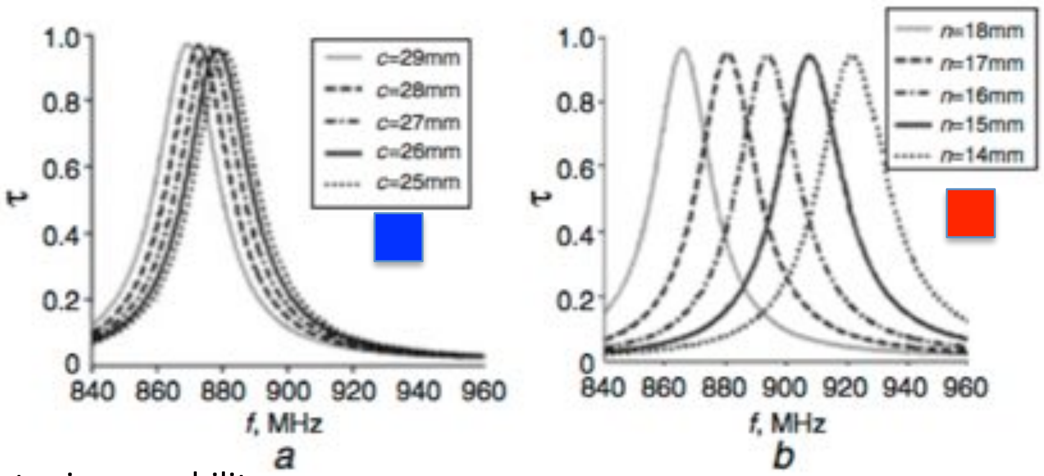


Observation: Normal incidence

Wearable textile RFID Tags

tuning



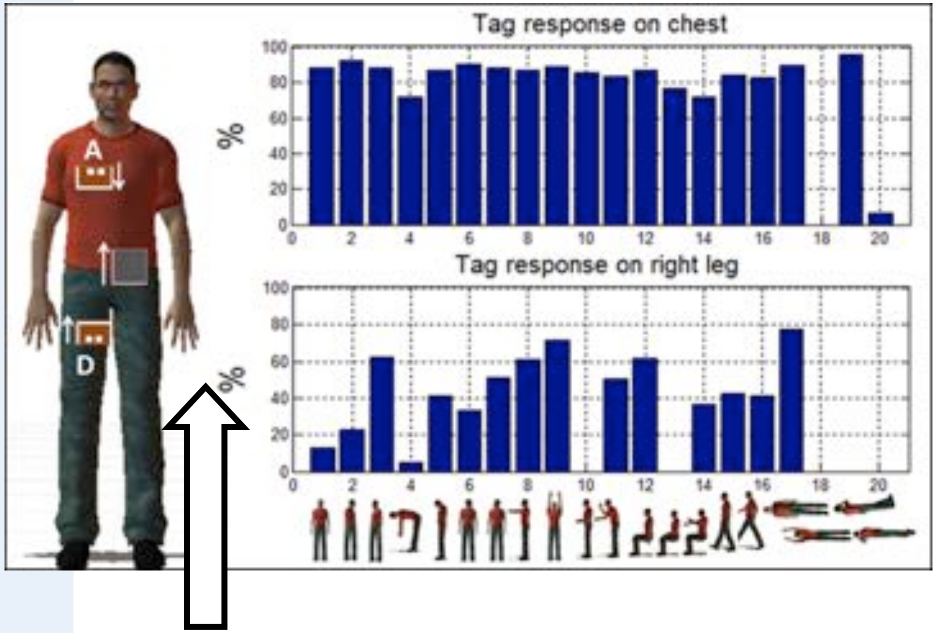


Miniaturized wearable UHF-RFID tag with tuning capability
S. Manzari, S. Pettinari, G. Marrocco, Electronics Letters, VoL. 48, N. 21, p.1325–1326

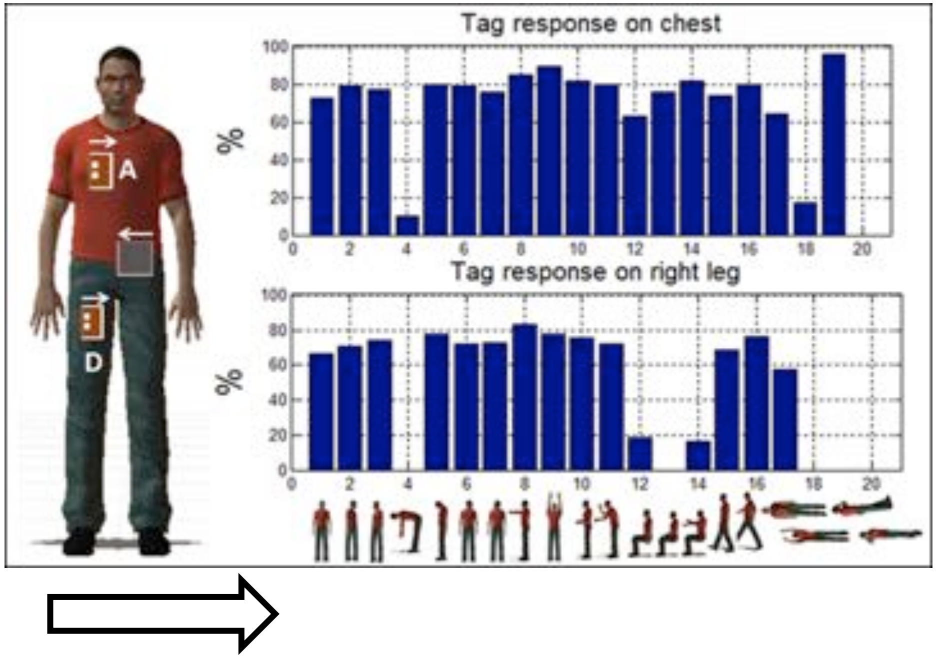
On-body RFID link

Pin=200 dBm/10

Vertical Polarization

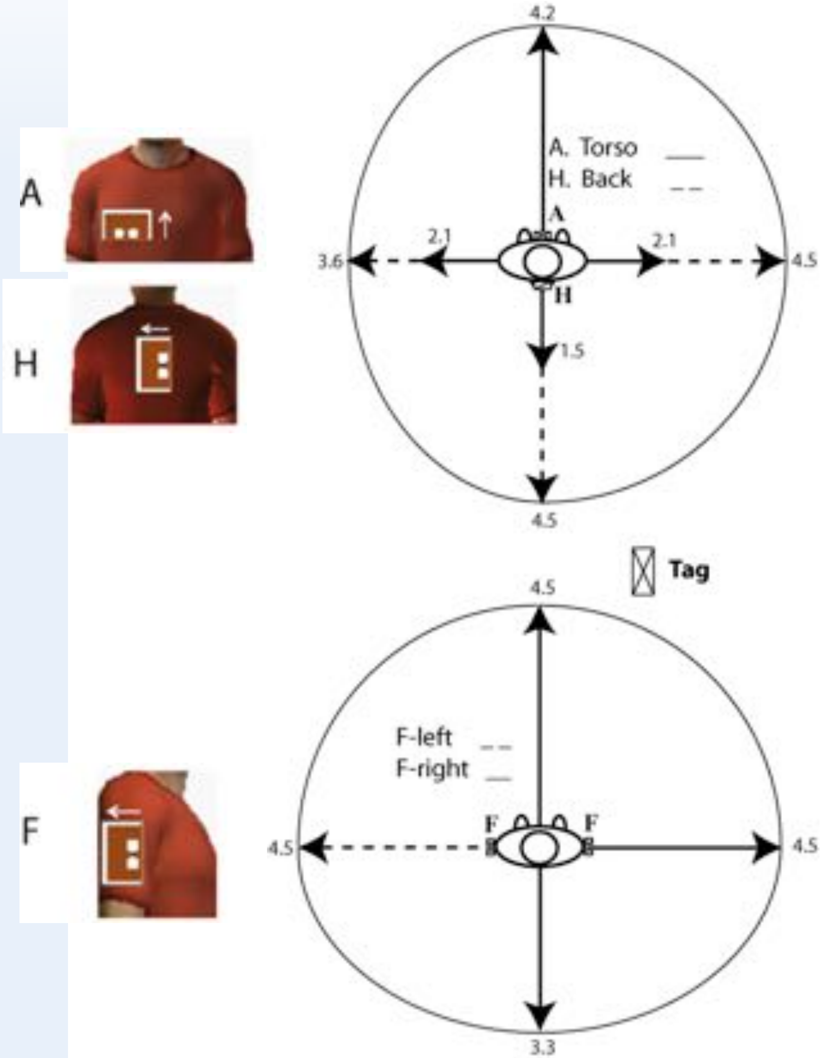


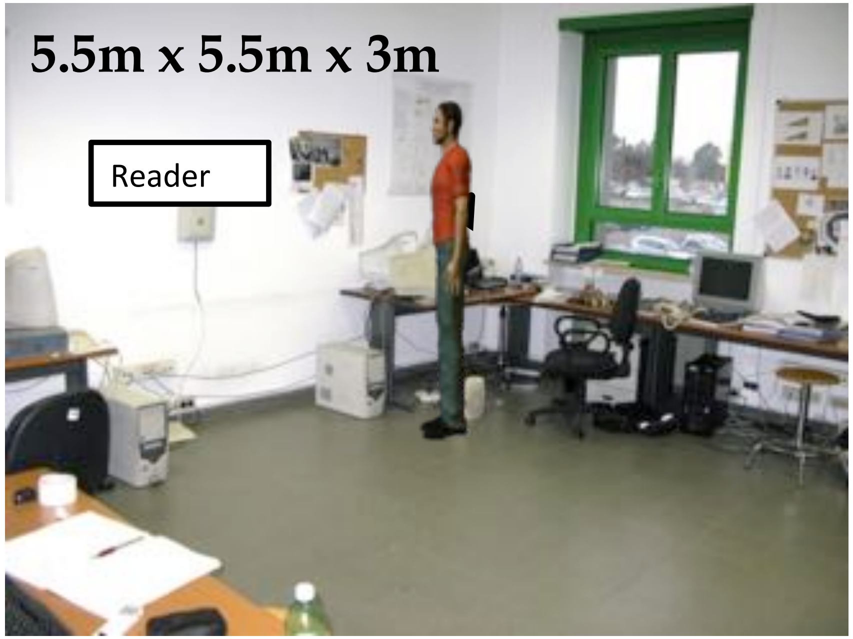
Horizontal Polarization



The tag on the chest is almost always visible except for one lying position

Off-body RFID link
- Real scenario

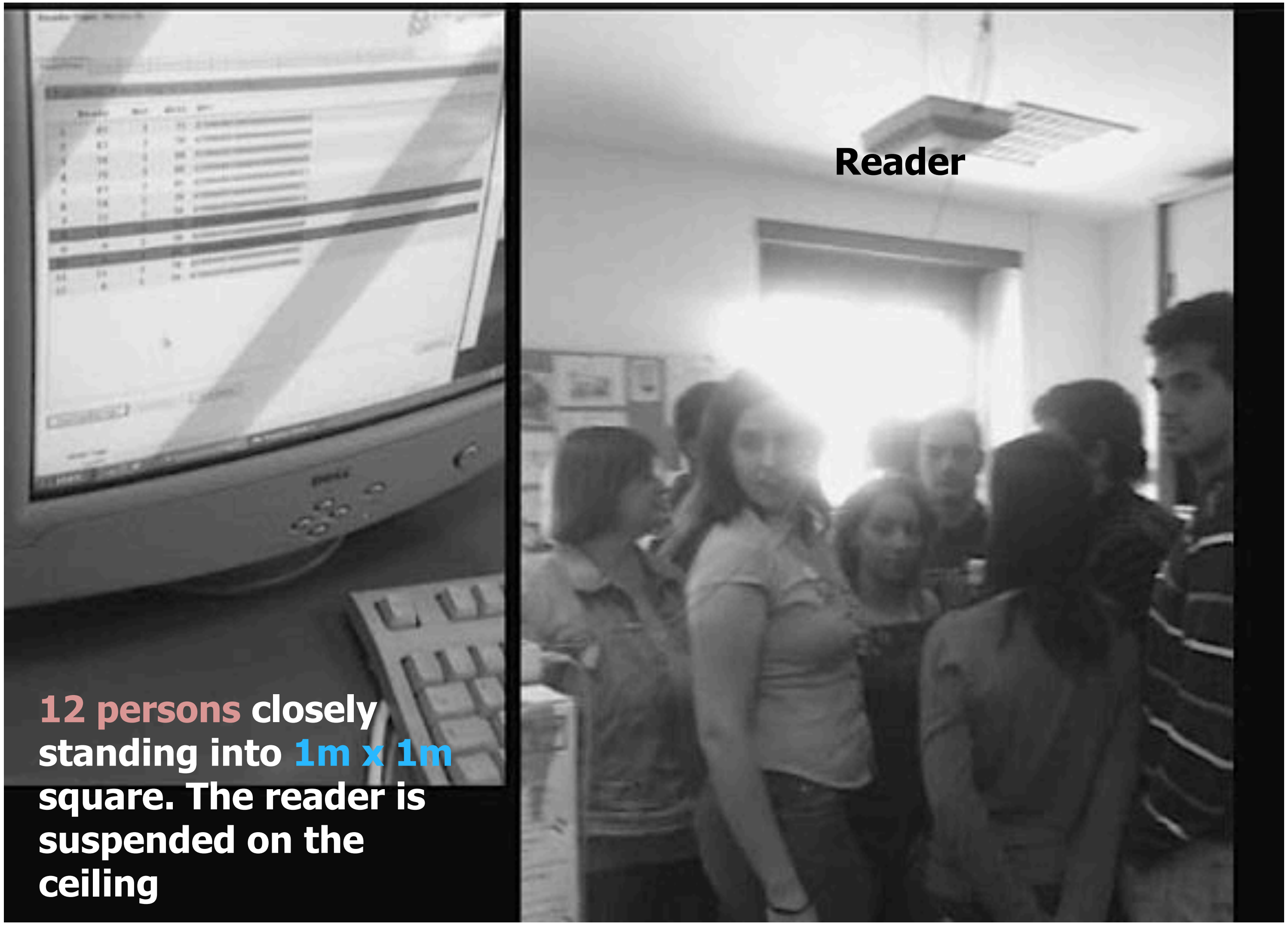




- Two tags properly placed enable a robust monitoring in a 4x3 m room
- **Chip Sensitivity -15dBm**
- No shadowing effects during normal activity

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

Off-body: Dense readings



-> VIDEO

Epidermal tags

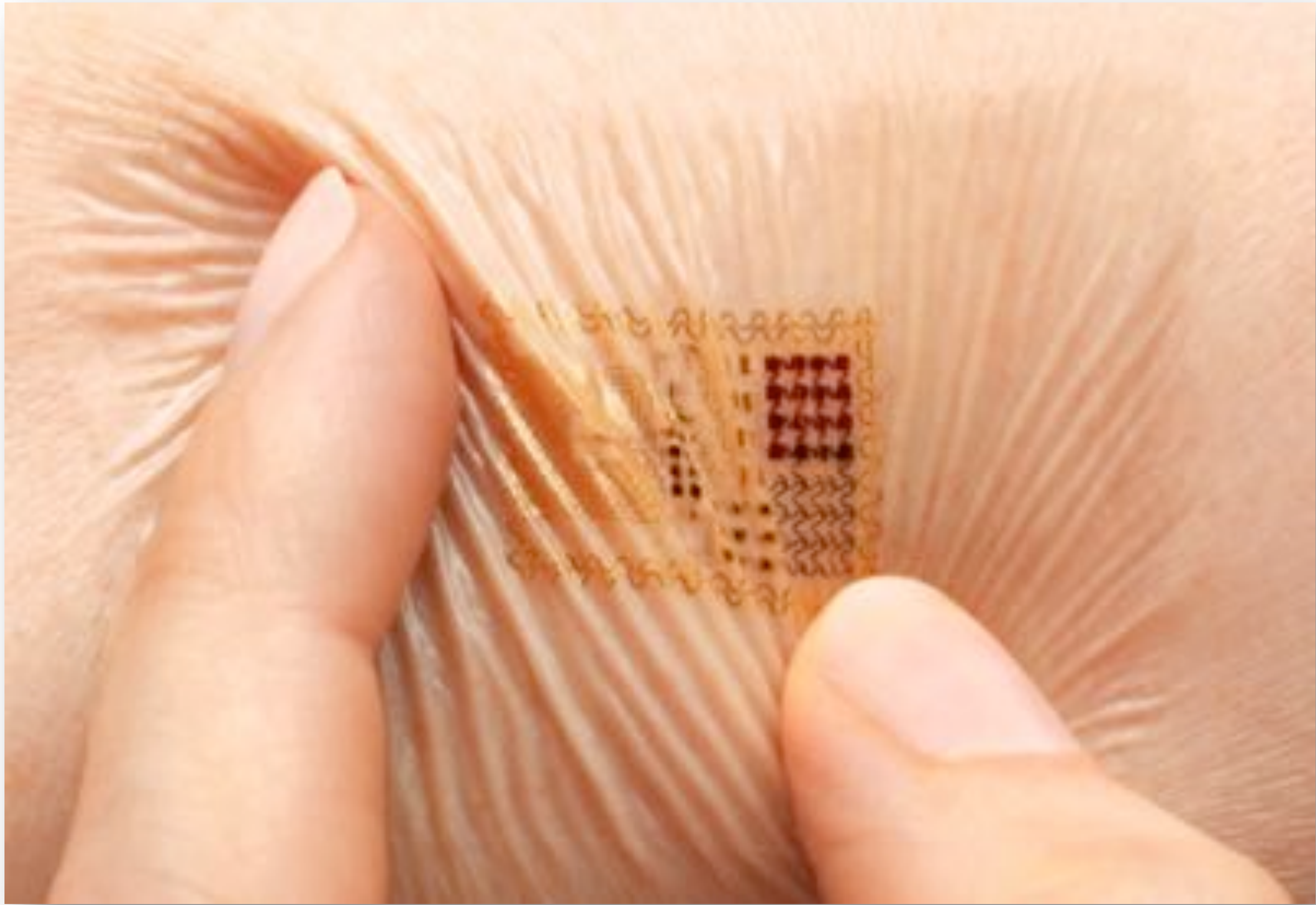
From Wearable to …

Huge scientific and industrial growth in the last decade

… to Bio-integrated Electronics

KEYWORDS

- **Skin**
- **Epidermal**
- **Flexible**
- **Stretchable**
- **Temporary**
- **Dissolvable**
- **Bio-absorbable**



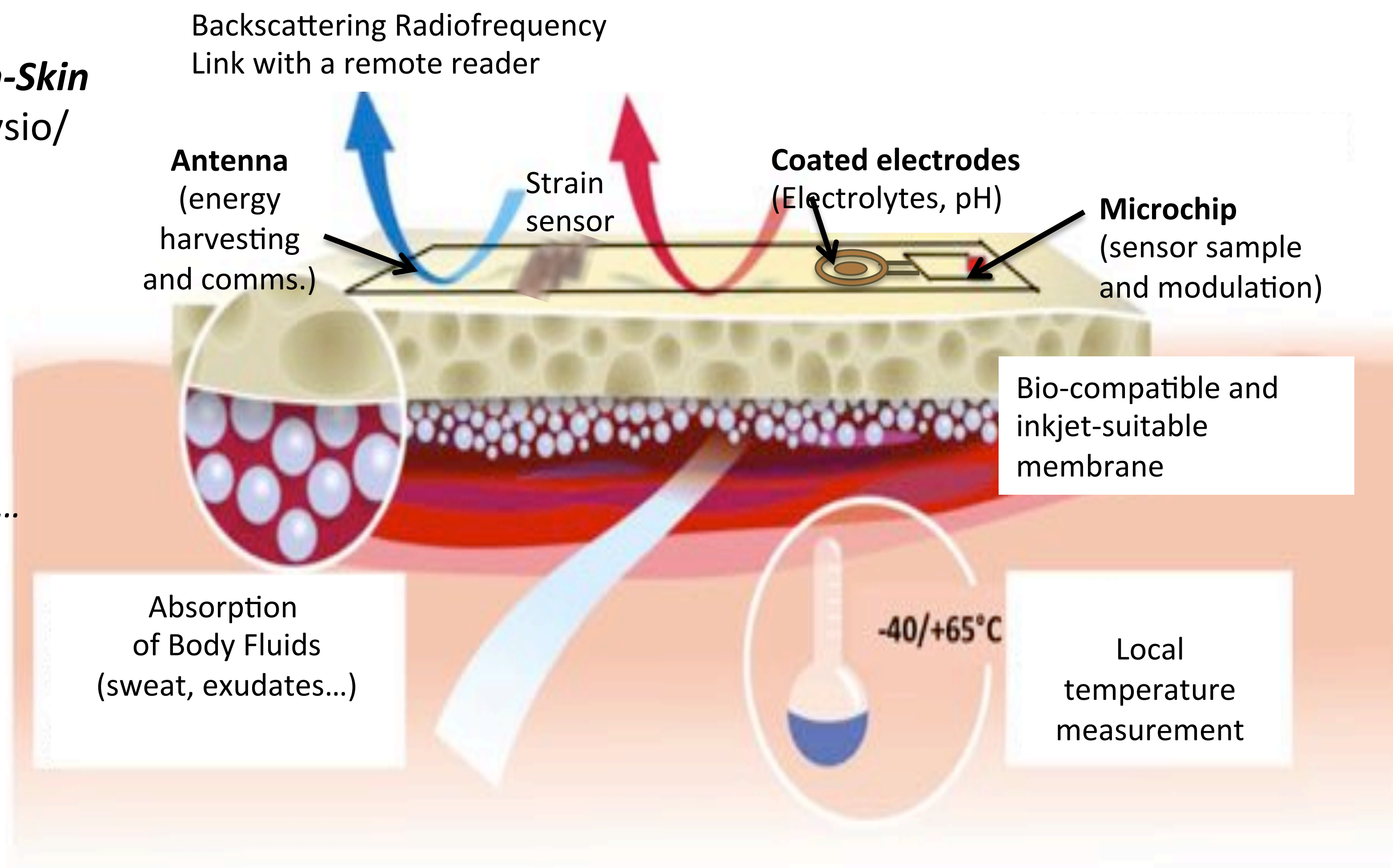
D-H. Kim, N. Lu *et al.*, "Epidermal Electronics", *Science*, Vol. 333, N.12, pp. 838-843, Aug. 2011.

Prof. J, Rogers, University of Illinois
Prof. F. Omenetto, Tuft University

Concept: Smart Plasters
- lab on skin

Unobtrusive ***On-Skin*** sampling of physio/ pathological parameters:

- *Temperature*
- *Hydration*
- *PH*
- *Strain*
- *Biopotentials…*



- Multi-sensors
- Sensor + Actuators (controlled drugs delivery)

Epidermal Electronics and EM community

IEEE SPECTRUM

Tissue-Thin Electronics That Float on the Breeze

By Eliza Strickland
Posted 25 Jul 2013 | 15:25 GMT

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Researcher Takao Someya has just unveiled an ultra-thin, ultra-flexible sheet of electronics that can stick to your skin and still works no matter how you bend, twist, or stretch your body.

By integrating sensors into the electronics, Someya says this lightweight

Hacking the Human OS > Reading the Code > Sensors

A Temporary Tattoo That Senses Through Your Skin

The Biostamp can replace today's clunky biomedical sensors

By Tekla S. Perry
Posted 29 May 2015 | 18:08 GMT

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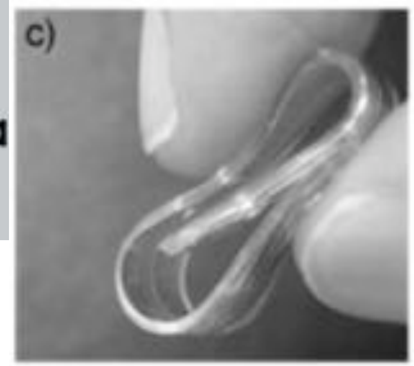
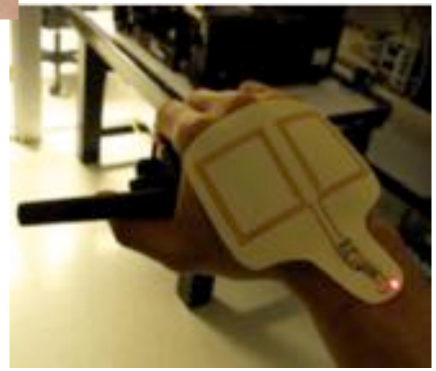
North American Radio Science Meeting
19–24 July 2015 • Vancouver, BC, Canada

IEEE

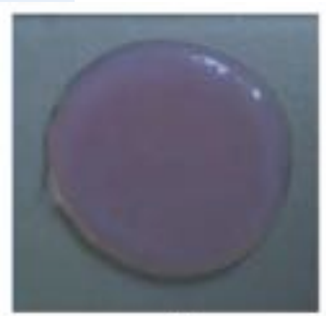


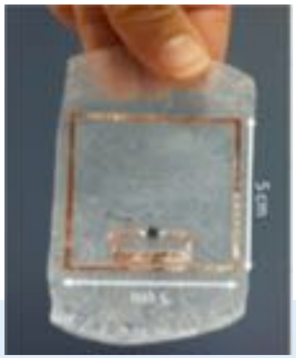
Antennas and Sensors for Epidermal Electronics

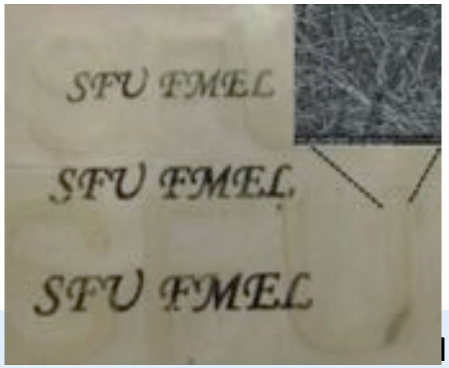


Organizers

Gaetano **MARROCCO** University of Roma Tor Vergata (IT)
John **BATCHELOR** University of Kent (UK)







2016 IEEE Interntational Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting

San Juan, Puerto Rico

June 25 - July 2, 2016

2016 AP-S/USNC-URSI IEEE Puerto Rico

Special Sessions

Requests to organize special sessions should be submitted to xxx yyy@zzz no later than October 9, 2015. Each proposal should include the title of the special session, a brief description of the topic, and justification for its designation as a special session. All proposals should be submitted in PDF format. Special sessions will be selected and finalized by the end of November 2015. At that time, additional instructions will be provided to the organizers of the special sessions chosen for inclusion in the symposium and/or the meeting. The associated papers or abstracts will be due **January 15, 2015**. A list of special sessions will be posted at the symposium website in December 2015.

A few special sessions will be solicited by the TPC chair and topic co-chairs, on topics of particular interest and relevance. Examples of expected special sessions at the 2016 meeting may include:

- Mm-Wave Antenna Arrays and Massive MIMO
- Antenna Design/Analysis Based on Characteristic Modes
- Electromagnetic Skins: Epidermal Antennas, Flexible and Stretchable Antennas, Sensing Substrates
- Metamaterials in Industry
- Grand Challenges in Computational EM
- Novel Paradigms, Challenges and Perspectives in Wave Scattering and Propagation

SOLECITED SPECIAL SESSIONS 2016

Electromagnetic Skins:

Epidermal Antennas, Flexible and Stretchable Antennas, Sensing Substrates

Challenges of Epidermal UHF-RFID Tags

- Tag has to play as sensor and hence **the antenna is at close touch with the body** (very thin or no insulating substrate)

- **High loss** and modest antenna performance: proper selection of antenna layout. Unlike wearable applications, patch antenna are not useful

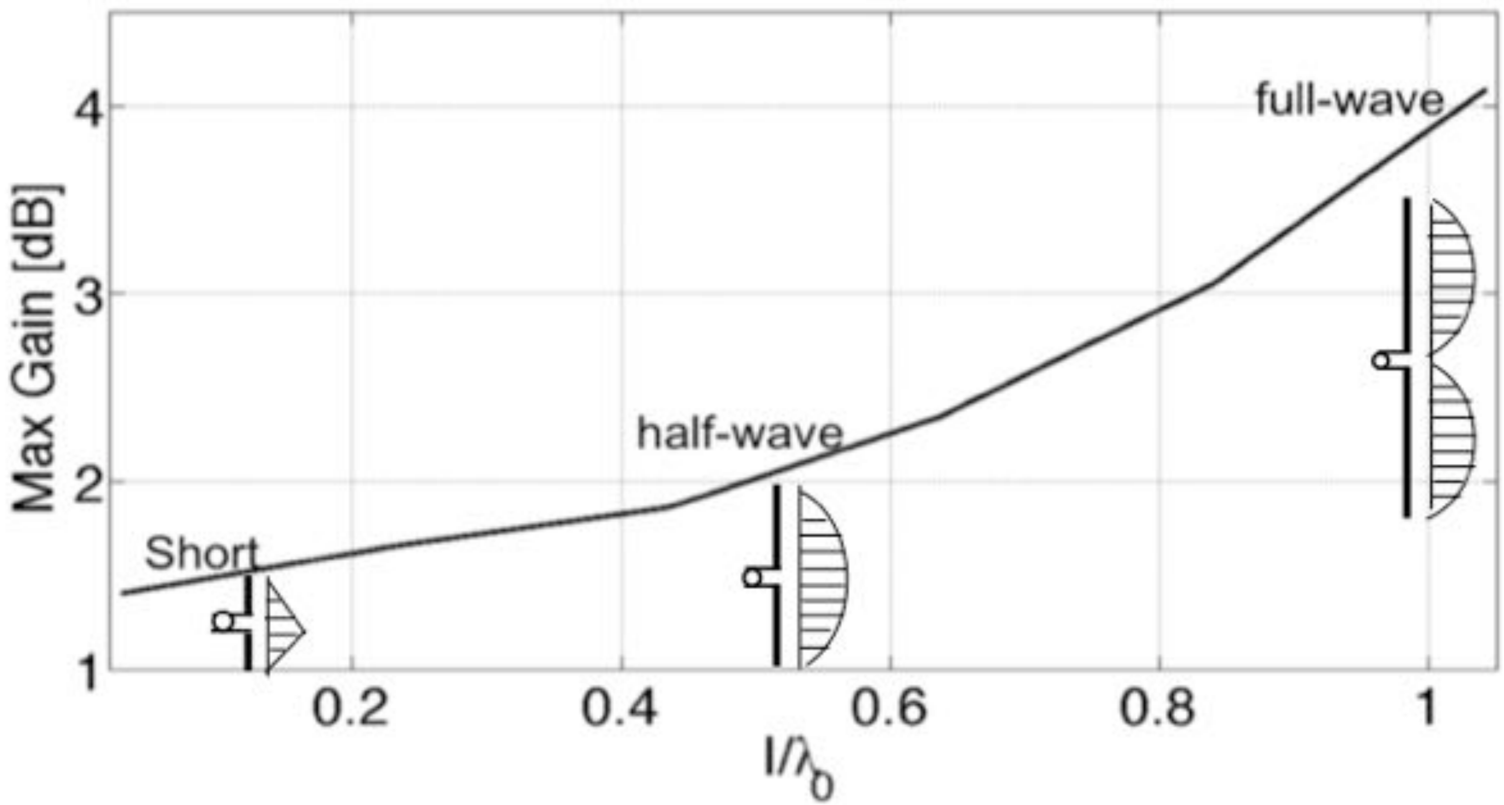
- **Human Variability**: broadband and/or possible on-body retuning

- Transfer modality of the Tag

- **Bio-compatibility** and **transpiration**

- **Deformation - immunity**

Optimal UHF antennas for Epidermal Tags



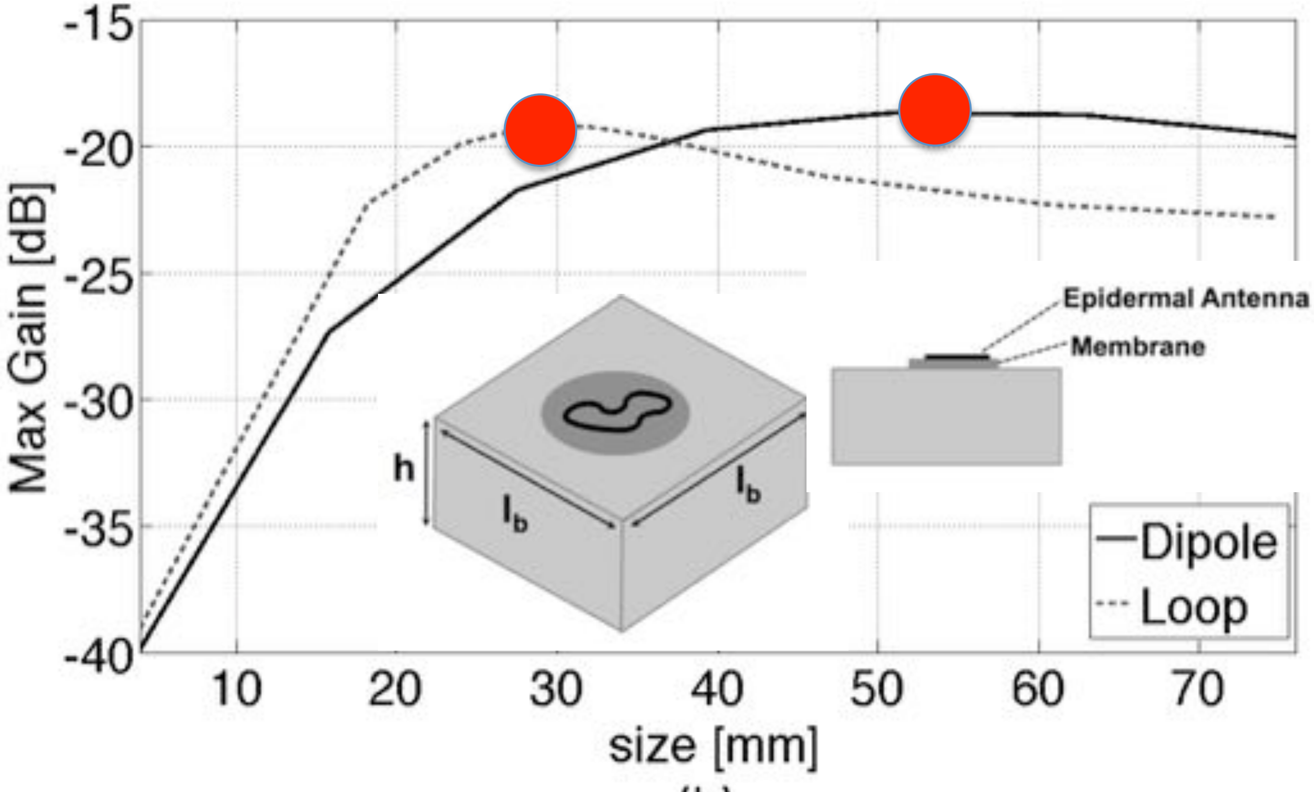
S. Amendola, G. Marrocco, "Optimal Performance of Epidermal Antennas for UHF Radiofrequency Identification ", IEEE Trans. Antennas and Propagat, under review
IEEE TAP, 2015

Optimal UHF antennas for Epidermal Tags

Two counteracting phenomena for Skin Antennas:

The initial increase in the gain is mostly due to the increase in the radiation resistance, which is proportional to the overall length of the antenna.

Further enlargements of the antenna produce more intense dissipation of power into the conductors and the surrounding tissues, because of the high conductivity of the hosting medium, which dominates radiation.



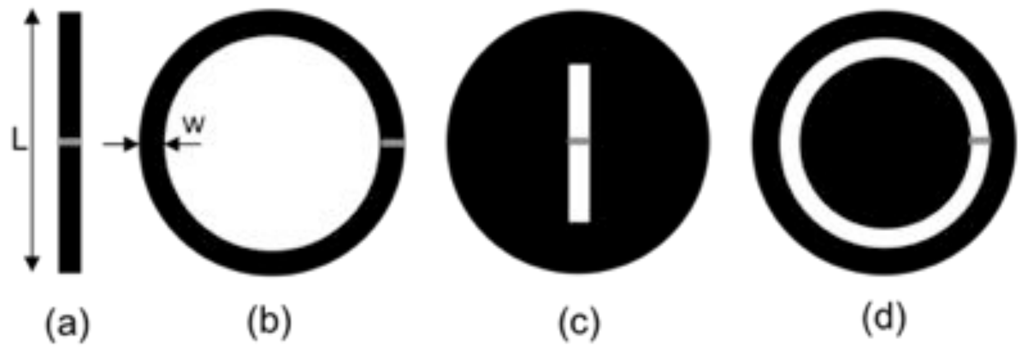
(b)

→ Optimal size of antennas over the skin

Optimal UHF antennas for Epidermal Tags

Which is the best shape for the antenna ?

- gain
- size
- amount of copper



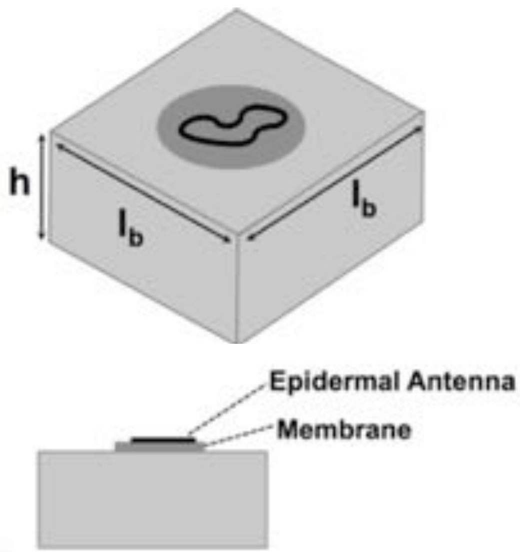
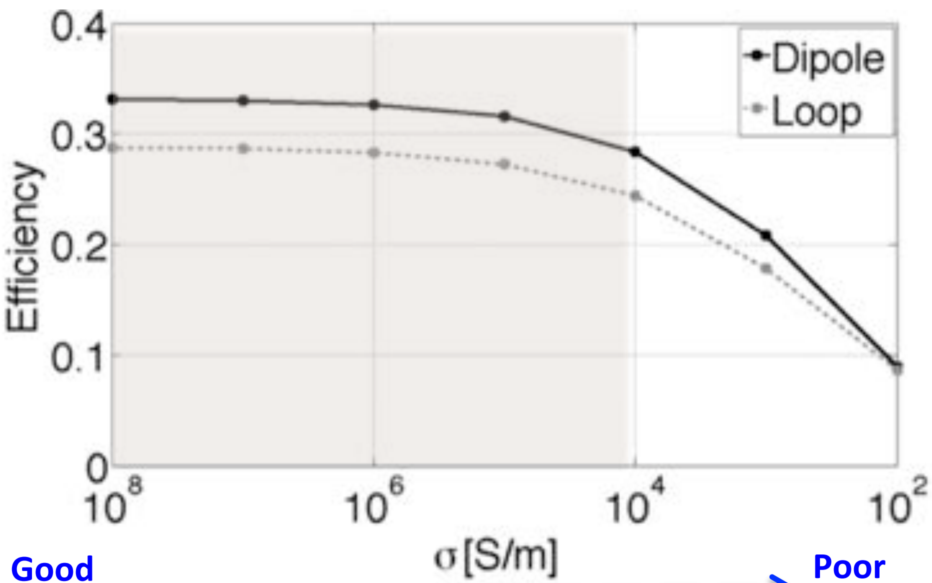


Table I
ELECTROMAGNETIC PERFORMANCE AND GEOMETRICAL PARAMETERS AT 870 MHZ OF THE REFERENCE EPIDERMAL ANTENNAS

Antenna	η [%]	G [dB]	L_{opt} [cm]	A_{metal} [cm^2]
	0.3	-18.7	5	0.5
	0.3	-19.1	3	0.9
	0.3	-19.4	6	27.6
	0.2	-19.5	8	46.7

Antenna size

Performance vs. trace conductivity



Good conductor — Poor conductor

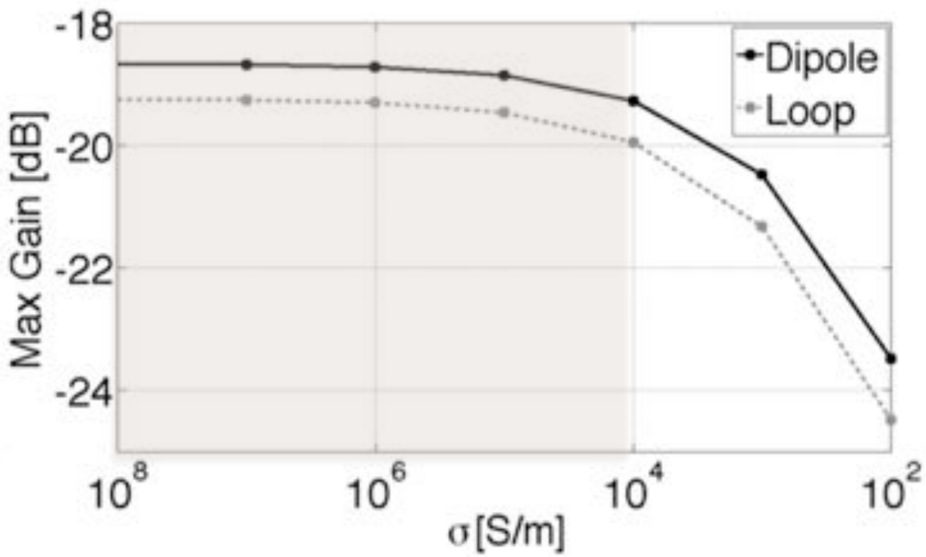
Variable trace conductivity

50 × 1 mm dipole
30 × 1mm loop

f=870 MHz

Antenna conductivity is a second-order parameter !!

- No variation in the radiation performance for $\sigma > 10^4$ S/m
- even by reducing the conductivity down to σ =1000 S/m, the gain drops by less than 2 dB



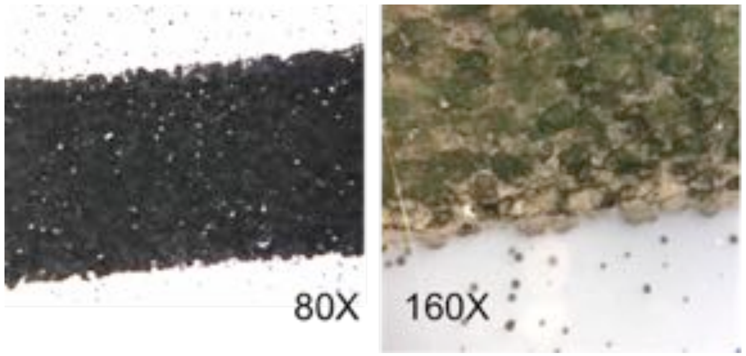
Low-Cost Inkjet Printing

Desktop printer

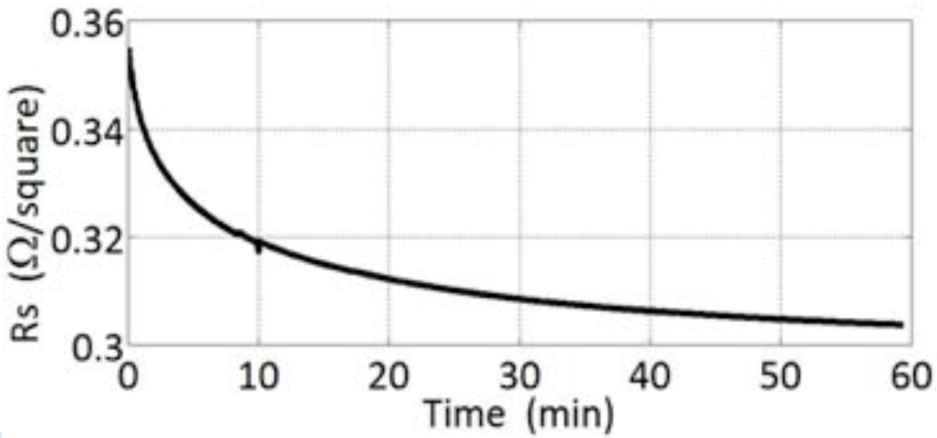
Ink Properties

- **Water-based, RoHS compliant**
- **Particle size average:** 20nm
- **Ag solid content:** 10 ~ 20wt%
- **Ethylene glycol content:** 10 ~ 40wt%
- **Viscosity:** < 10 cps
- **Surface tension:** 25 - 35 mN/m
- **Density:** 1.2 - 1.3 grams/ml
- **Jetting properties:** excellent
- **Designed for fast curing**
- **Minimal VOC**
- **Easy cleanup**

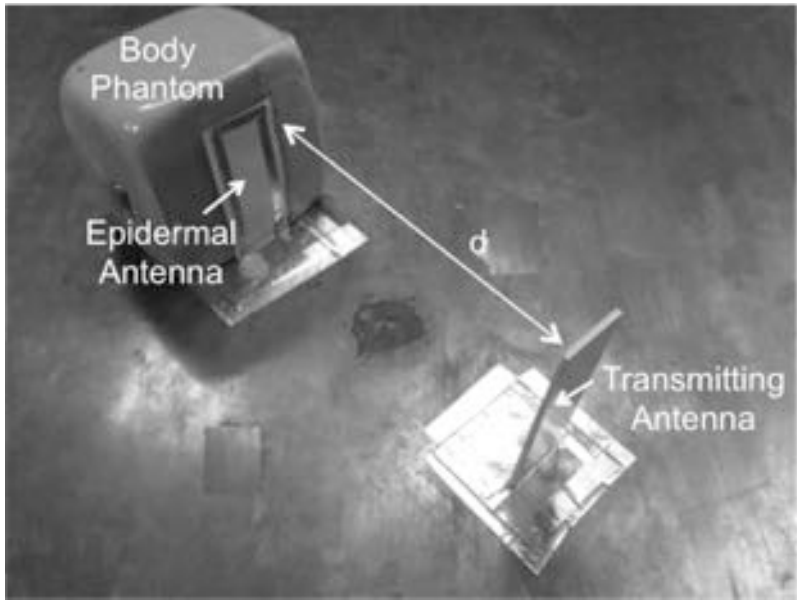
Ag Nano-ink



Self-Sintering **at room temperature**
after 20min



Experimentations:
Optimal length



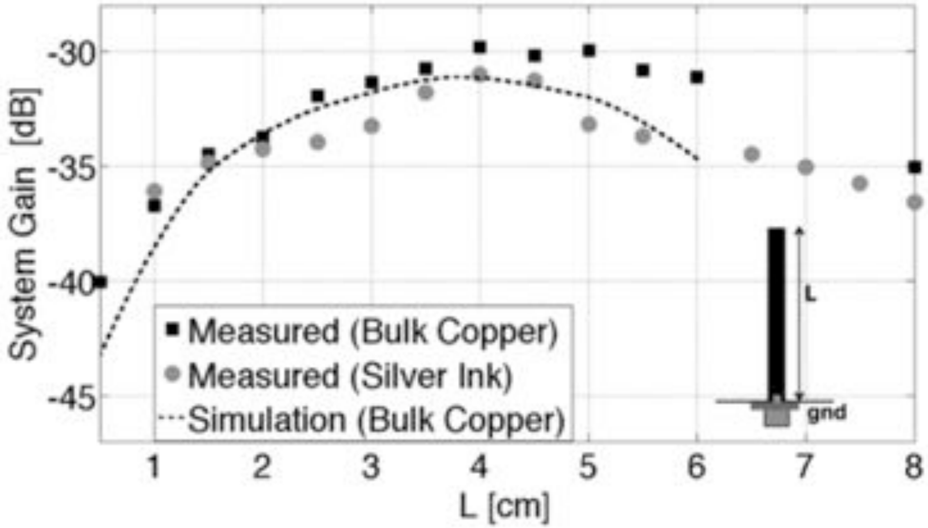
System Gain

$$g = \frac{P_{out,av}}{P_{in}}$$

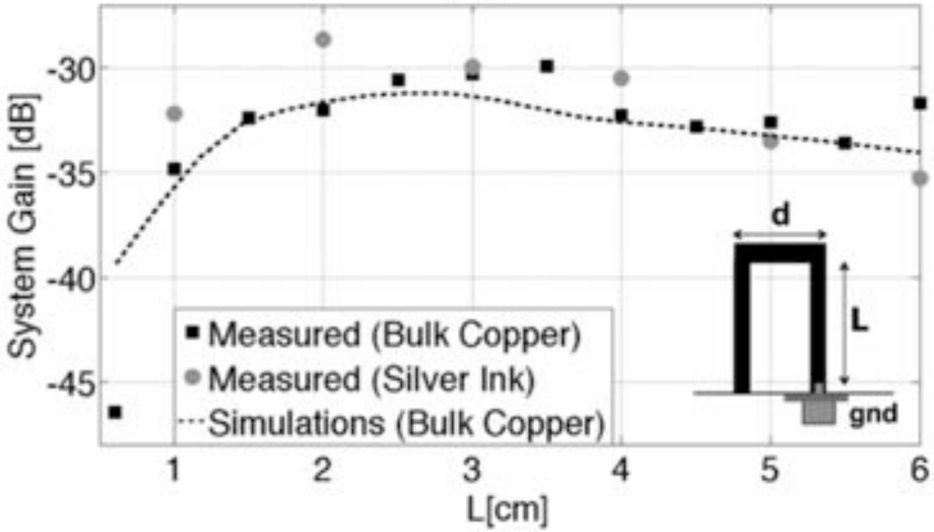
Maximum power deliverable to the epidermal antenna load

Power entering into the TX antenna

$$g = \frac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

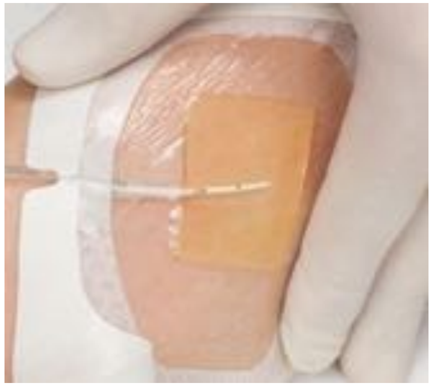


(a)



Membranes for Skin Antennas

Thin-layer Band-aid - Silicone

Summary Table of Medical Grade Adhesives			
Feature	Synthetic Rubber	Acrylate	Soft Silicone Gel
Peel Adhesion	High	Low to high	Low to medium
Sterilisation Compatibility	EtO, Gamma, Steam	EtO, Gamma, Steam	EtO
Breathability	Low	Tuneable	Medium
Repositionability	×	×	✓
Initial Tack	Good	Low to high	Good
Skin Trauma on Removal	High	Medium	Low

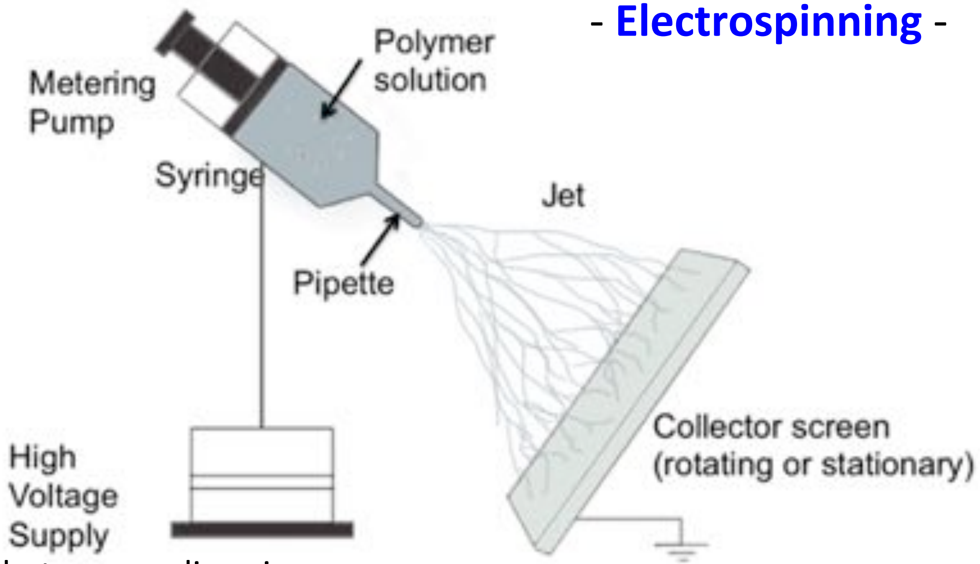
Table 1: Summary table of the features of synthetic rubber PSA, acrylate PSA and soft silicone adhesive gel.

3M

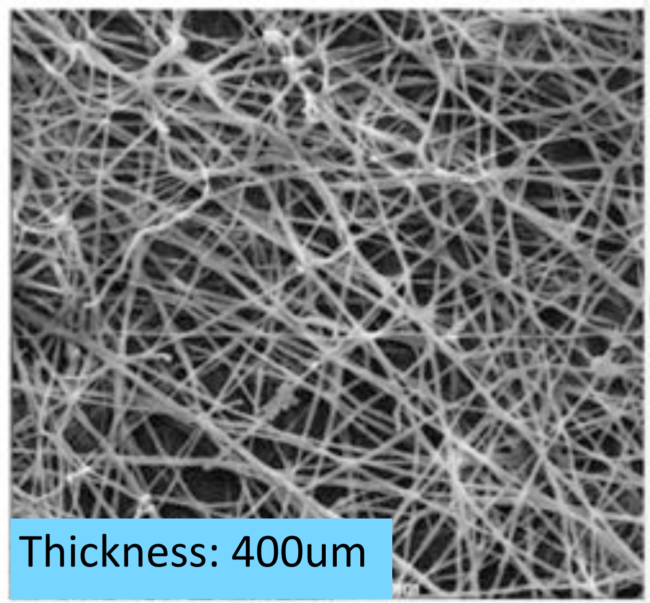
Membranes for Skin Antennas

Scaffold - Poli ε-Caprolactone (PCL)

- **Electrospinning** -



between polimeric



Semi-crystalline bio-readsorbable membrane with slow degrading rate due to its hydrophobic nature and high crystallinity degree.

Produced by Electrospinning techniques (dense non-woven micro and/or nano-fibrous fabrics)

Flexible and stretchable **scaffold**.
Natural transpiration

Possibility to be **functionalized** with specific chemical receptors

Del Gaudio, Bianco et al, Wiley InterScience,2007.

Membranes for Skin Antennas

Hydrogel

Figure 20. PVA/XG membranes under test having different compositions.

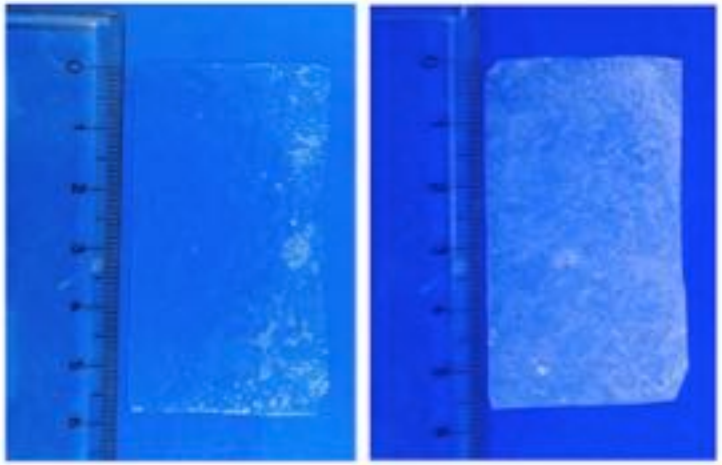


Figure 21. Samples of the fabricated hydrogel membrane. Left) Swollen; Right) Dried

An hydrogel membrane is a stretchable substrate made of **a polyvinyl alcohol/xyloglucan** (PVA/XG). **Polyvinyl alcohol is a biocompatible synthetic polymer** while Xyloglucan is a hemicellulose that occurs in the primary cell wall of every vascular plant.

PVA/XG membranes **are able to absorb body fluids** (such as wound exudates) **and release water and drugs**. Their structure hence undergoes swelling and drying processes according to the skin conditions being able to absorb in the specific case up to **40% of fluid**.

Membranes for Skin Antennas

Fibres-based Dressing

Carboxy methyl cellulose (CMC)

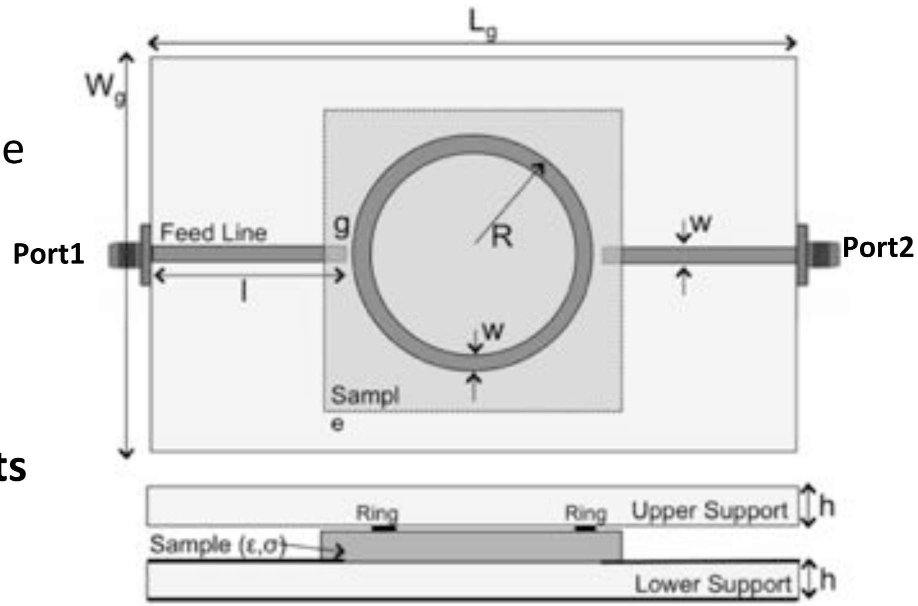
Huge liquid Absorption

Membrane characterization

Dielectric Meter

Suspended-Ring Resonator:[1]

- Not disruptive method
- Good flexibility in terms of size/shape of the sample
- **Liquid and solid materials**
- No preliminary calibration with reference materials
- Possible **exposure to external agents** (liquid, gases and mechanical solicitations..): **time-variant sample** characterization.



Sample Parameters { *Permittivity* ε_r, *Conductivity* σ, *Thickness* } → RING → S_{12} vs frequency

I. Waldron, S.N. Makarov, S. Biederman, R. Ludwig, "Suspended Ring Resonator for Dielectric Constant Measurement of Foams," *Microwave and Wireless Components Letters, IEEE* , vol.16, no.9, pp.496-498, Sept. 2006

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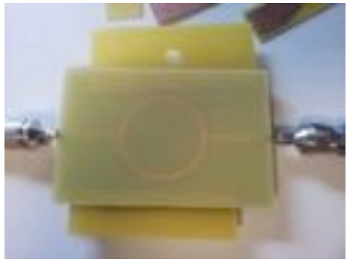
Parametric Identification

Experimental ⟷ Numerical



1. VNA Measurements

↓

2. Features extraction

$$\left\{ f_{res}, Q = \frac{f_{res}}{\Delta f_{-3dB}} \right\}$$

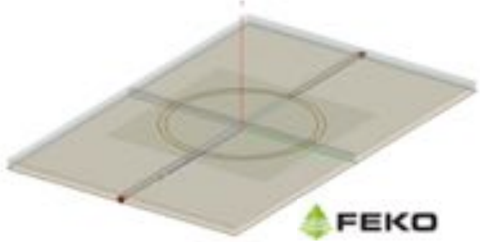
1. EM Modeling (FEM)

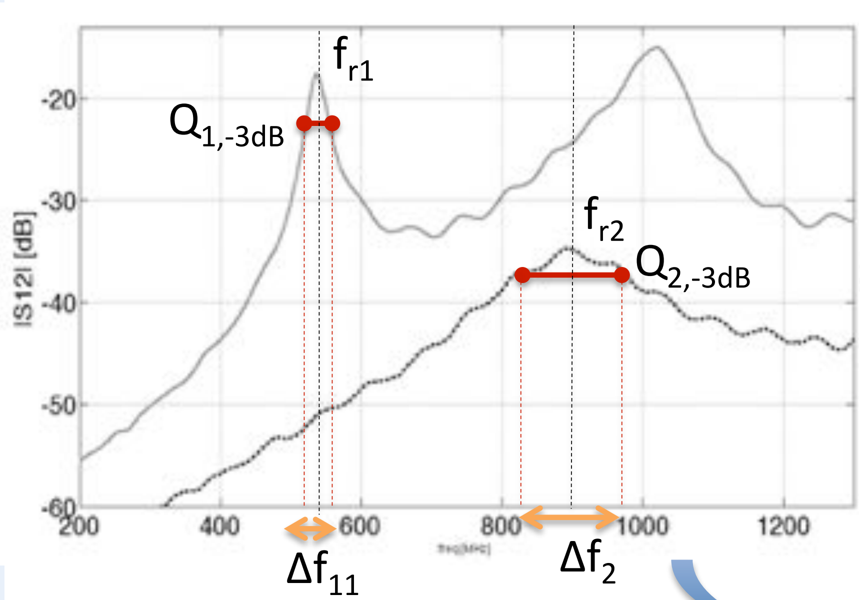
↓

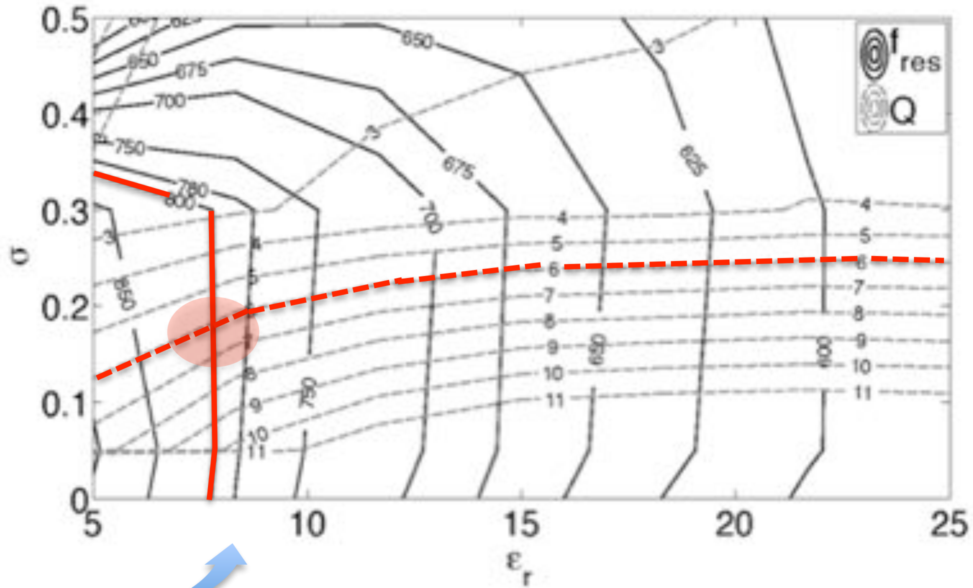
2. Parametric Simulation

Data Inversion Charts

$$\left\{ f_{res,sim}(\varepsilon,\sigma), Q_{sim}(\varepsilon,\sigma) \right\}$$



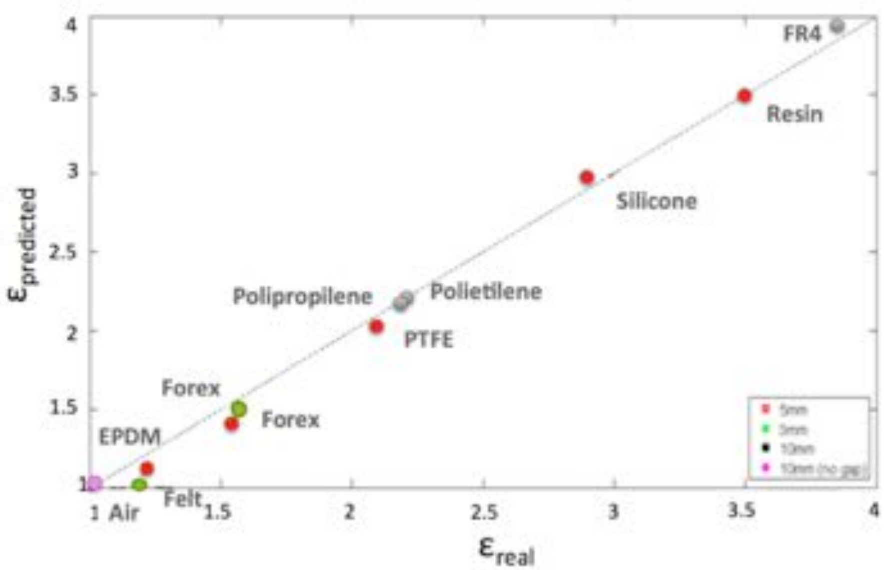


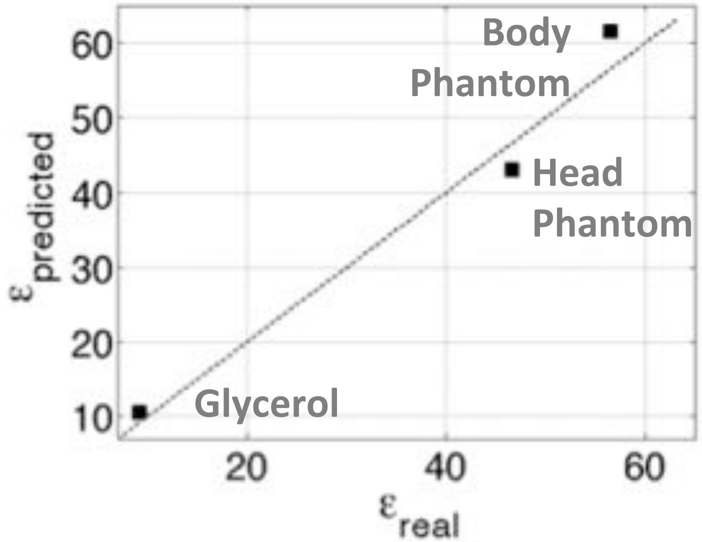


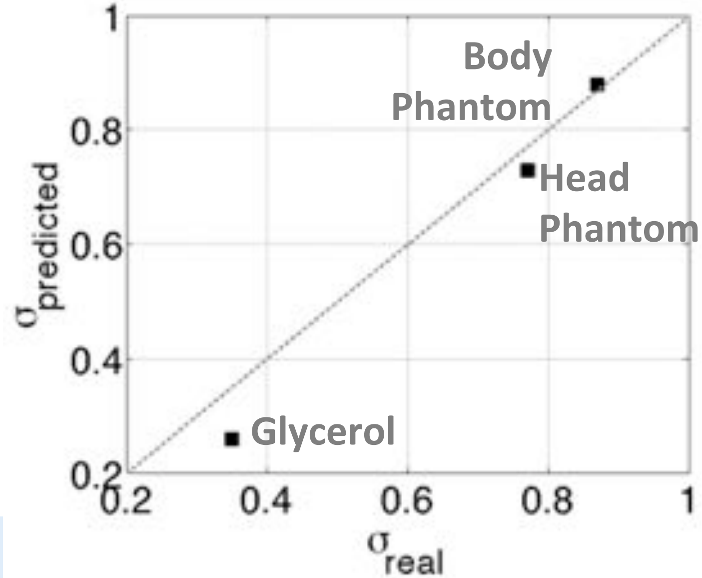
Parameters Retrivial

Validation

Low & High permittivity and losses







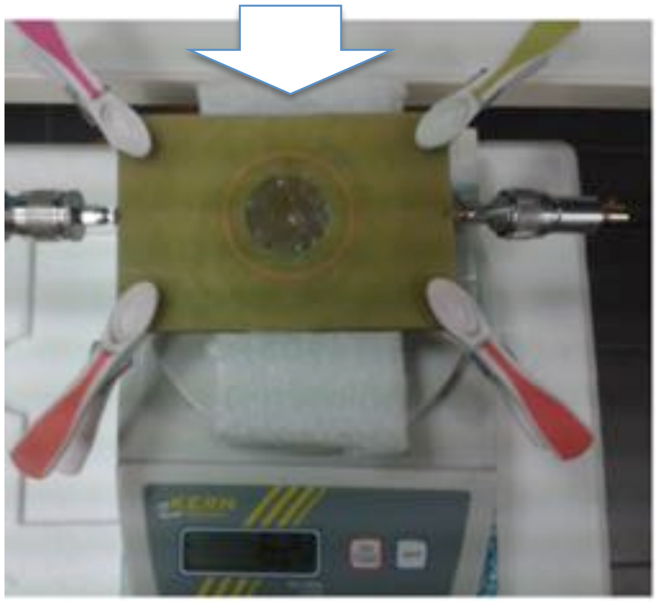
Solid Samples, Different Thickness

Validated for both low-permittivity and high-permittivity materials

Characterization of e.m. Parameters

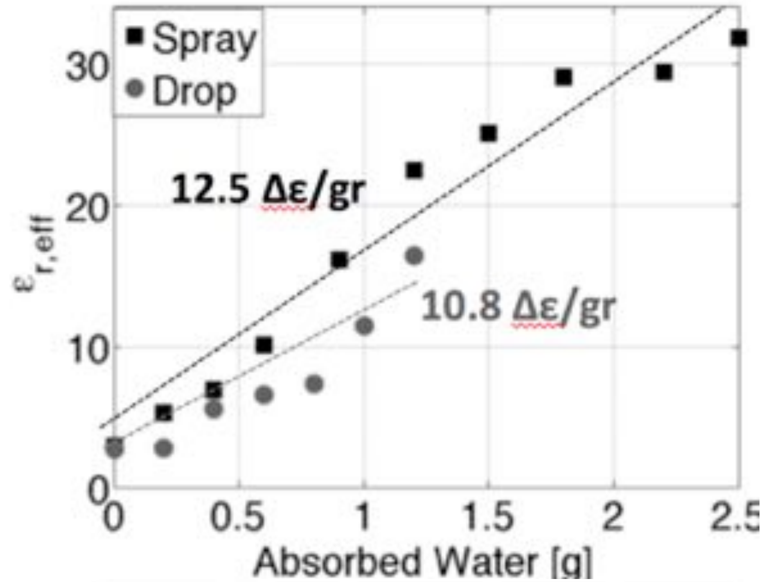
- Hydrogel

fluid



→ VNA

scale



- **Distributed Exposure**

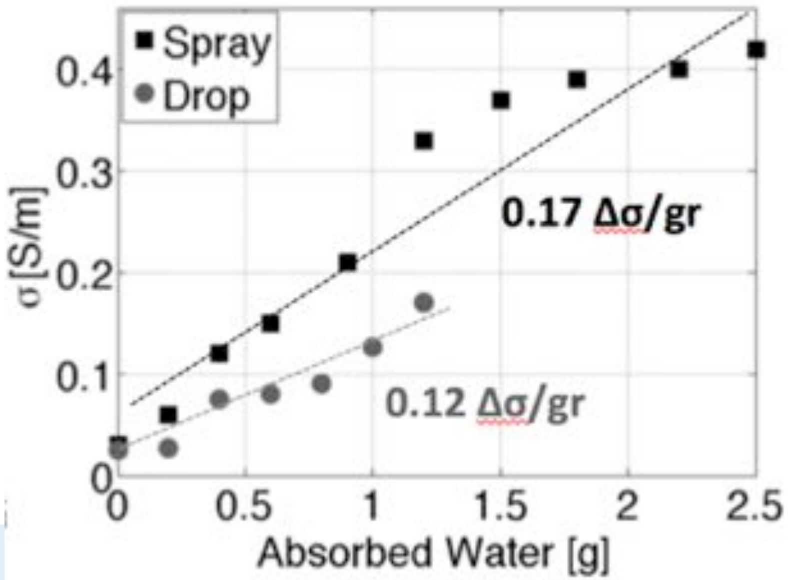
  Solution uniformly dispersed by spray nozzle

  Large burns, ulcers, Bedsores, Sweat loss

- **Localized Exposure**

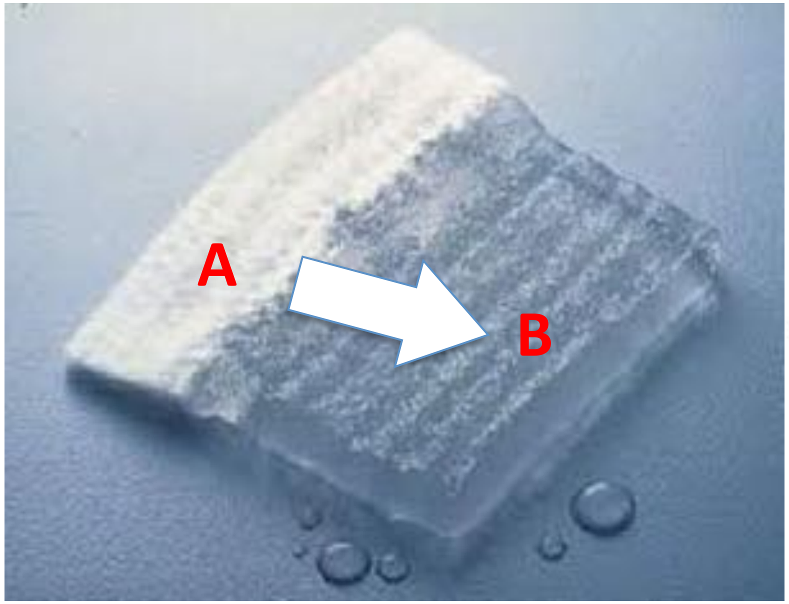
  Solution locally release by syringe

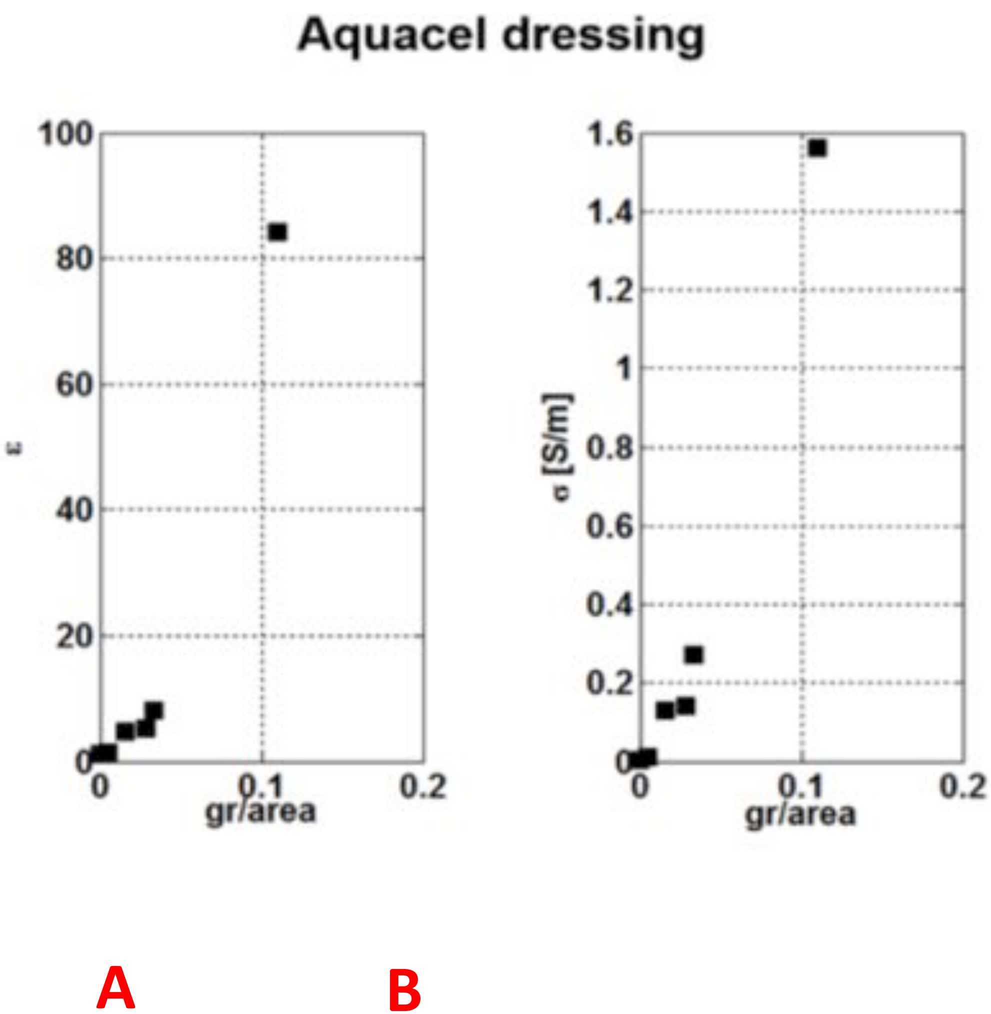
  Punctured wounds, Gunshot wound, Incision



Characterization of e.m. Parameters

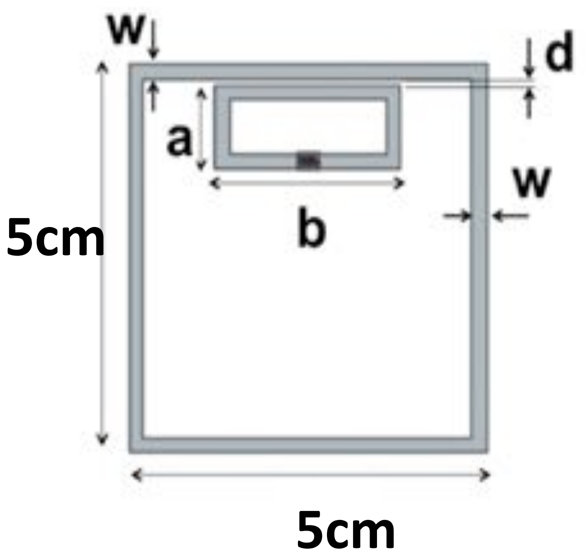
- Fibres dressing

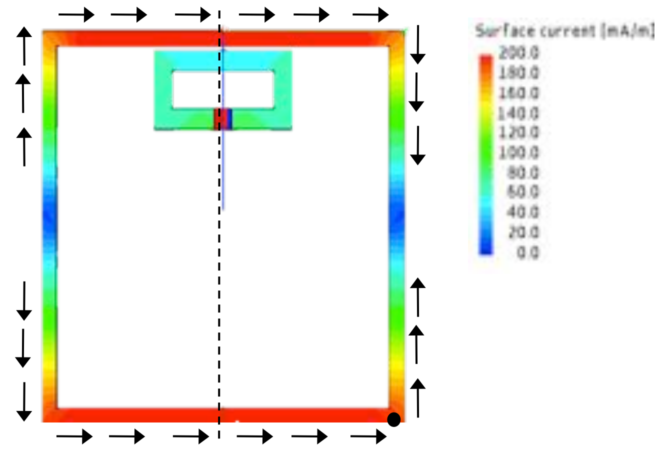


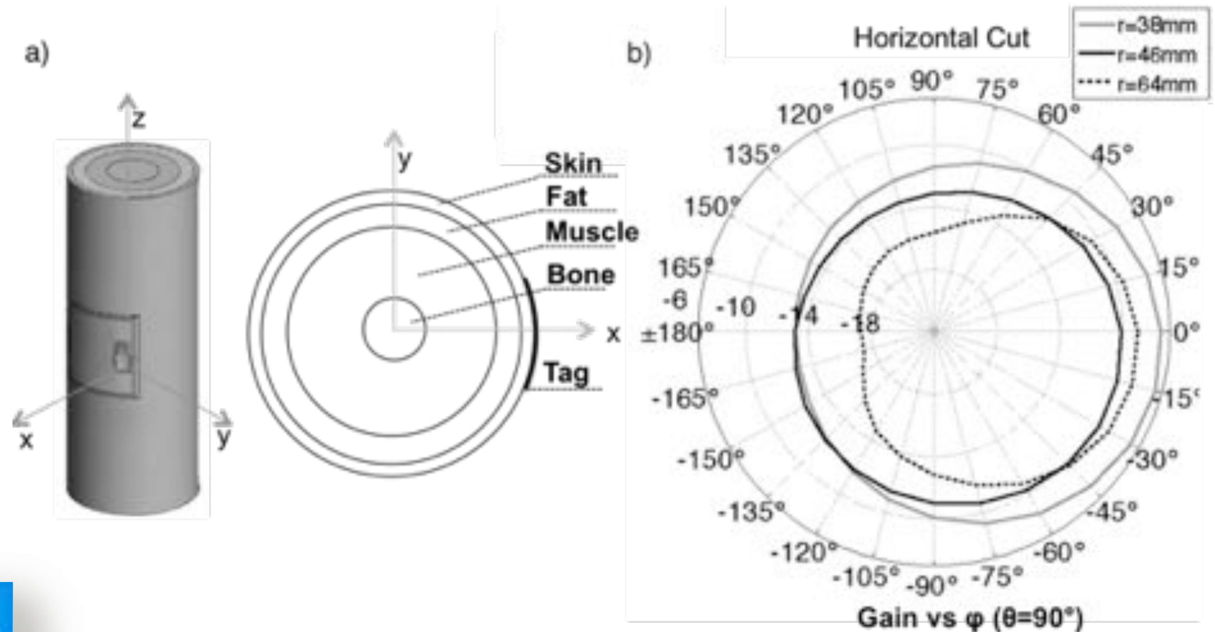


Step-wise behavior

Skin antennas: Dual-Loop tag





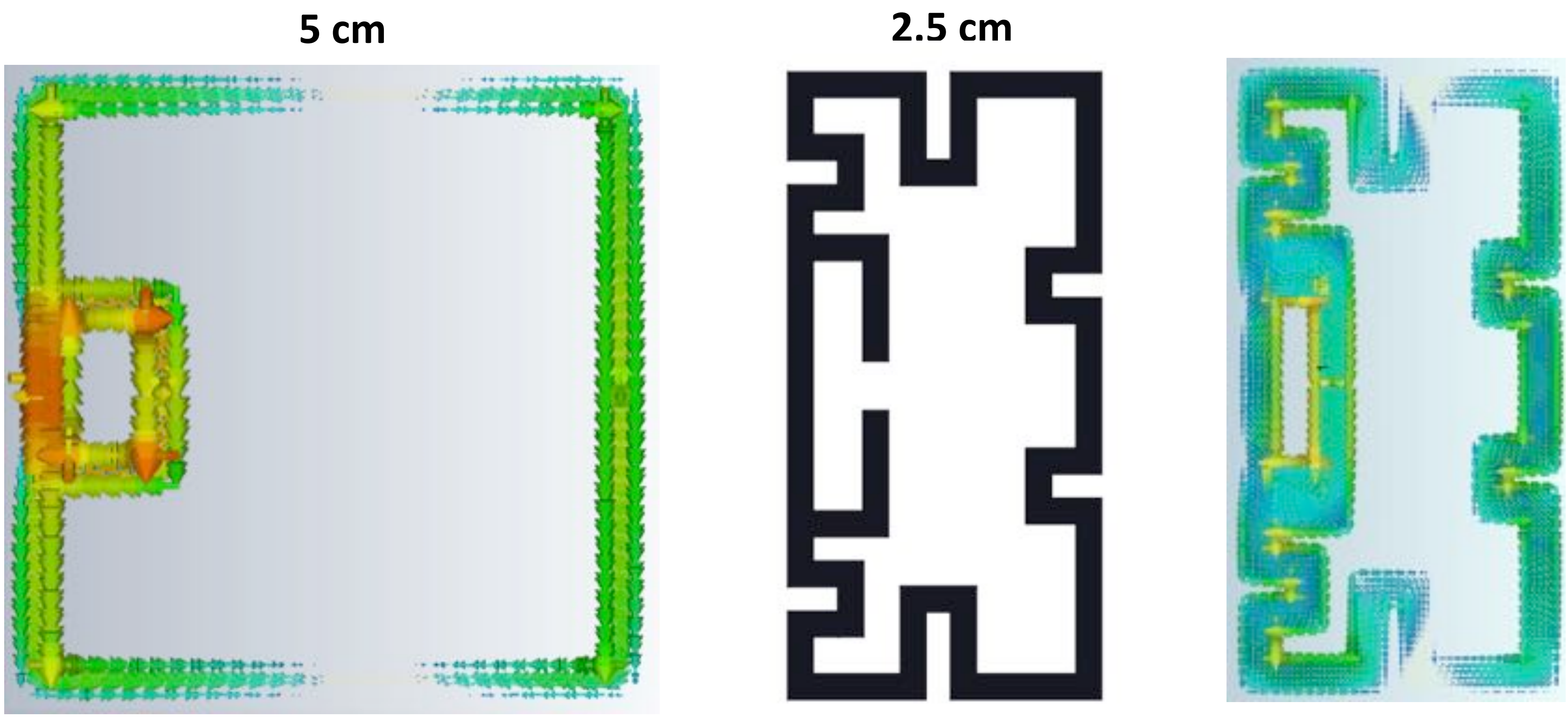


Radiation like a two C-dipoles

Loop exciter for impedance matching

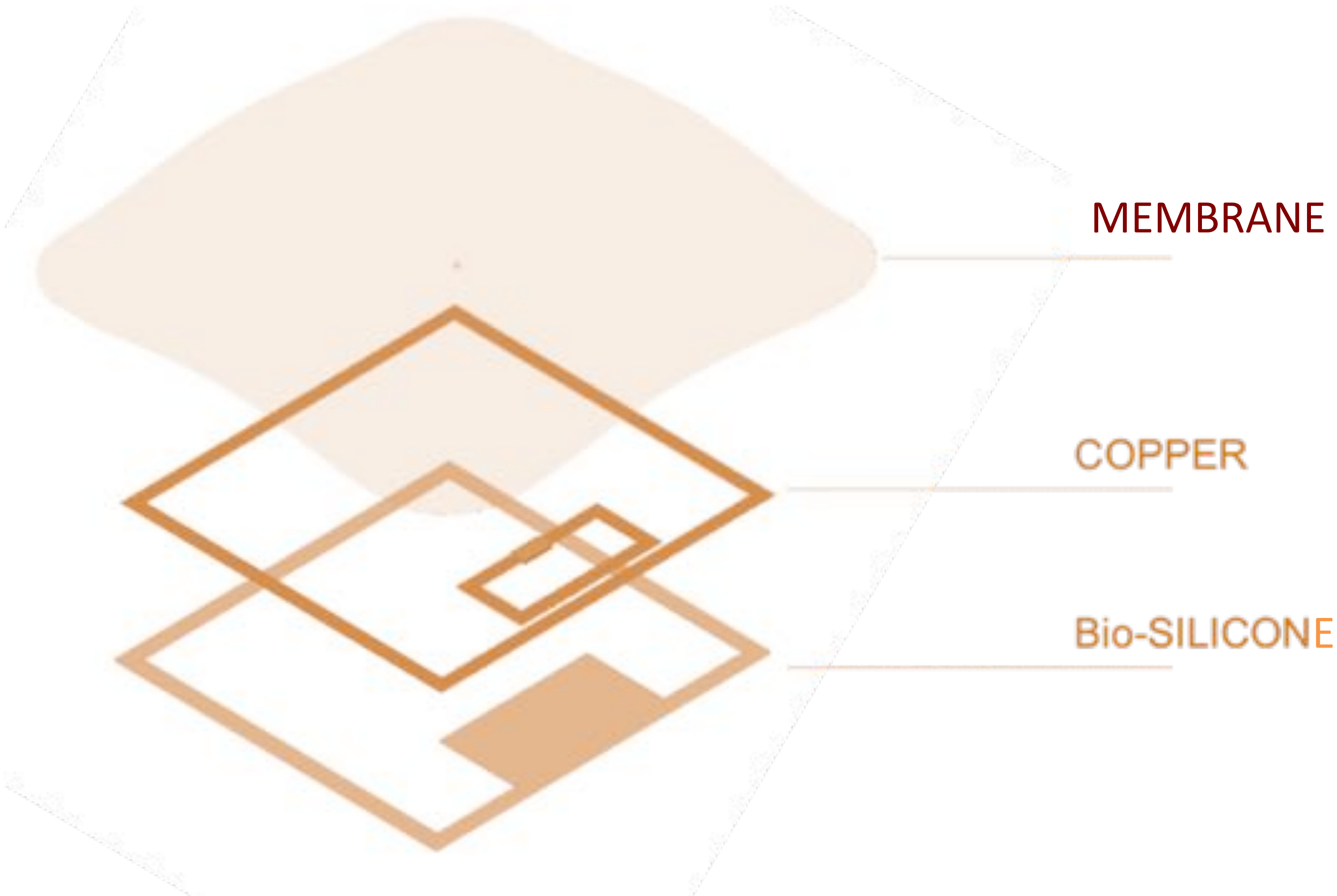
S Milici, S Amendola, A Bianco, G Marrocco, "Epidermal RFID passive sensor for body temperature measurements", IEEE RFID-TA 2014

Miniaturized Skin Antennas

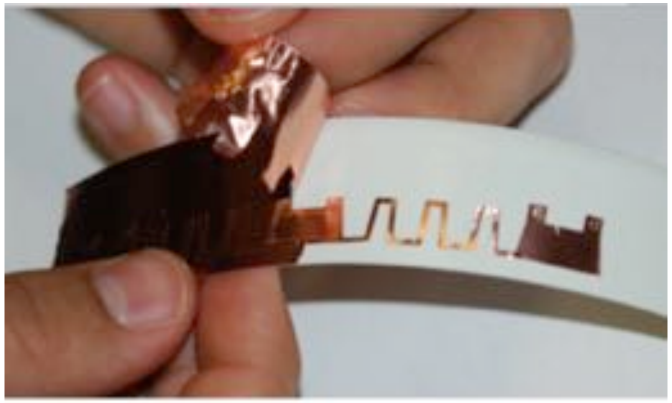


- Miniaturization of the “un-useful” traces
- Additional meandering to achieve stretching
- Performance , practically unchanged

Fabrication

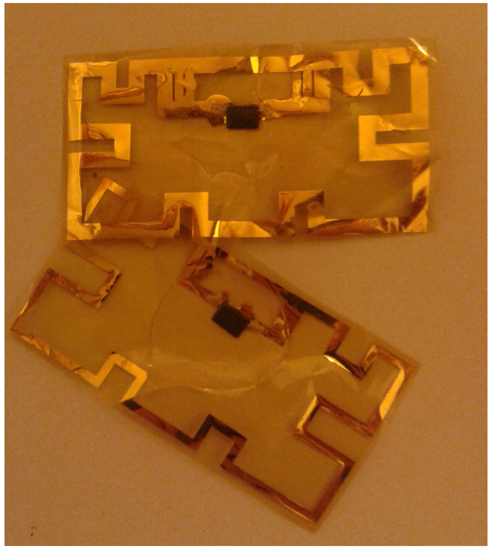


Traces Deposition


Carved adhesive copper sheet


Stencil and conductive paint

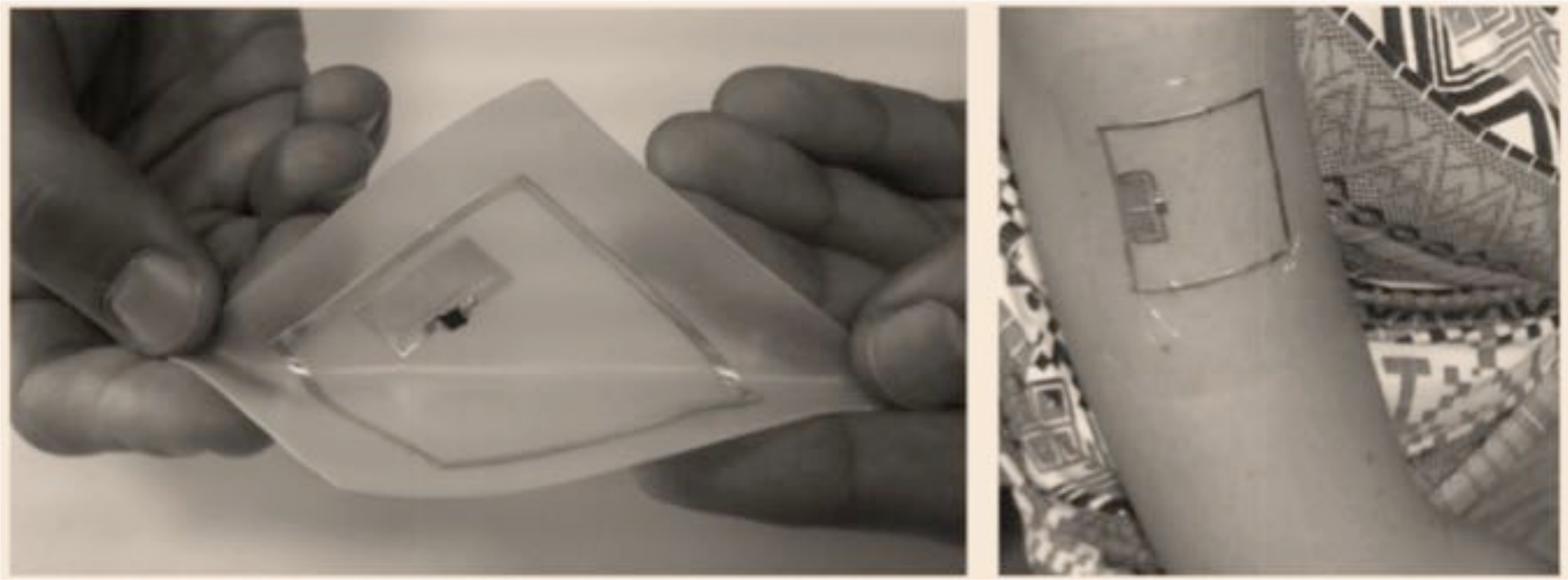

Coated
Micro-wires


Micro-fabrication


Inkjet printing

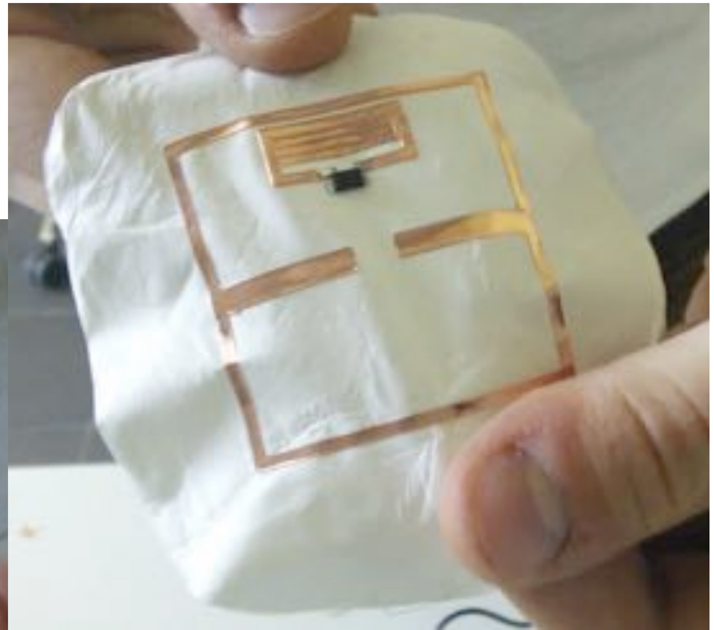
Antenna on Silicone Membrane

On bio-compatible silicone



Antenna on Scaffold-like Membrane

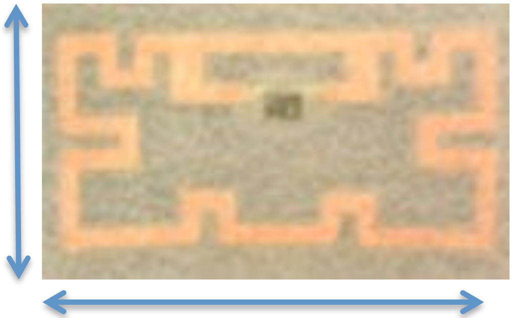
- Poli ε-Caprolactone (PCL)



Antenna: adhesive copper

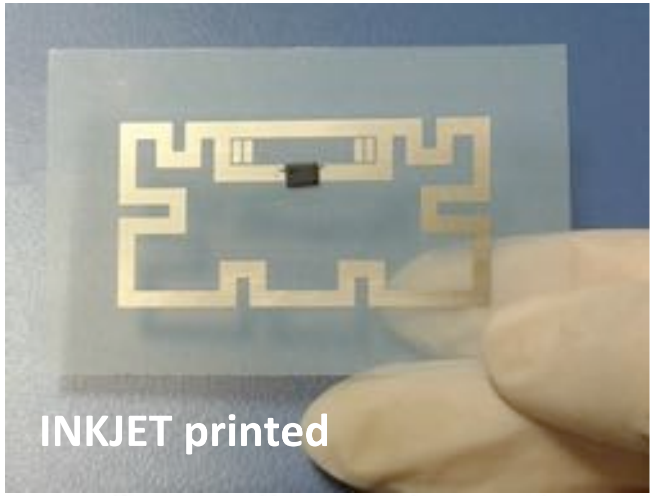
Skin antennas over PET

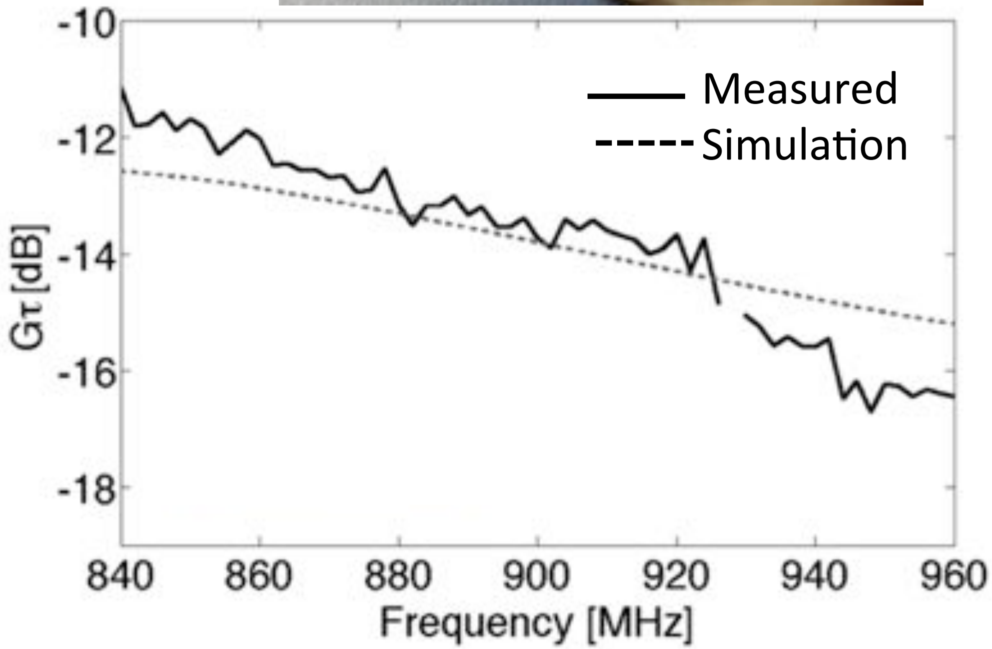
2.5cm



5 cm

Carved Adhesive copper

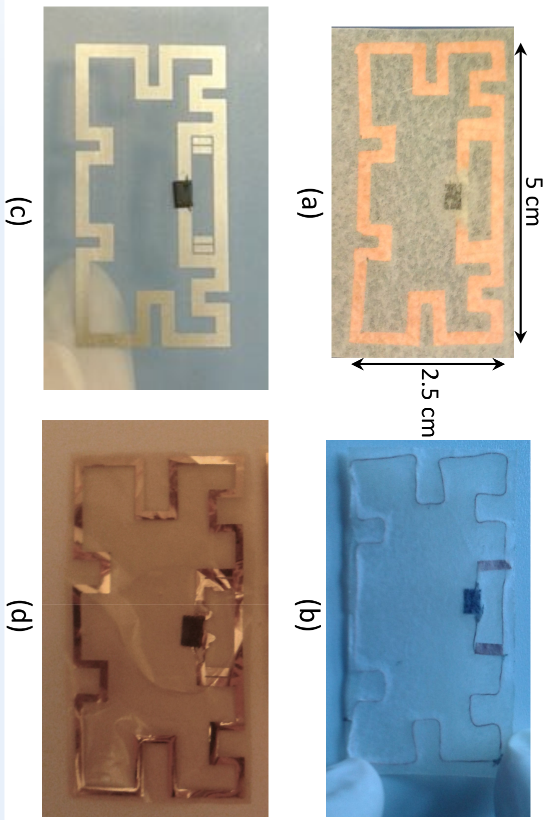


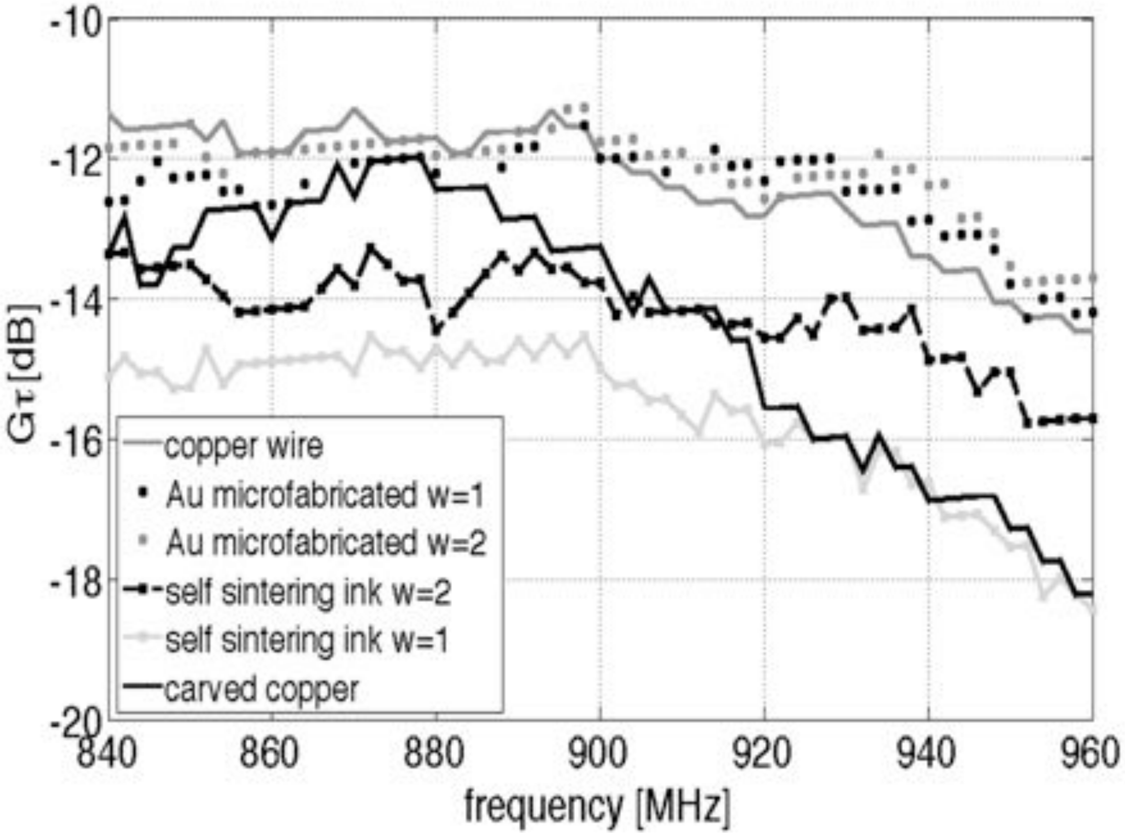


0.5m < D_{max} (EIRP 3.2W) < 3.5 m

Temp. Label.

Skin Antennas: performance comparison

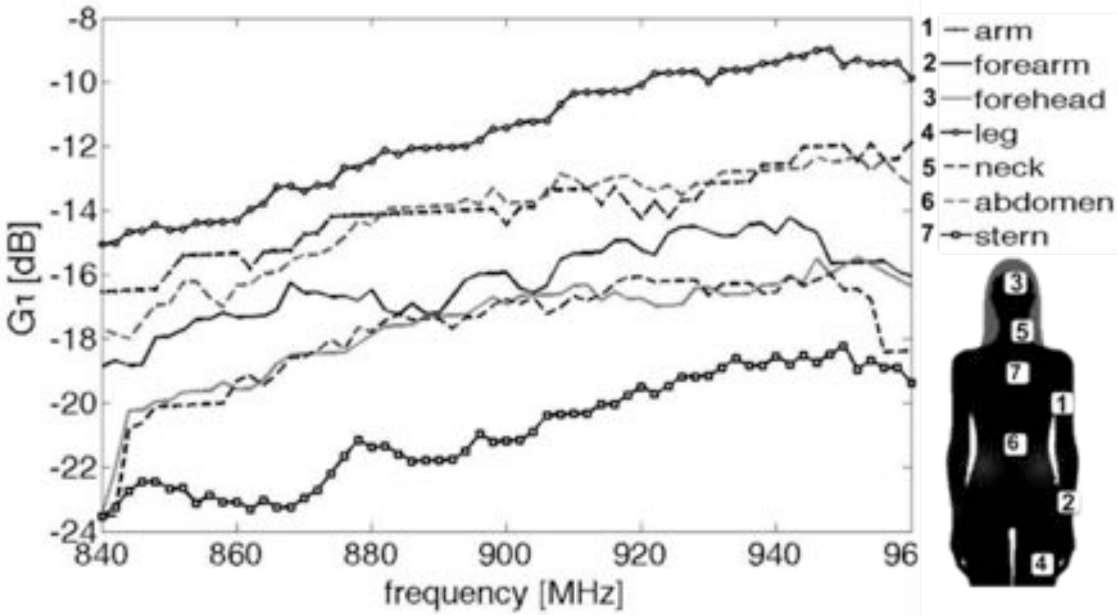


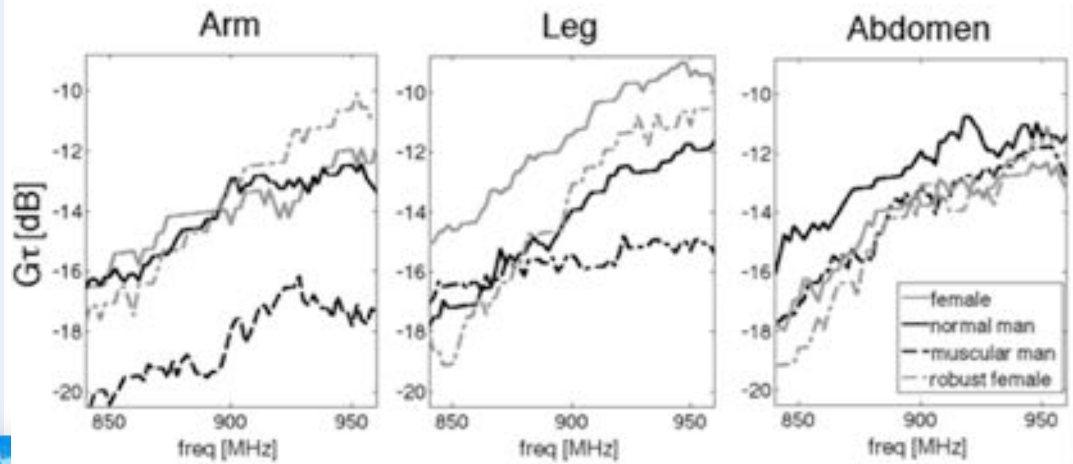


a. Adhesive Copper foil (plotter)
b. Micro-wire
c. Inkjet printing
d. Micro-fabrication (gold)

Antennas over a liquid body-phantom

Human Body Variability





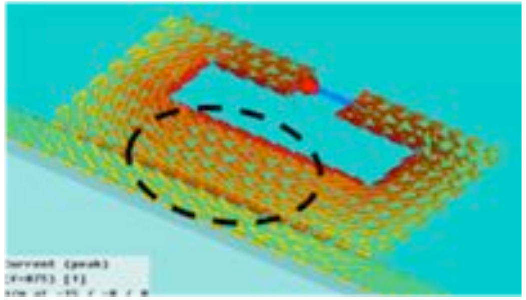
Body size

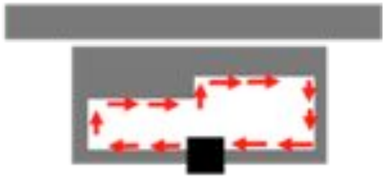
Position

DATA OF THE FOUR VOLUNTEERS FOR EPIDERMAL TAG MEASUREMENTS

Volunteer	height [cm]	weight [Kg]	Body mass Index
tiny female	155	45	18.7
robust female	178	75	23.7
normal male	174	64	21.4
muscular male	184	85	25.1

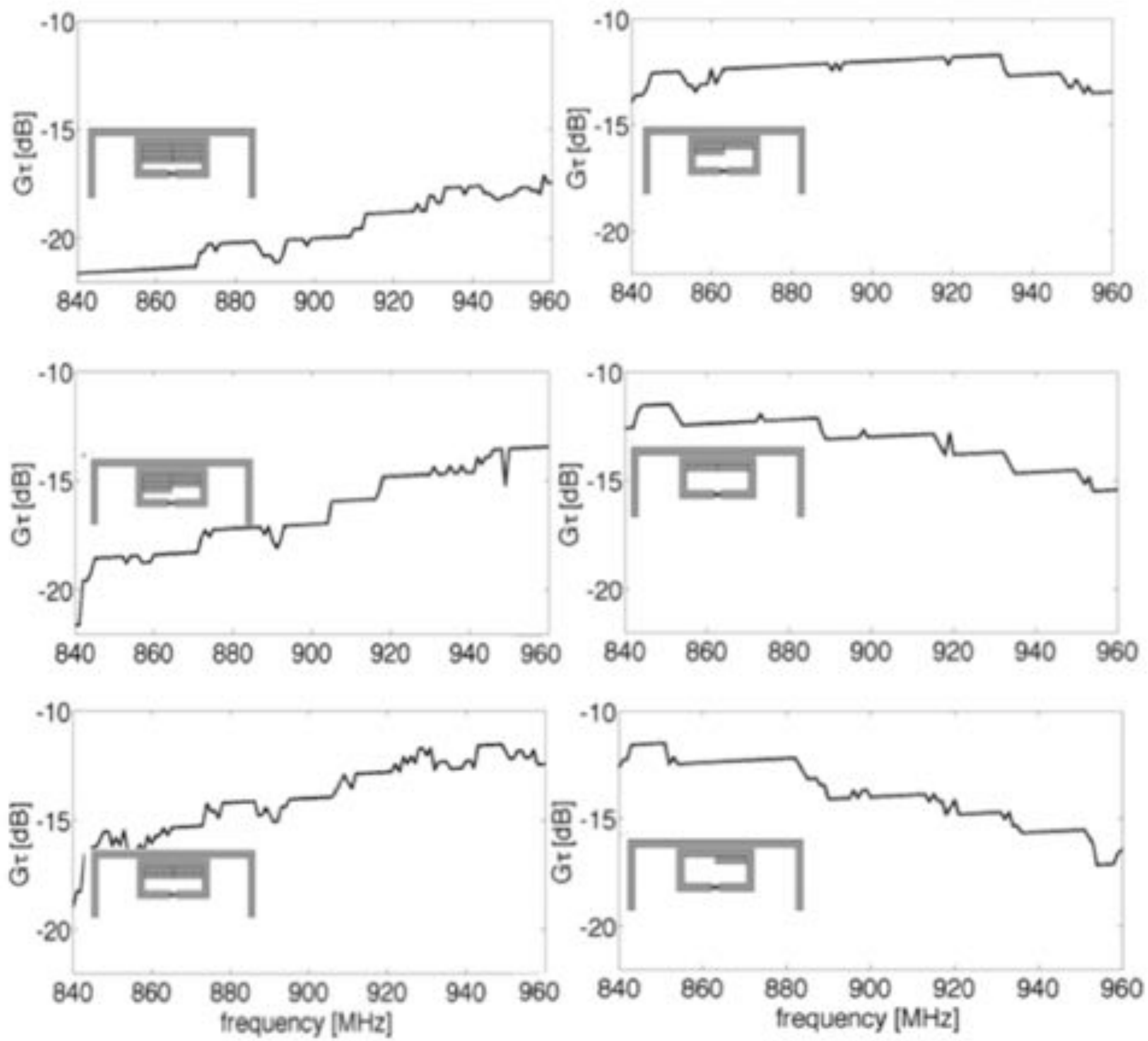
Tuning





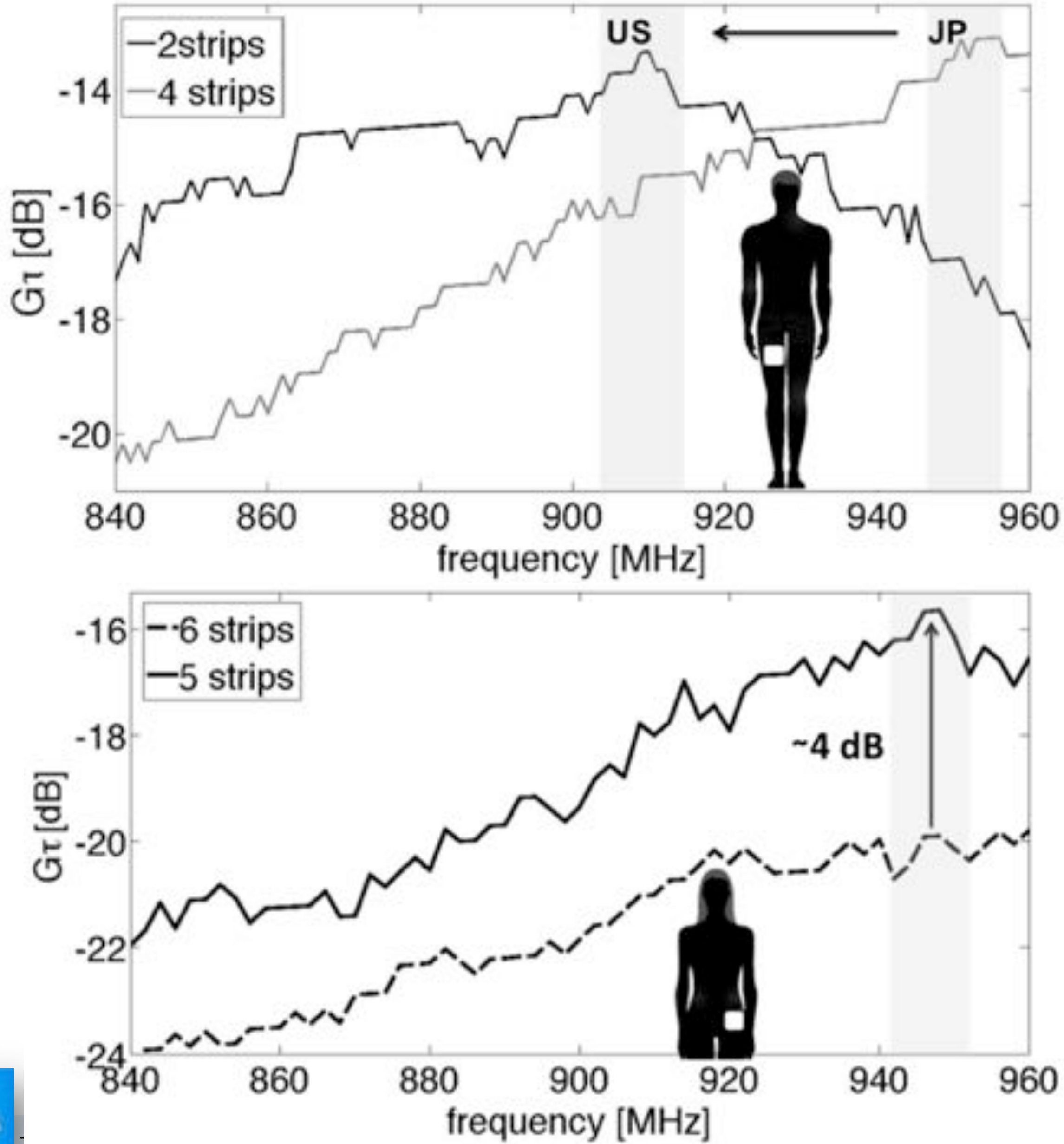
Pre-carved loop

(b)



OnBody Retuning

examples



S. Amendola, S. Milici, G. Marrocco, "Performance of Epidermal RFID Dual-loop Tag and On-skin Retuning ", IEEE TAP. 2015

Implantable sensors

Implantable Sensors
Why ?

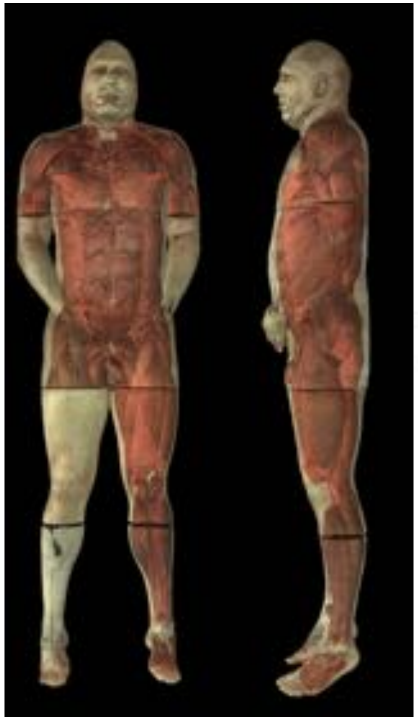
Self-diagnostic orthopedic prosthesis
- monitoring of bio-mechanical parameters from the inside

Smart sutures
- monitoring of post-surgery local inflammation (temperature)

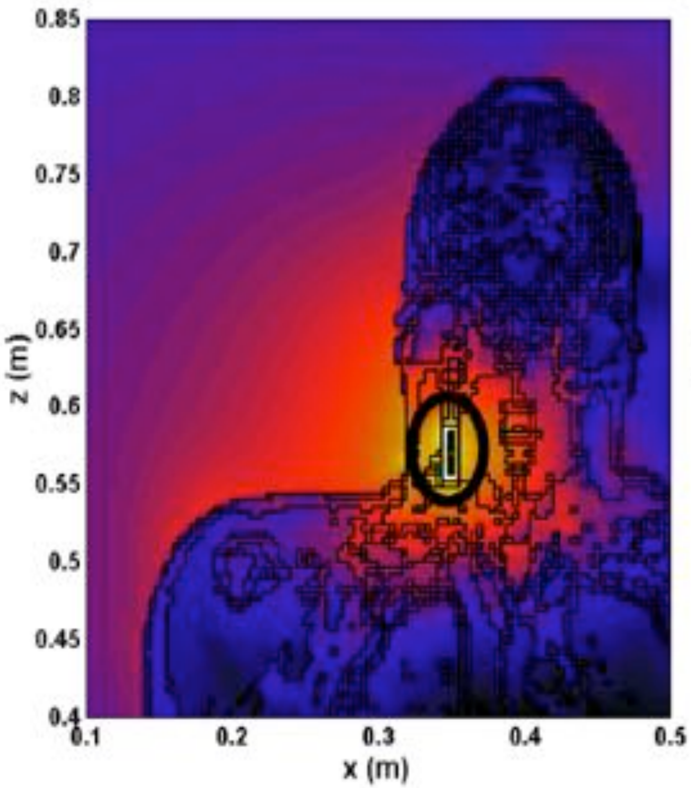
Smart Stents
- monitoring of re-stenosis inside blood vessels

→ Through the Body Links
→ Near field interactions

Electromagnetic Models & Phantoms for Implanted RFID tags



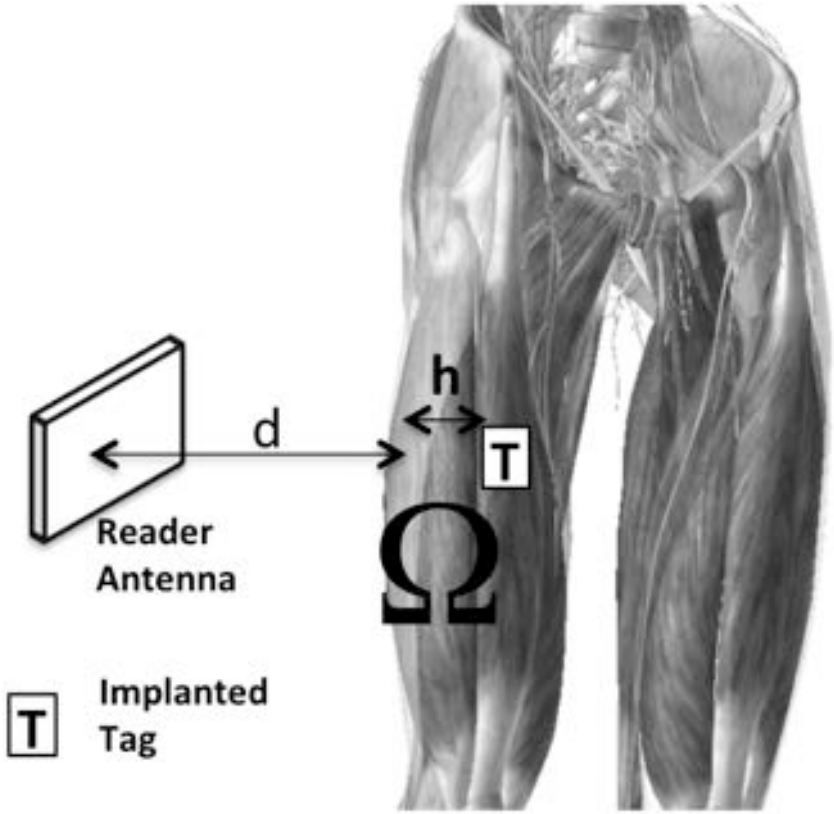
Visible Human Project



RFID tag implanted into charotid

Human body phantom

Limb Implants



Integration of sensors into a prosthesis to monitor its health status

- Deformations
- Temperature ,..

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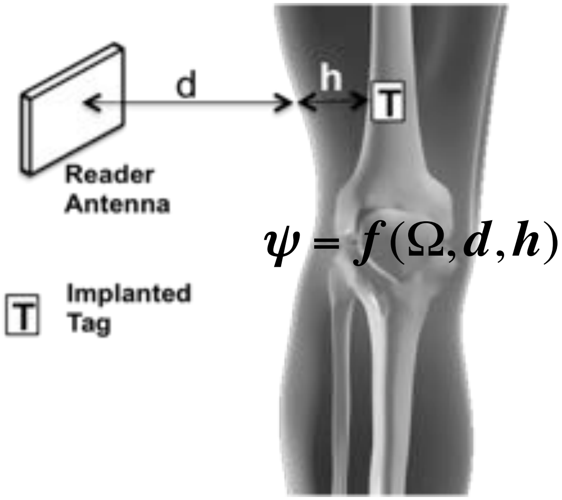
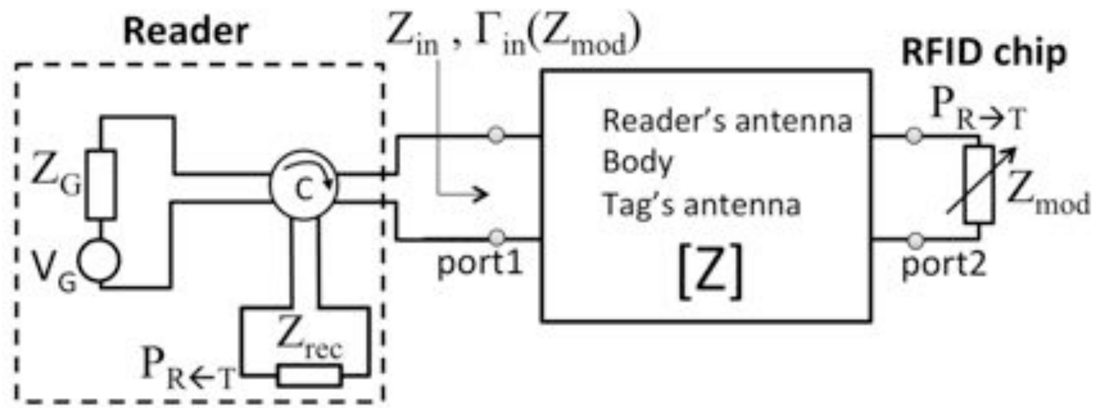
Implanted RFID radio channel





Forward link
Transducer Gain

$$G_T(\psi) = \frac{P_{R\to T}(\psi)}{P_{avG}}$$

$$\frac{4R_{chip}R_G\left|Z_{21}\right|^2}{\left|\left(Z_{22}+Z_{chip}\right)\left(Z_{11}+Z_G\right)-Z_{12}Z_{21}\right|^2}$$

Backward link
Round-trip Gain

$$G_{RT}(\psi) = \frac{P_{R\leftarrow T}(\psi)}{P_{avG}} = \frac{1}{4}\left|\Gamma_{in}(\psi, Z^{ON}) - \Gamma_{in}(Z^{OFF})\right|^2$$

$$\left|\frac{Z_G Z_{12}}{Z_{rec}}\right|^2 \frac{1}{\left|\left(Z_{11}+Z_G\right)\left(Z_{22}+Z_{chip}\right)-Z_{12}Z_{21}\right|^2}$$

Feasibility Margins

Quantify the feasibility and reliability of the RFID channel

Direct Link Margin

$$M_{DL}(\psi) = \underbrace{G_T(\psi)P_{avG}}_{P_{R\rightarrow T}(\psi)} - p_{chip}$$

Backward Link Margin

$$M_{BL}(\psi) = \underbrace{G_{RT}(\psi)P_{avG}}_{P_{R\leftarrow T}(\psi)} - p_{rdr}$$

Margin > 0dB in order to establish the transcutaneous link

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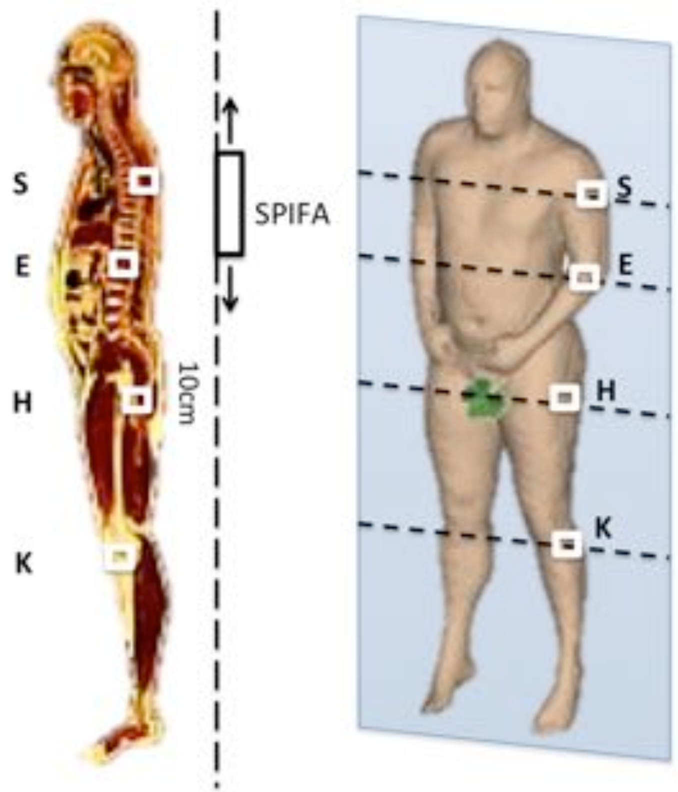
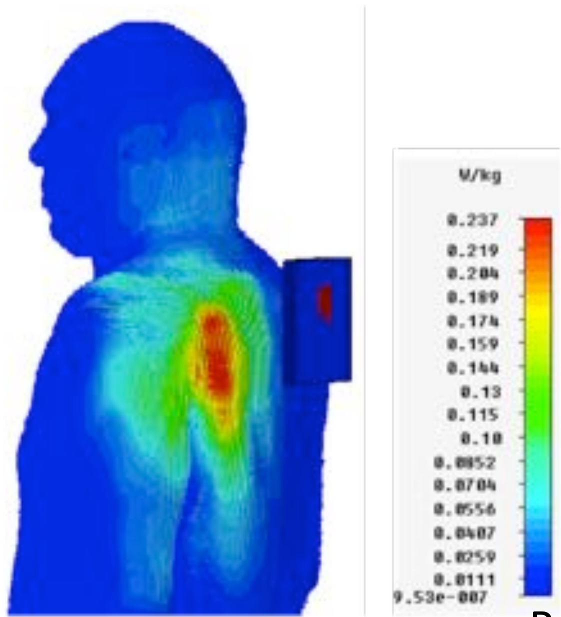
Through-the-body UHF-RFID link

Limb Implants: simulation with Visible Human



Locus of implant	$M_{DL}(dB)$	$M_{BL}(dB)$
shoulder (humerus)	+2	+20
elbow (humerus)	+10	+34
hip (femur)	+3	+18
knee (femur)	+2	+17

Safety

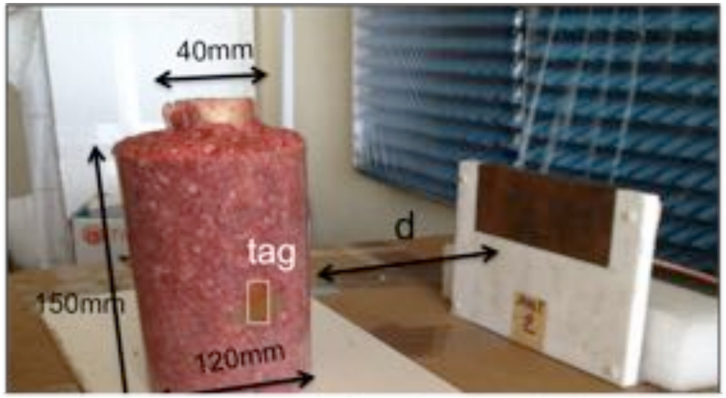


Locus of implant	Localized SAR 10g (W/kg)
Shoulder	0.23
Elbow	0.36
Hip	0.36
Knee	0.30

Regulations: SAR<2W/Kg

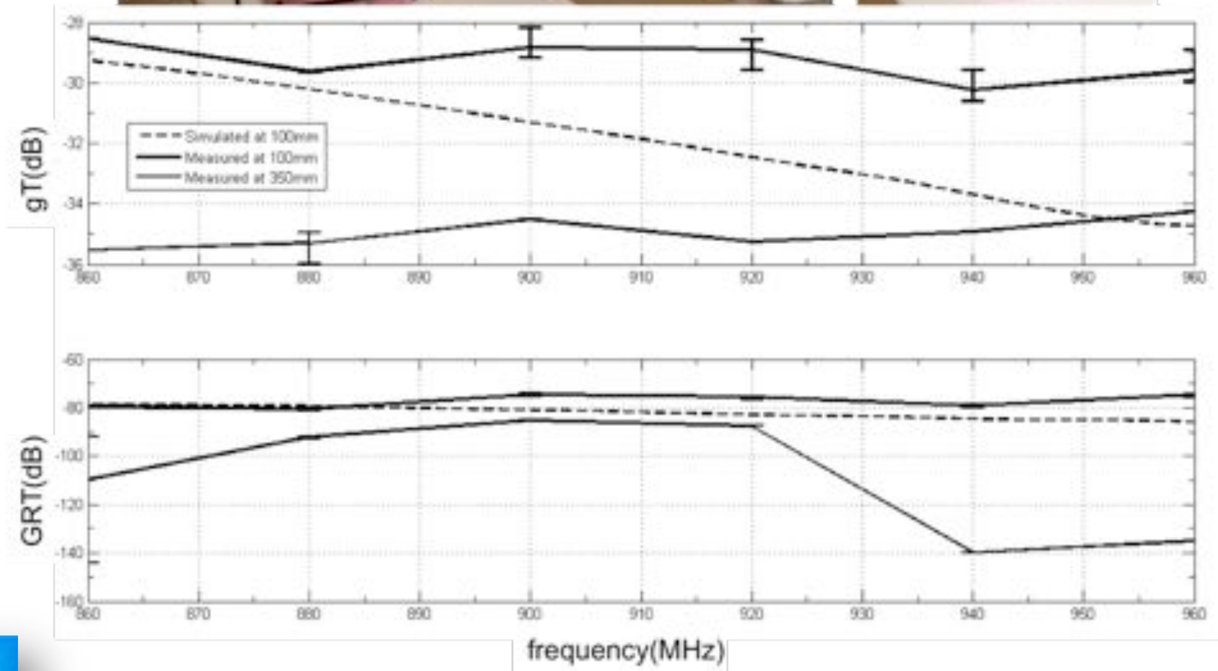
Through-the-body UHF-RFID link

Limb Implants: Experiments over phantoms



Cow Bone
Muscle: 65%
Fat: 35%

Av. Permittivity:
ε = 38 σ = 0.60 S/m

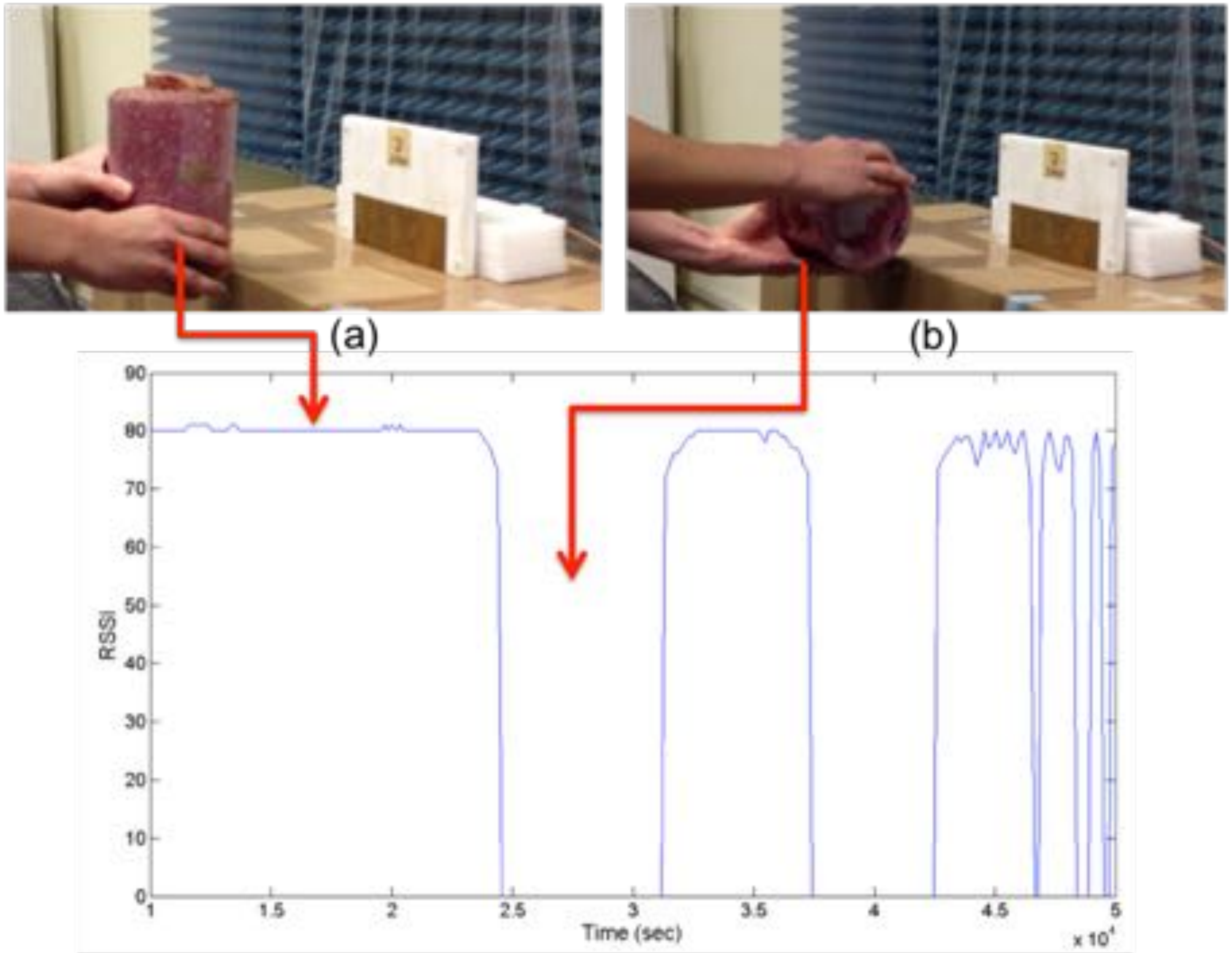


Pin=30dBm W

Read-distance <=25cm

Through-the-body UHF-RFID link

- Motion detection

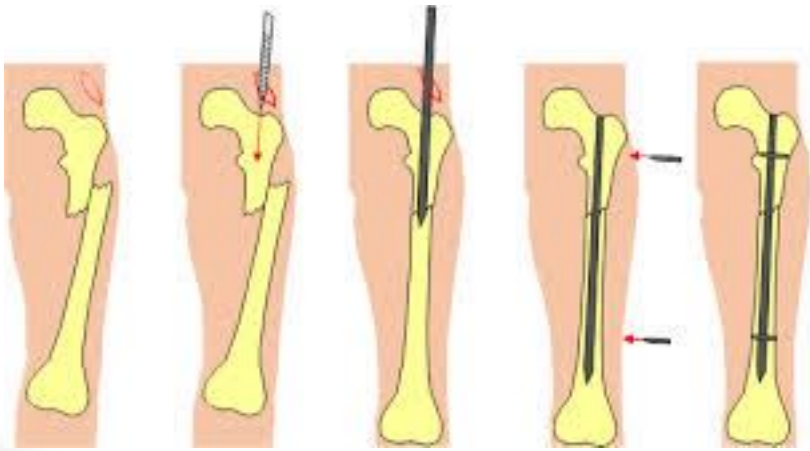


(c)

Intra-medullary Smart Nail

	Femoral nail	Tibial nail
Distal diameter (mm)	9-16	8-13
Proximal diameter (mm)	13.5 -16	11-13
Length (mm)	300-480	255-465

an anatomically curved rod generally made of titanium alloy whose size depends on the type of the fracture and on the specific implantation locus such as, for instance, the **femur** and the **tibia**. Fixing holes are drilled at the extremities of the device at the purpose to lock the prosthesis to the bone by means of screws.



Intra-medullary Smart Nail

"Antennification "

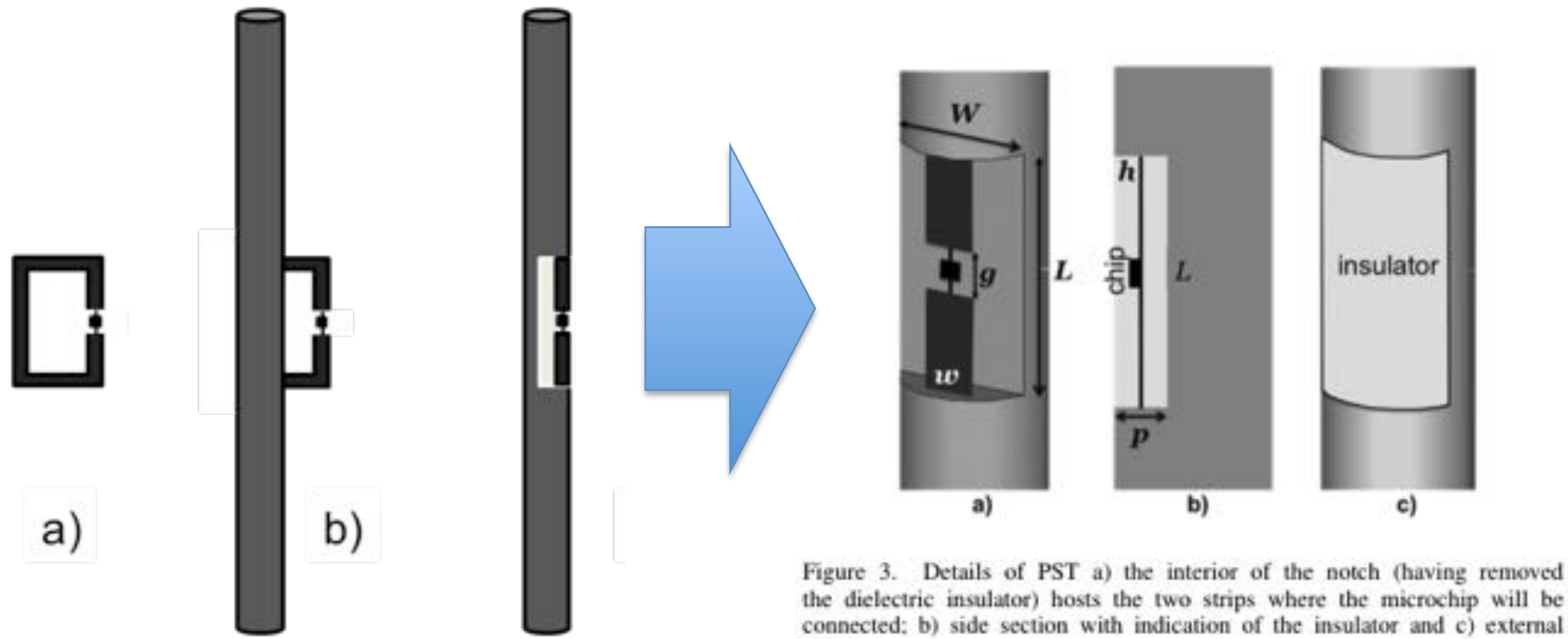
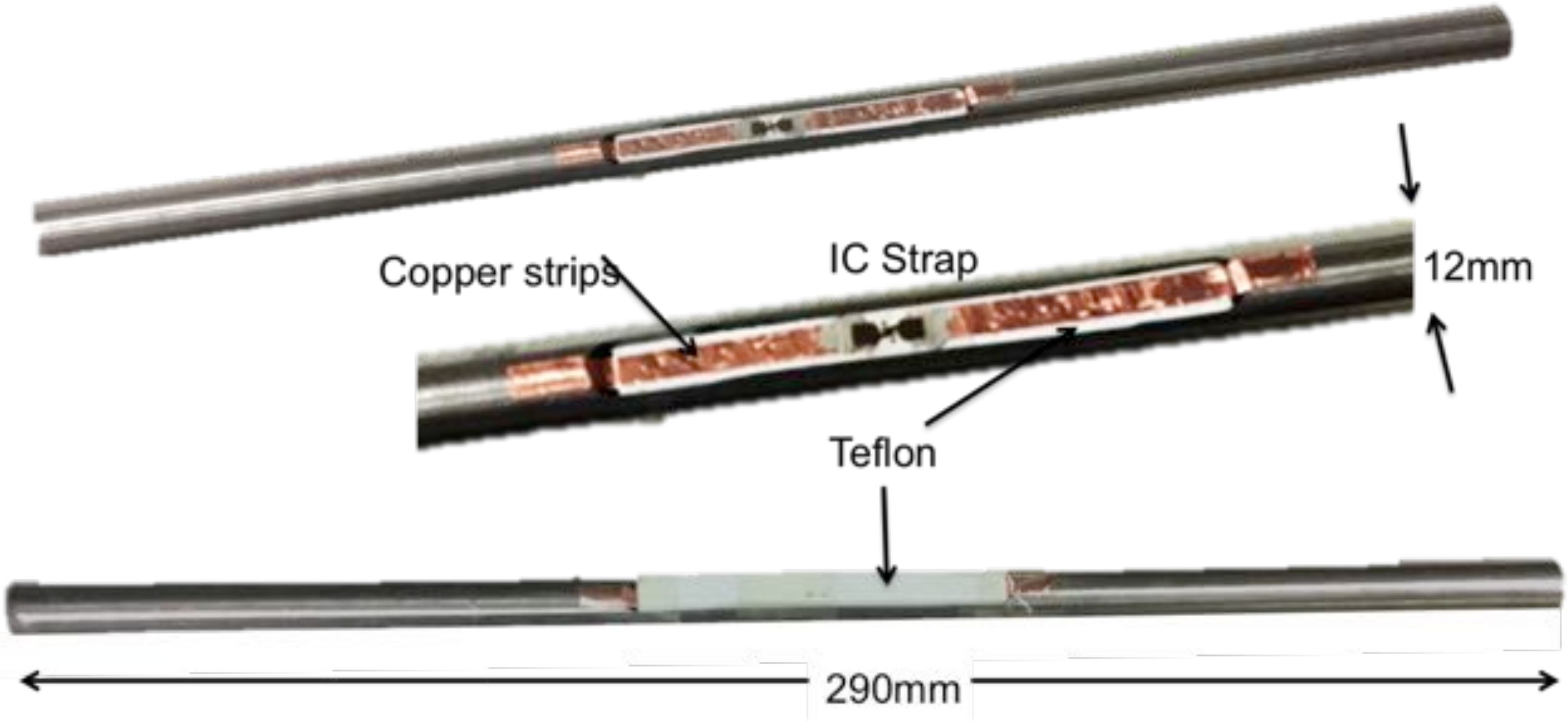


Figure 3. Details of PST a) the interior of the notch (having removed the dielectric insulator) hosts the two strips where the microchip will be connected; b) side section with indication of the insulator and c) external view.

Intra-medullary Smart Nail

Proof of concept



Intra-medullary Smart Nail

experiments

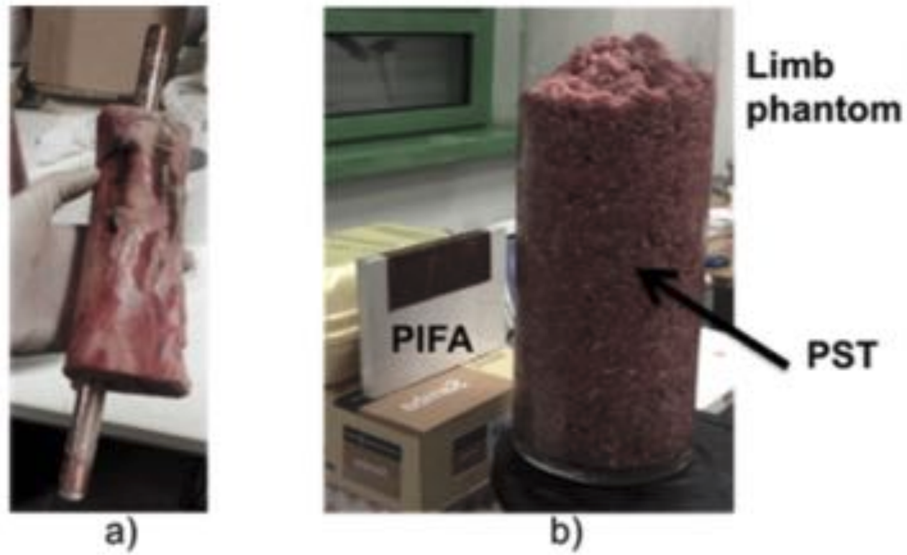


Figure 10. a) PST placed inside the medullary canal of a cow bone and b) measurement set-up comprising a ThingMagic M5 reader (not shown) connected to a Stacked PIFA antenna and the limb phantom with the bone inside.

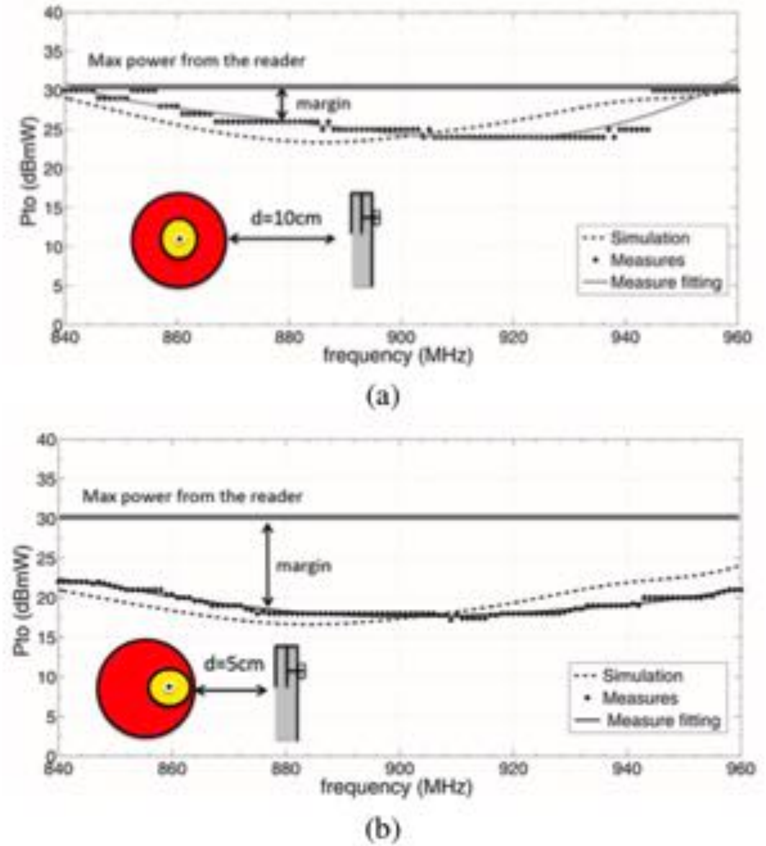


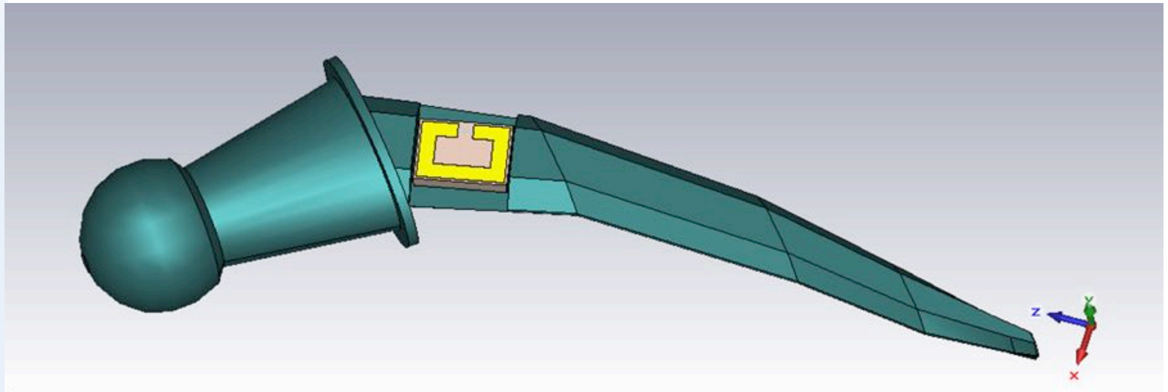
Figure 11. Simulated and measured turn-on power P_{to} for PST implanted as in Fig.9 having included also the S-PIFA antenna of the reader that is placed at distances $d = 10cm$, $5cm$, respectively.

Dmax: 30cm
(identification only)

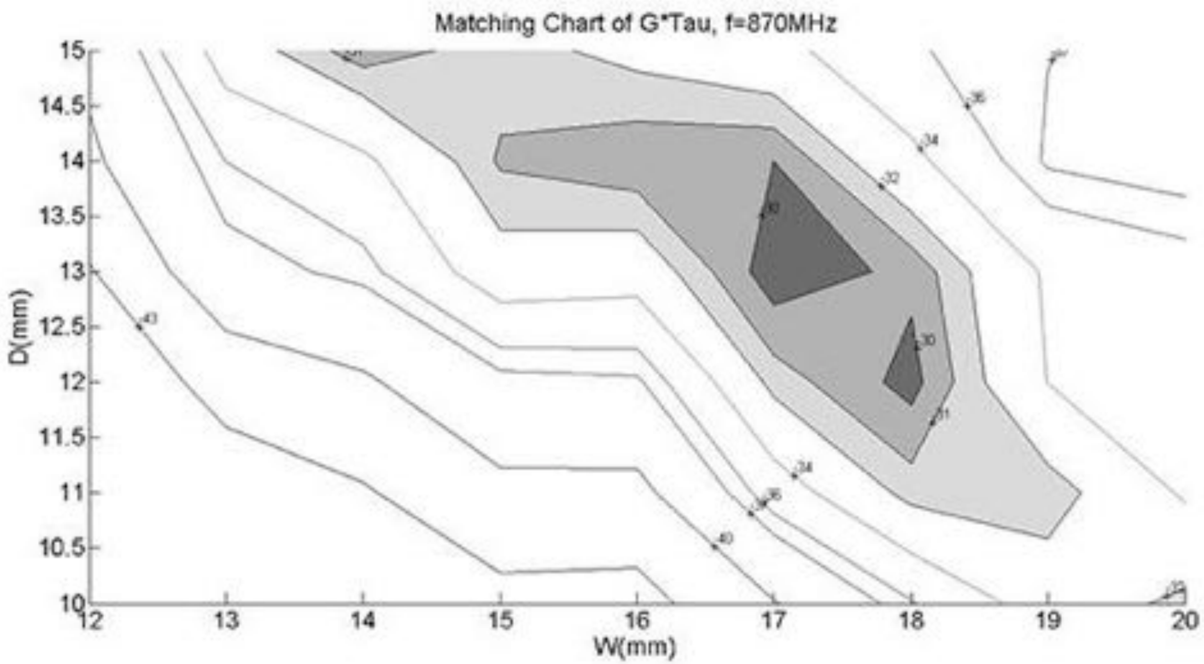
Hip Prosthesis

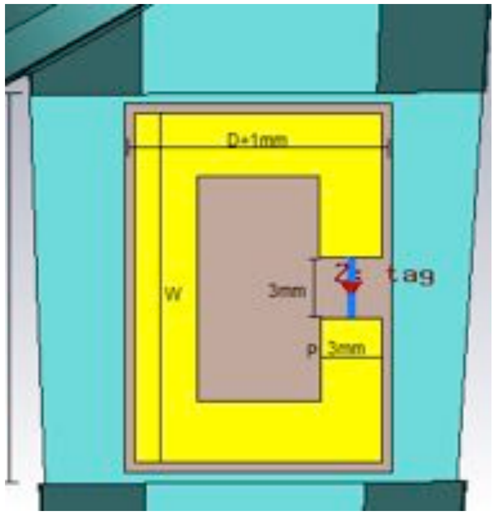
Hip Prosthesis

- Structural sensor



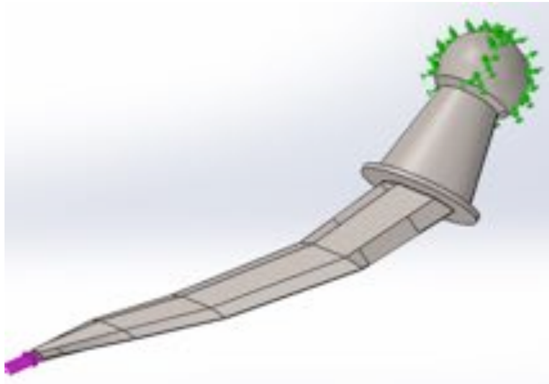
Onsite optimization of the tag

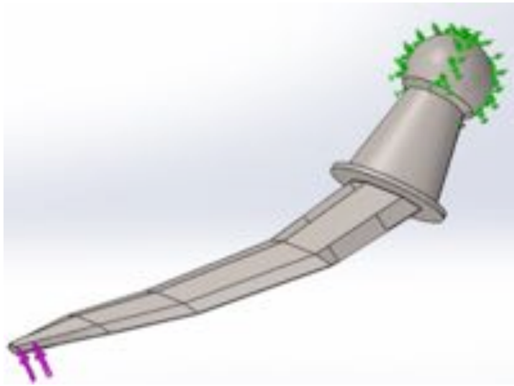


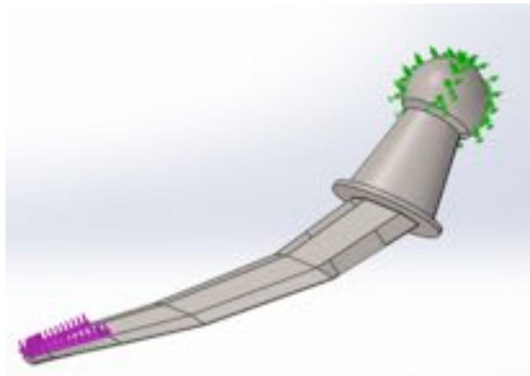


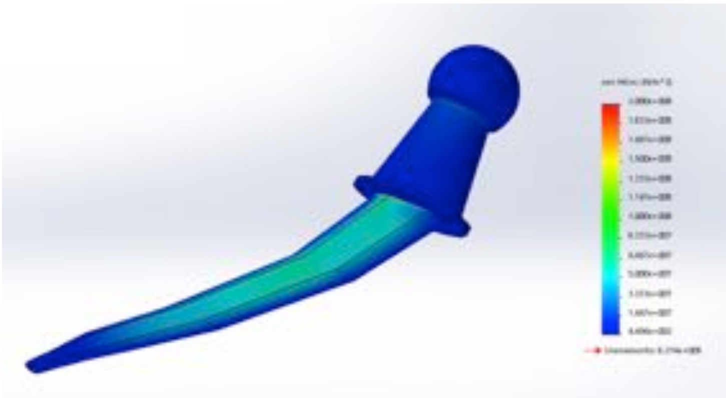
Bio-mechanic Analisis

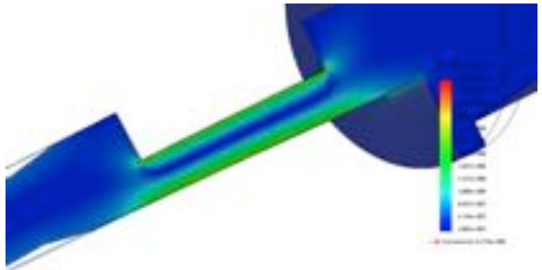
stress

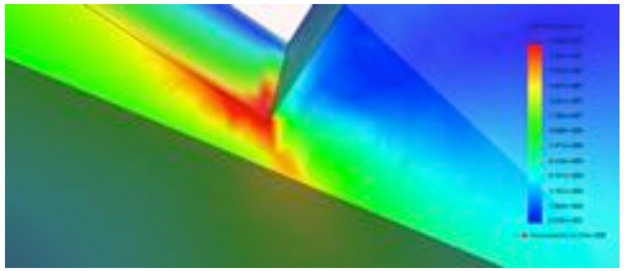








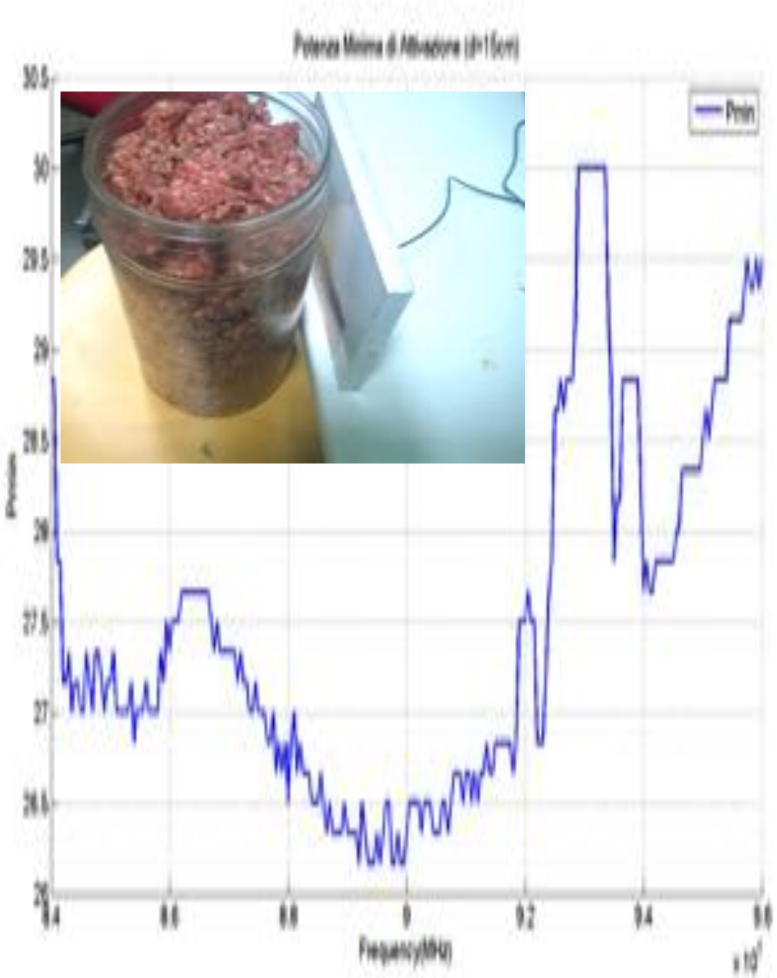




➔ No sensible change in the mechanical robustness

Hip Prosthesis

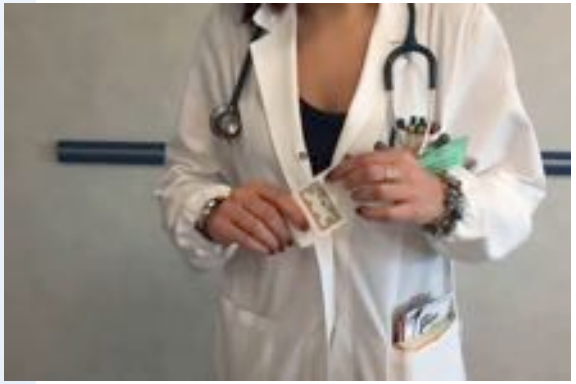
- Additive manufacturing

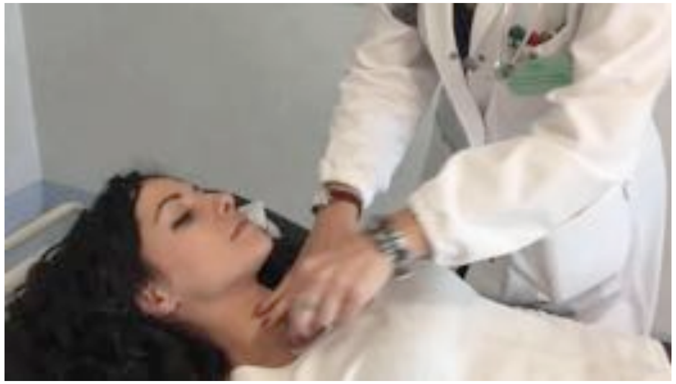


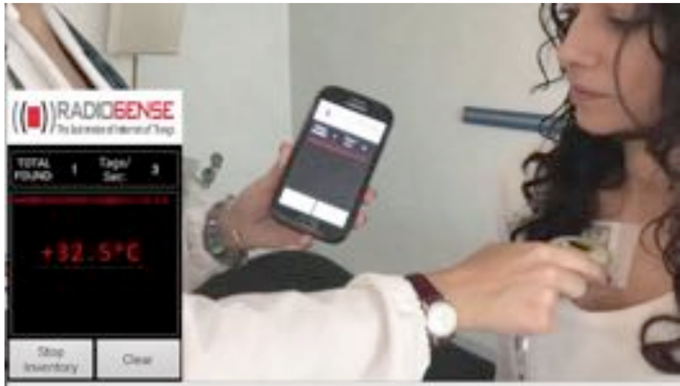
Dmax=20cm
(identification omly)

Systems and Applications

In-hospital Temperature Monitoring







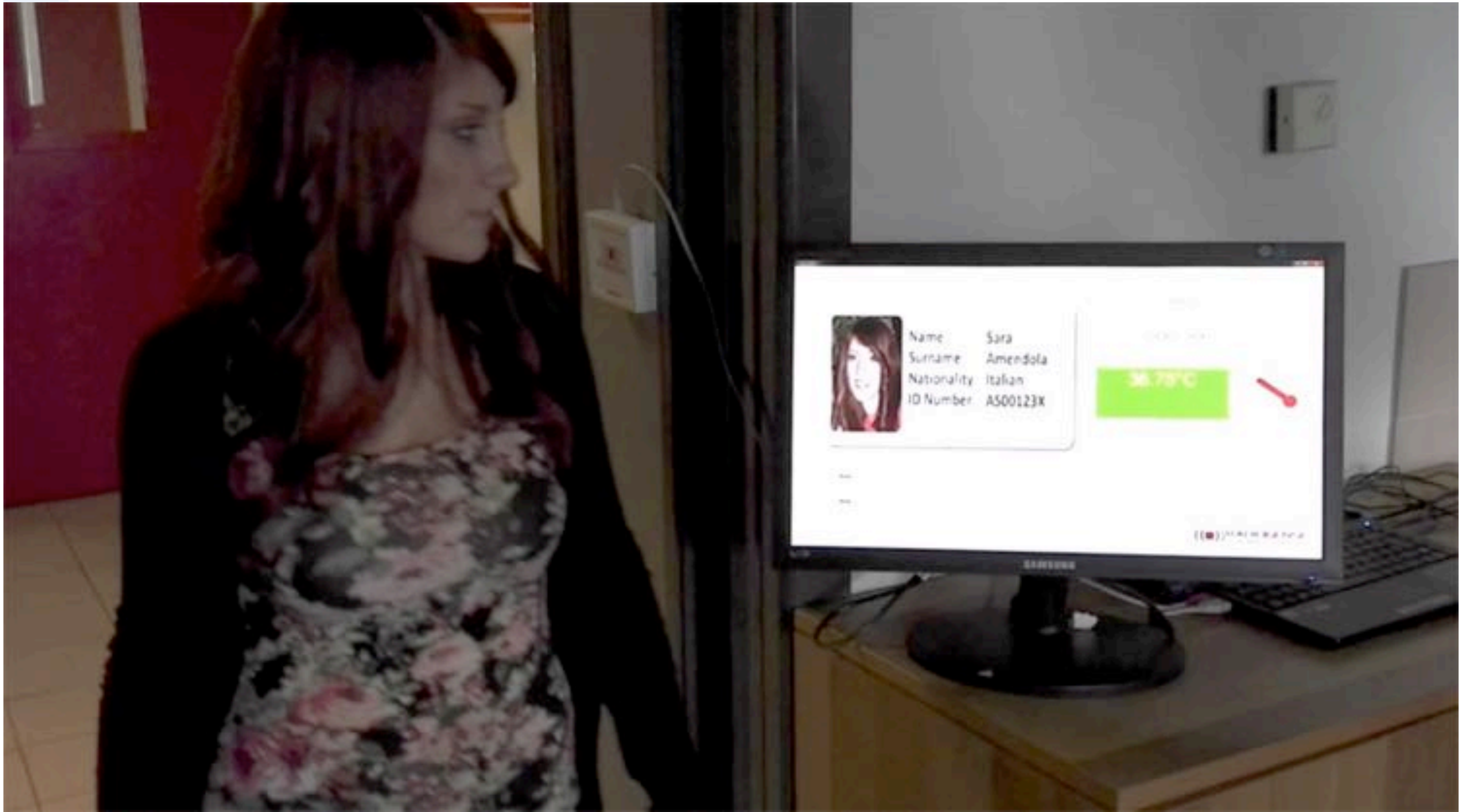
On the flight Identification & sensing of moving people

Epidemic control at airport and hospital

In-house automatic screening on crossing door

Figure 25. Possible setup for the automatic health monitoring of in transit people.

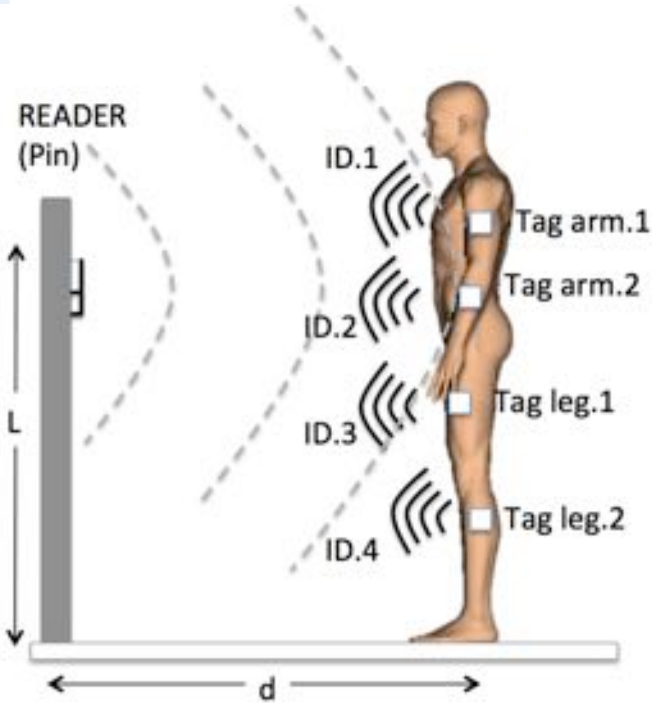
On the flight Identification & sensing of moving people

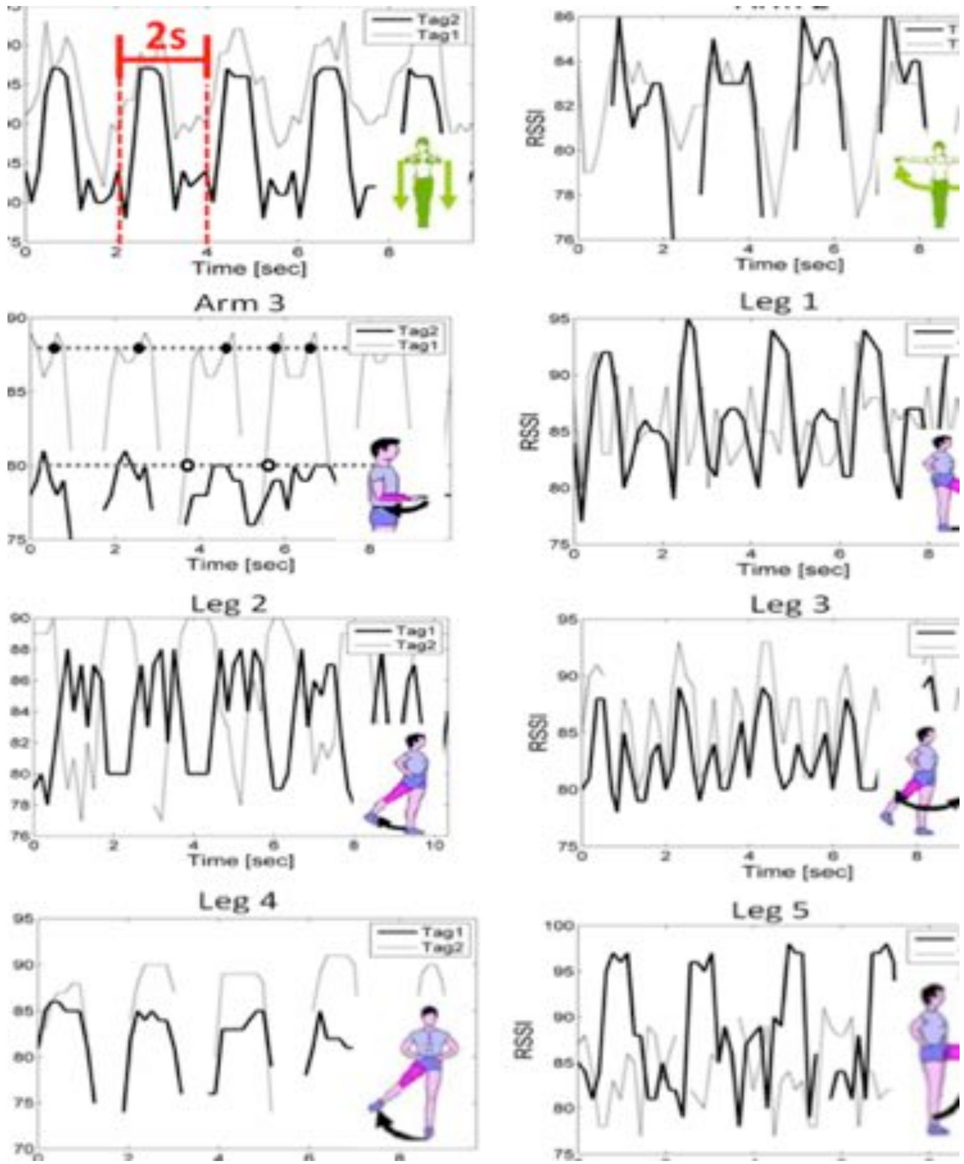


→ **Video**

Motion-detection and Gesture Recognition

Classification of body motion





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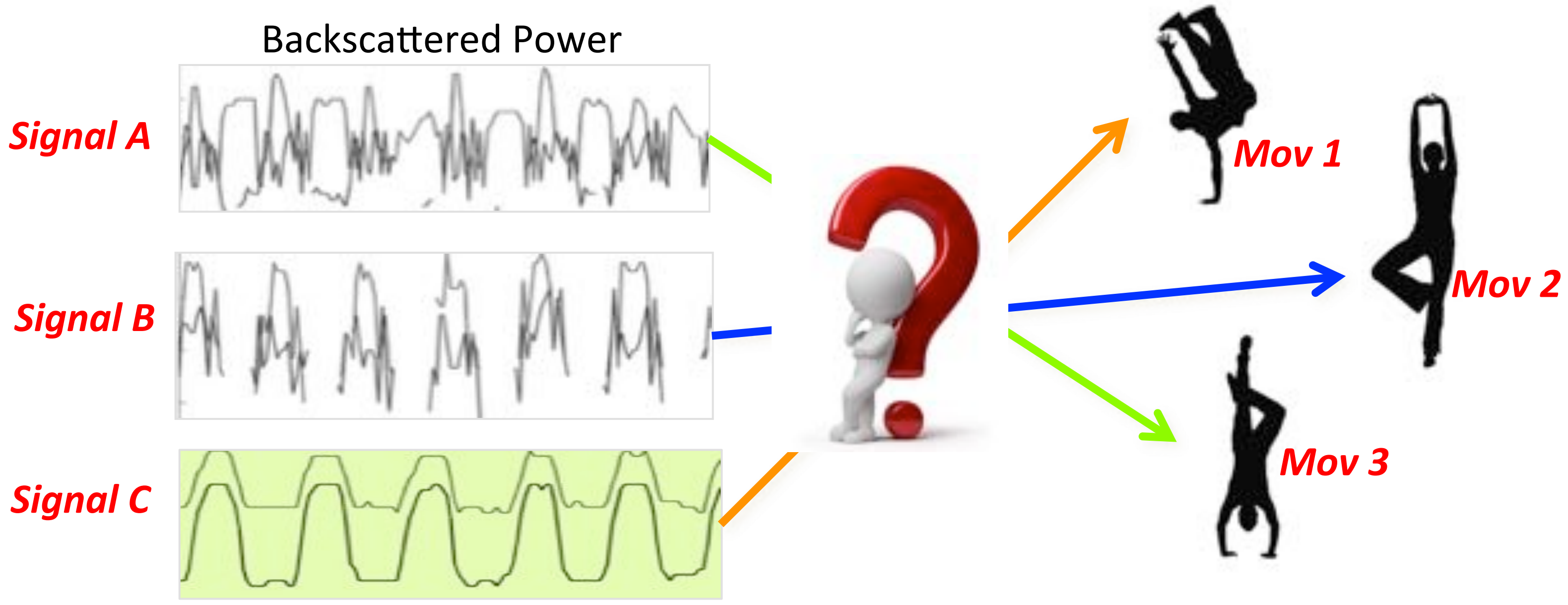
Classification Method (Data Analystics)

The term classifier refers to the problem of identifying to which one within a predefined set of movements type an observation belongs



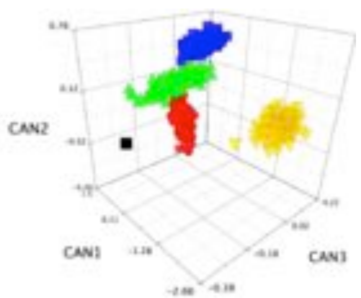
.. Borrowed from the BRAIN COMPUTER INTERFACE (Machine Learning)

Classification Method

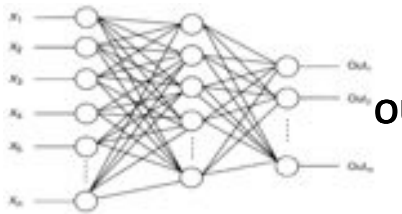
Supervised Learning Paradigm

Training → **Classification**

Signals ↔ *Labels*



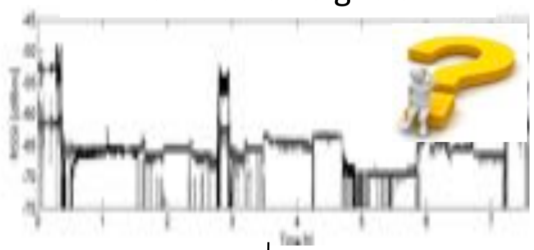
IN



OUT

Collect Dataset
↓
Features Extraction
↓
Set-up Parameters
↓
Evaluate accuracy
↓
Refine Parameters (→ back to Features Extraction)

Unlabeled Signals

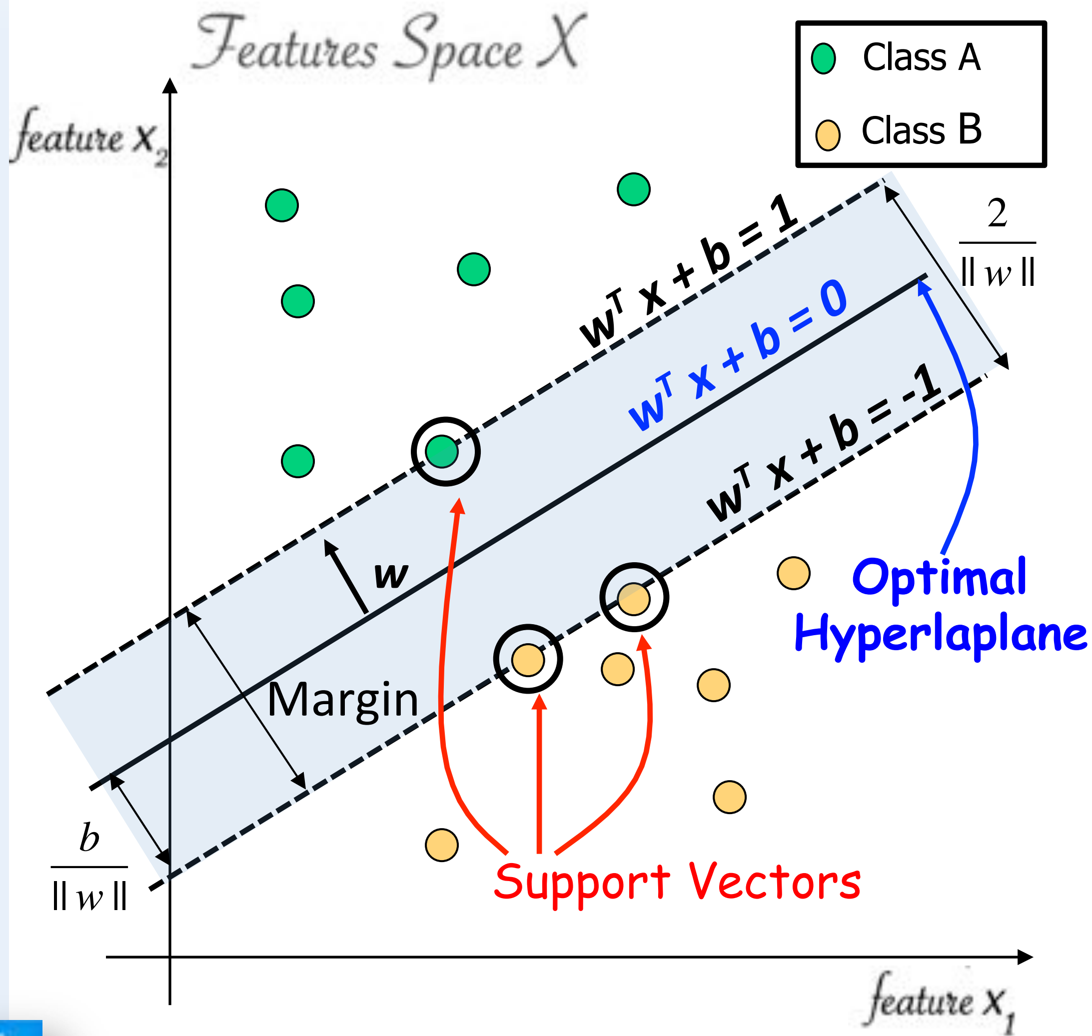


↓

Mov X

Classification Method

SUPPORT VECTOR MACHINE (SVM)



Original Formulation[1]:

- Binary classification
- Linear separability of datapoints

How to chose the best hyperplane?

Maximum-Margin Hyperplane

$$\min_{\mathbf{w}\in\mathbb{R}^n, b\in\mathbb{R}} \quad \|\mathbf{w}\|^2$$

$$\text{subject to} \quad y_i\,(w \cdot \mathbf{x_i} - b) \geq 1$$

Quadratic constrained Optimization Problem

Classification of body motion

- **Electromagnetics + Neuroscience**
- **Application of Machine Learning algorithms**

➔ video

Ambient Modulation

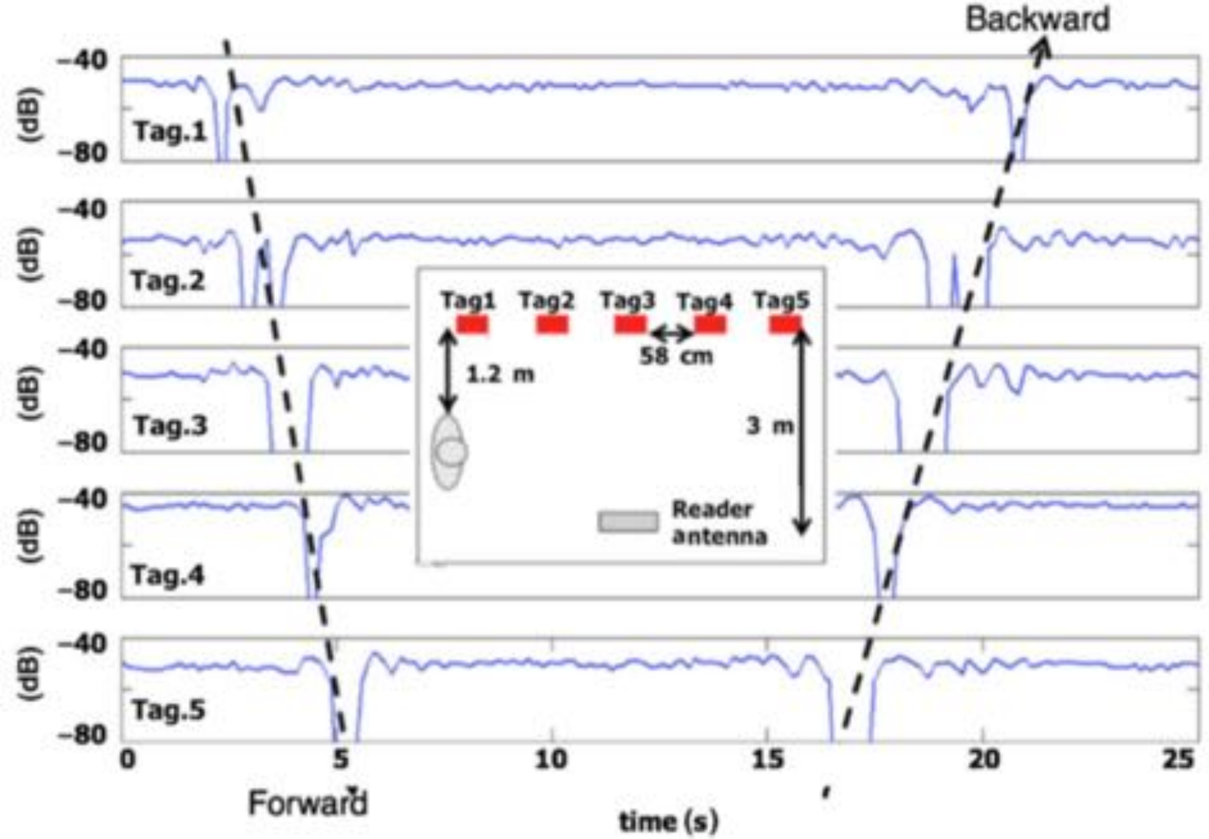
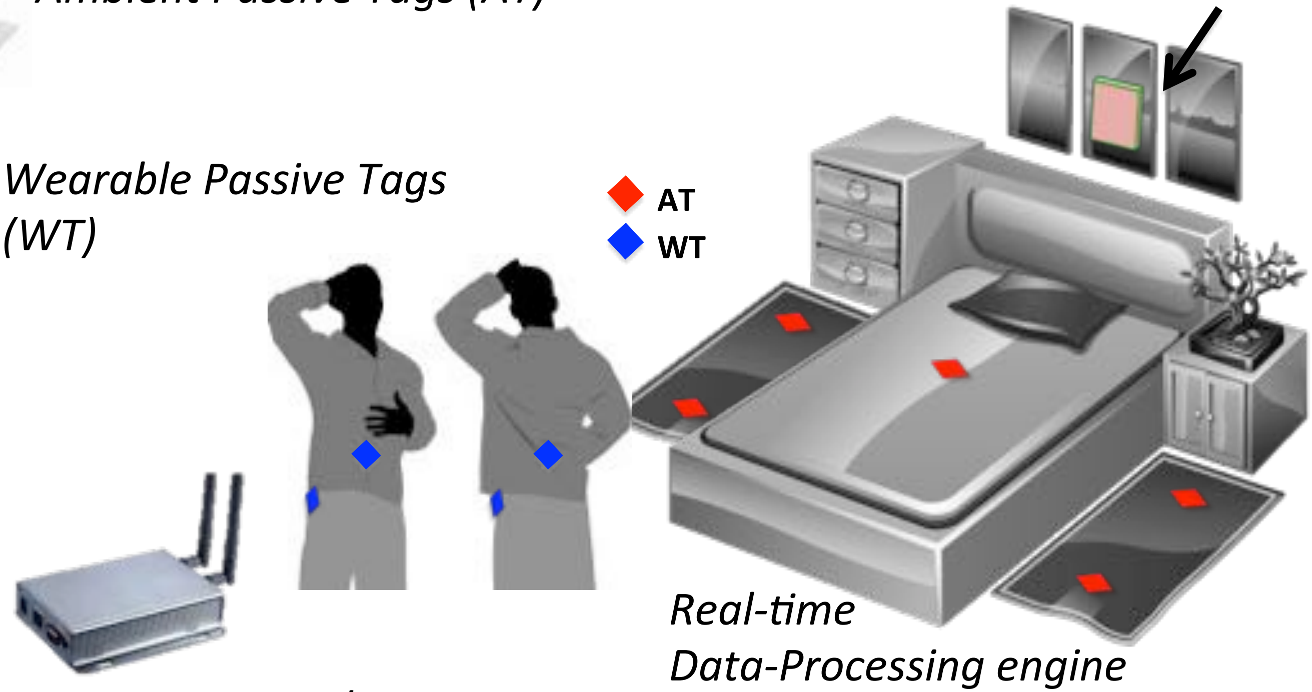


Fig. 7. Backscattered power variation from a linear cluster of tags attached on the wall during the walk of a subject into a corridor. The sequence of the nulls carries information about the direction of motion (delays among nulls) and velocity (slope of the enveloping line through the nulls)

Multi-channel monitor of Overnight sleep

Ambient Passive Tags (AT)

Wearable Passive Tags (WT)



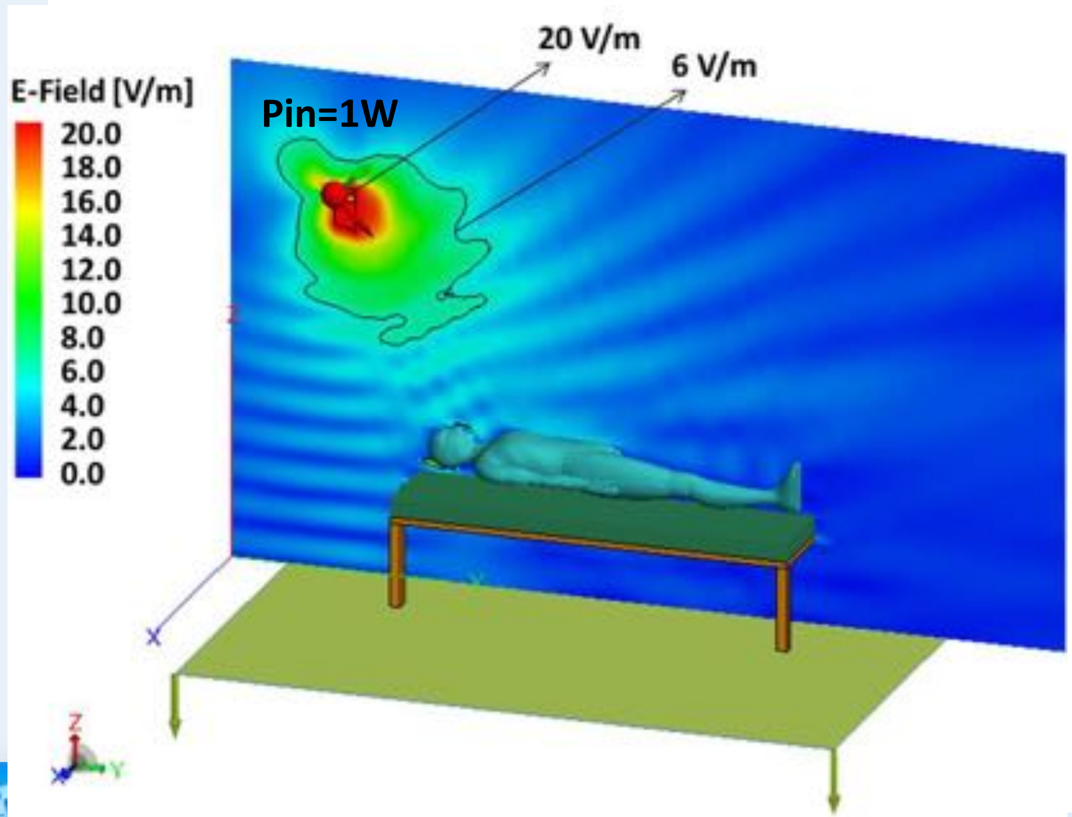
The backscattered response of the tags to the reader's query is modified by the proximity of the human body with the tags themselves.

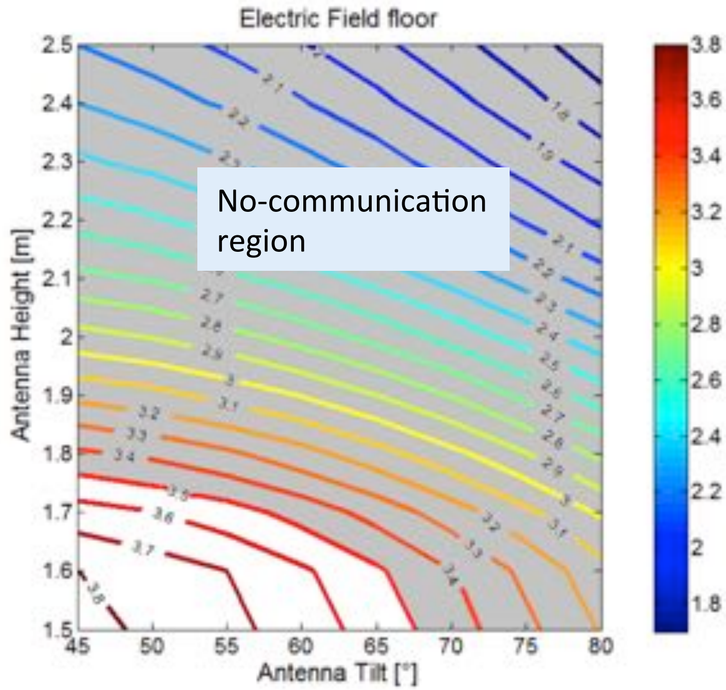
<u>Goal</u>: extract information about motion and about specific *postures* during the sleep.

EM Models

European Recommendations:
- |E|<41 V/m

Italian Law: 1 interrogation per second
- |E|<6V/m

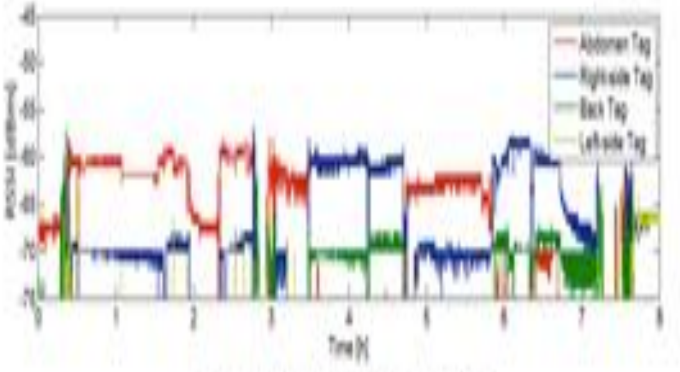




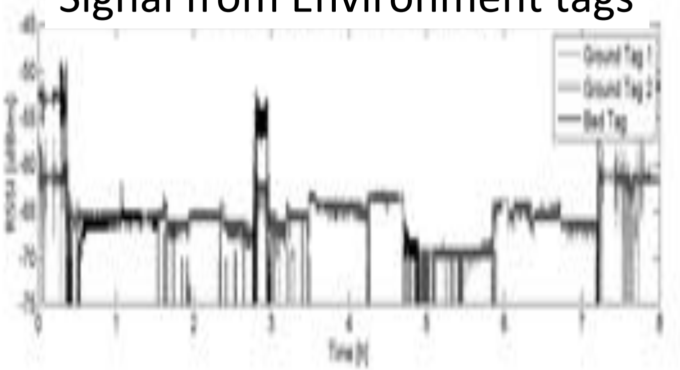
45° < Tilt < 65°
1.5m < height < 1.75m

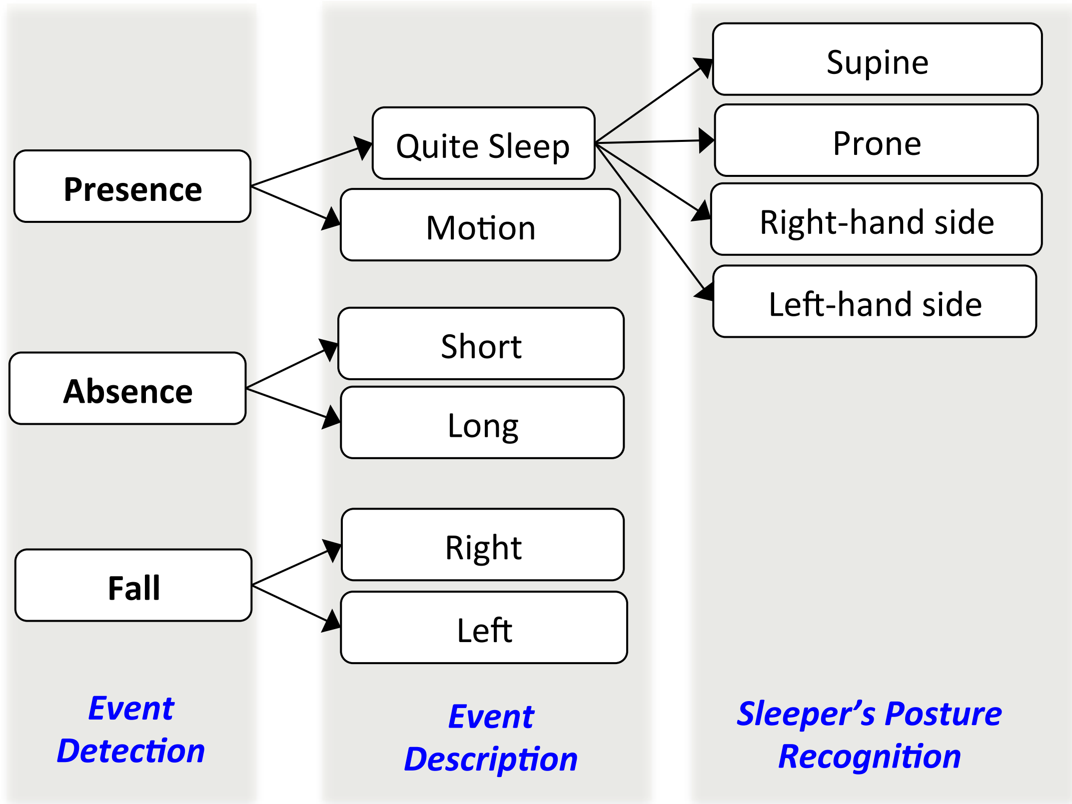
Multi-channel Proc.

Signal from wearable tags



Signal from Environment tags



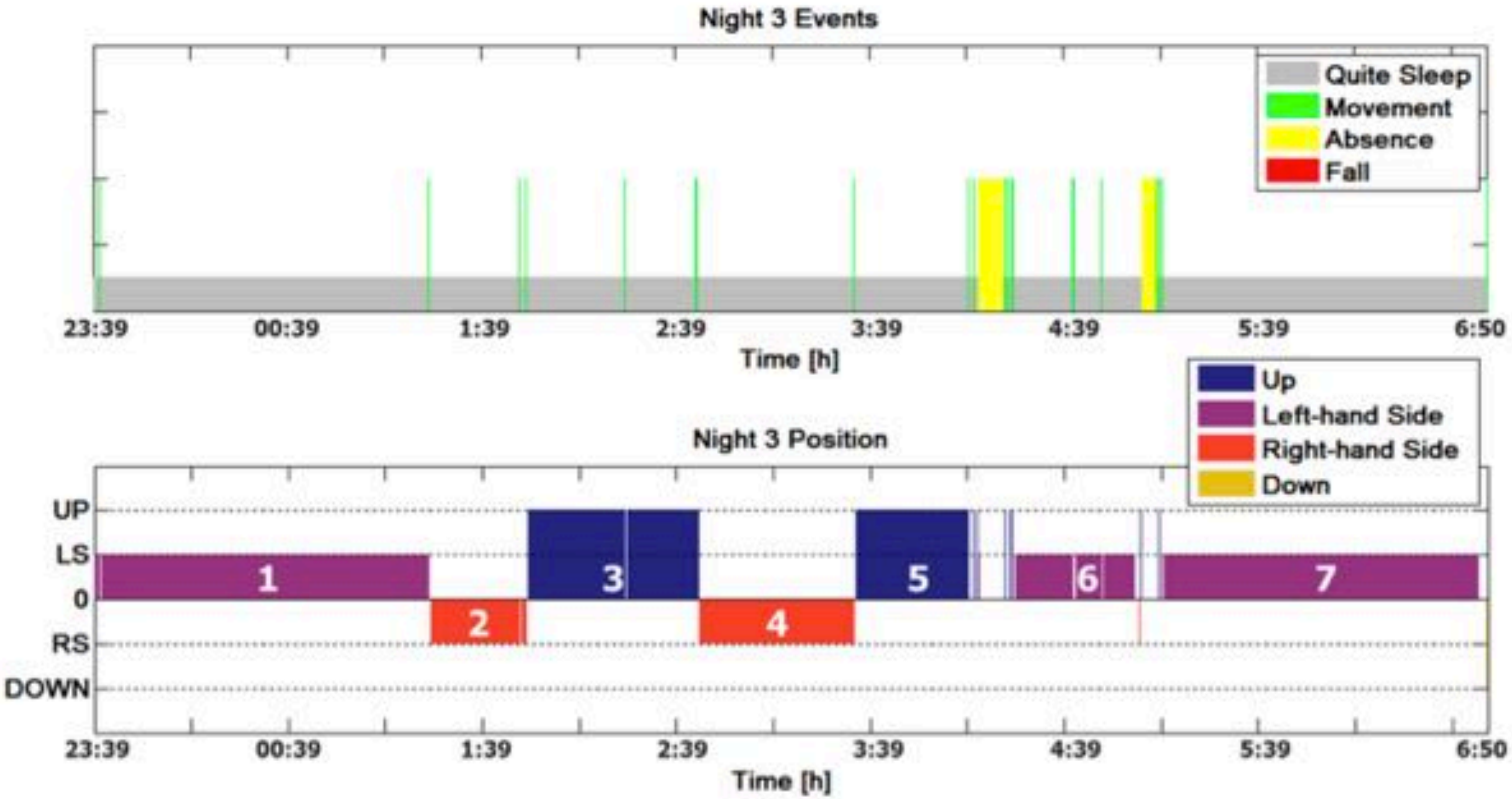


Filtering
Threshold
Classification

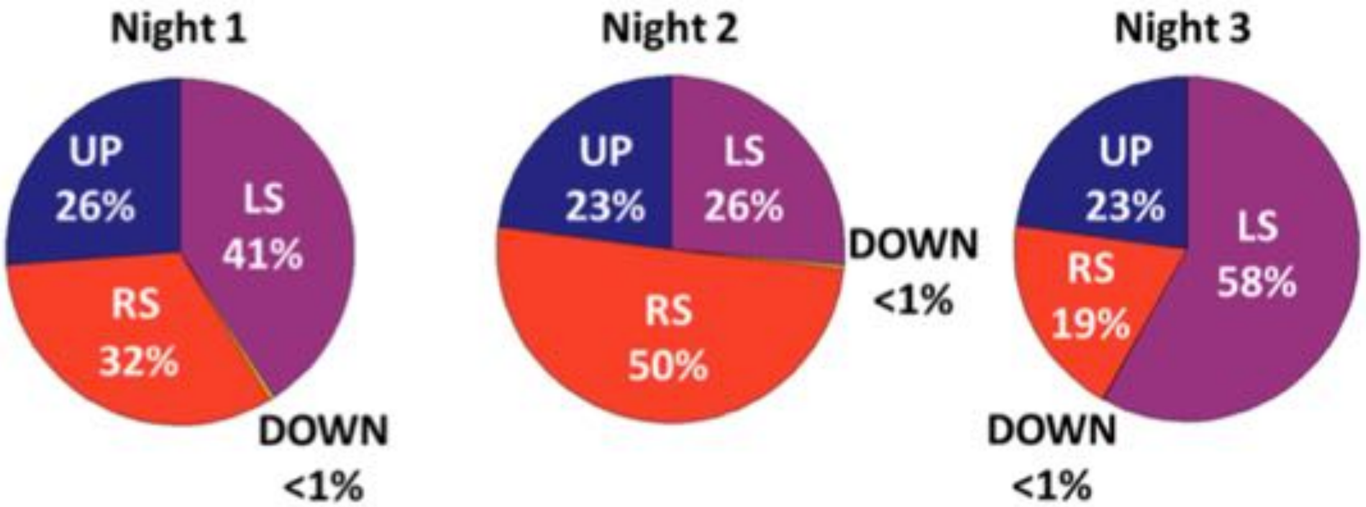
- User's state
- Activity and quite sleep conditions

➔ **Video**

Young Subject in Domestic Environment

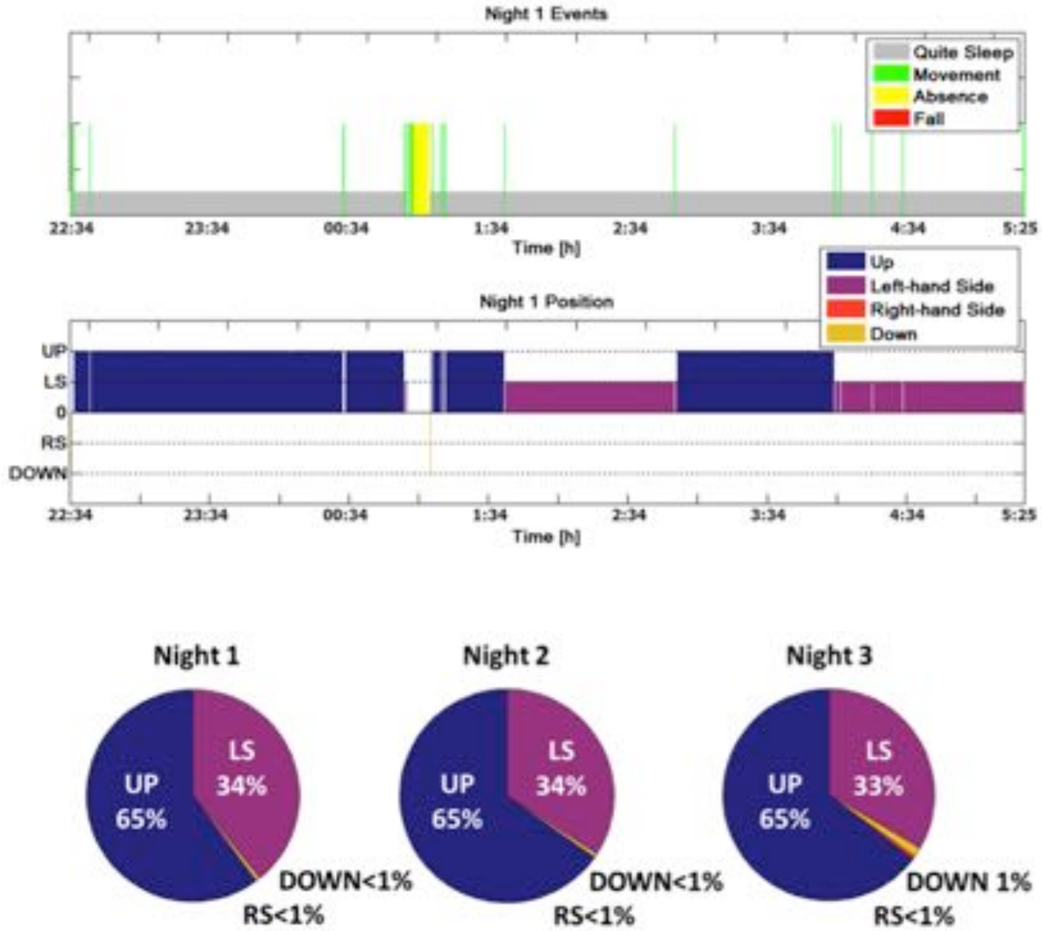


Elder Subject in Nursing House

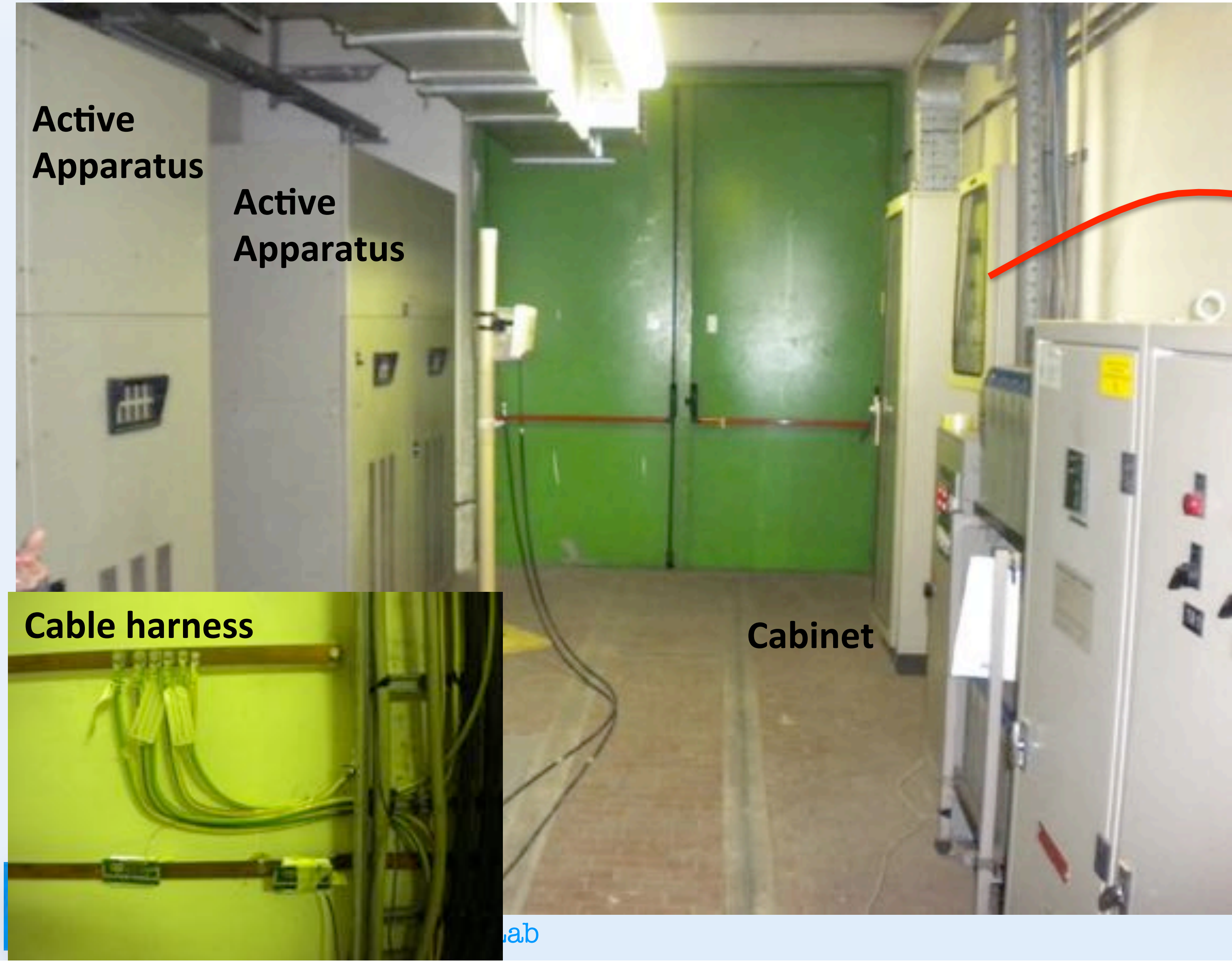


Night	Time	Absence	Number of movements
1	23:10-6:50	23:20-23:23 23:44-23:47 1:20-1:27	about 12
2	23:20-6:50	23:46-23:51 2:50-2:54	about 8
3	23:39-6:50	4:12-4:20 5:03-5:08	about 7

Aged volunteer



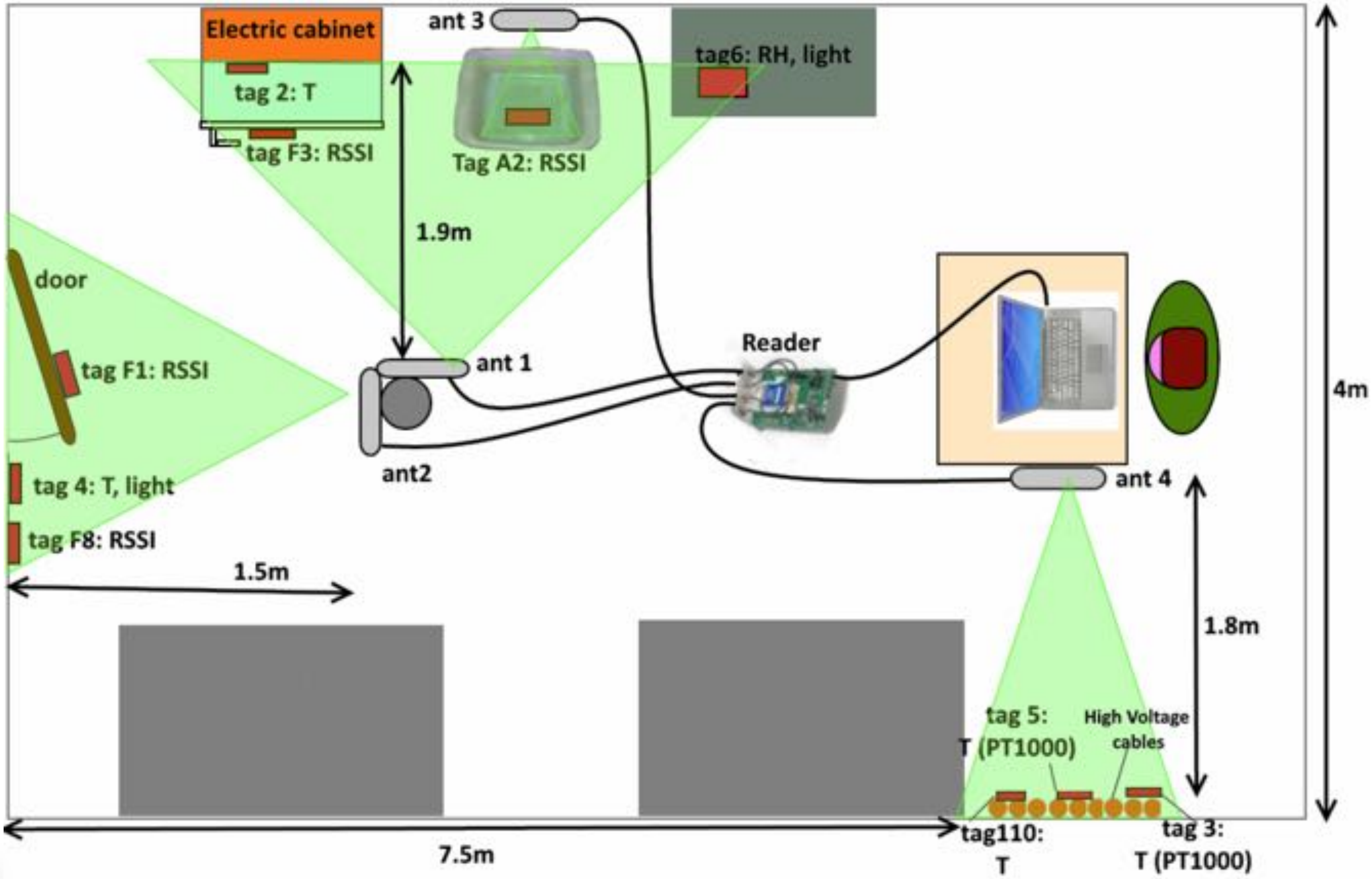
Advanced Human-Things Interactions and multi-parameters monitoring



Cabinet
With internal
devices

Antennas coverage

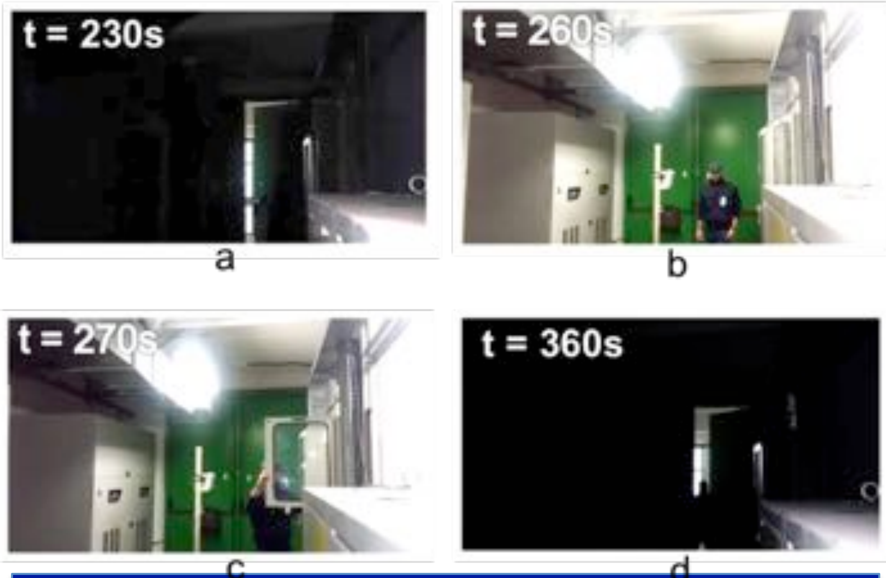
N.4 switchable surveillance antennas



ROSARIO
the maintenance technician
(*authorized personnel*)
badge

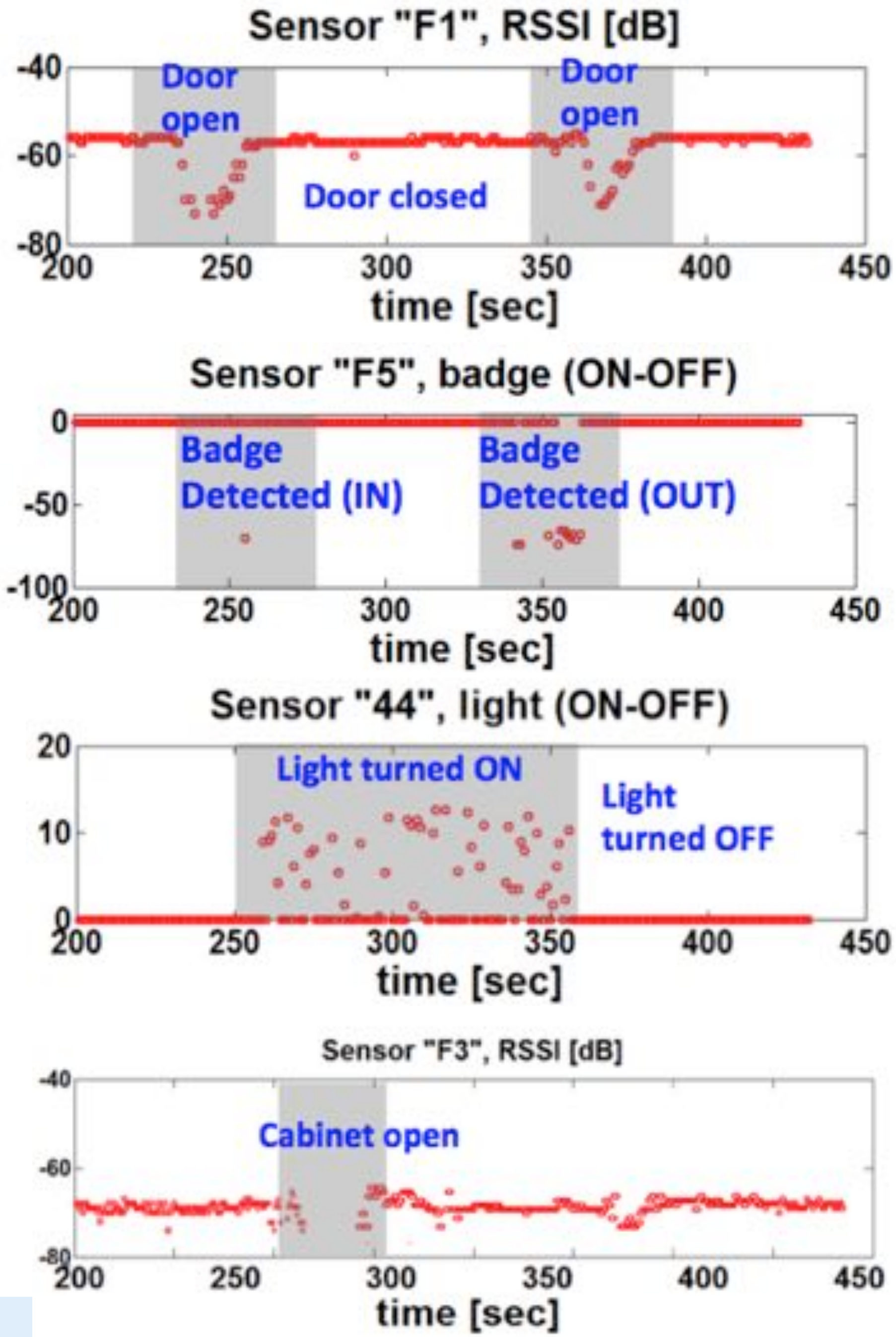
STEFANO
the intruder
(un-*authorized personnel*)
No badge

Authorized access

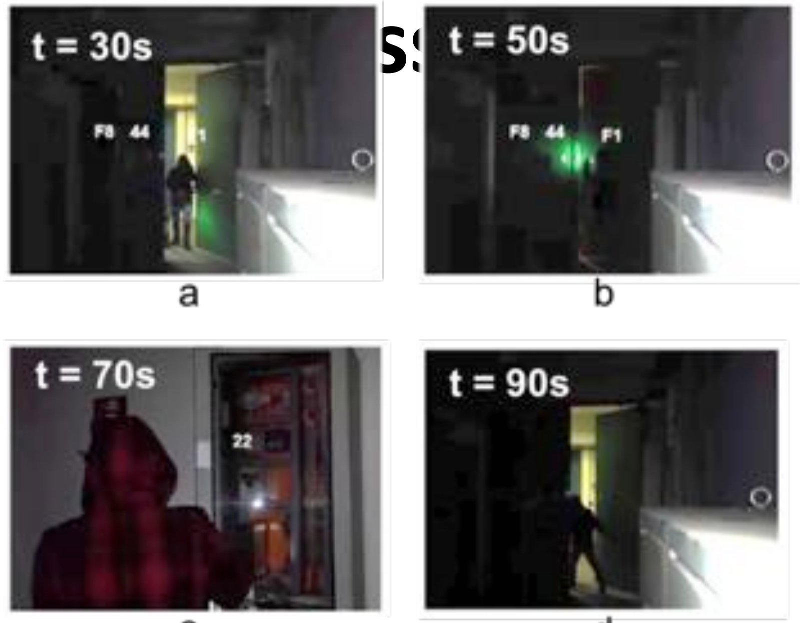


Human-based Semantic Analysis

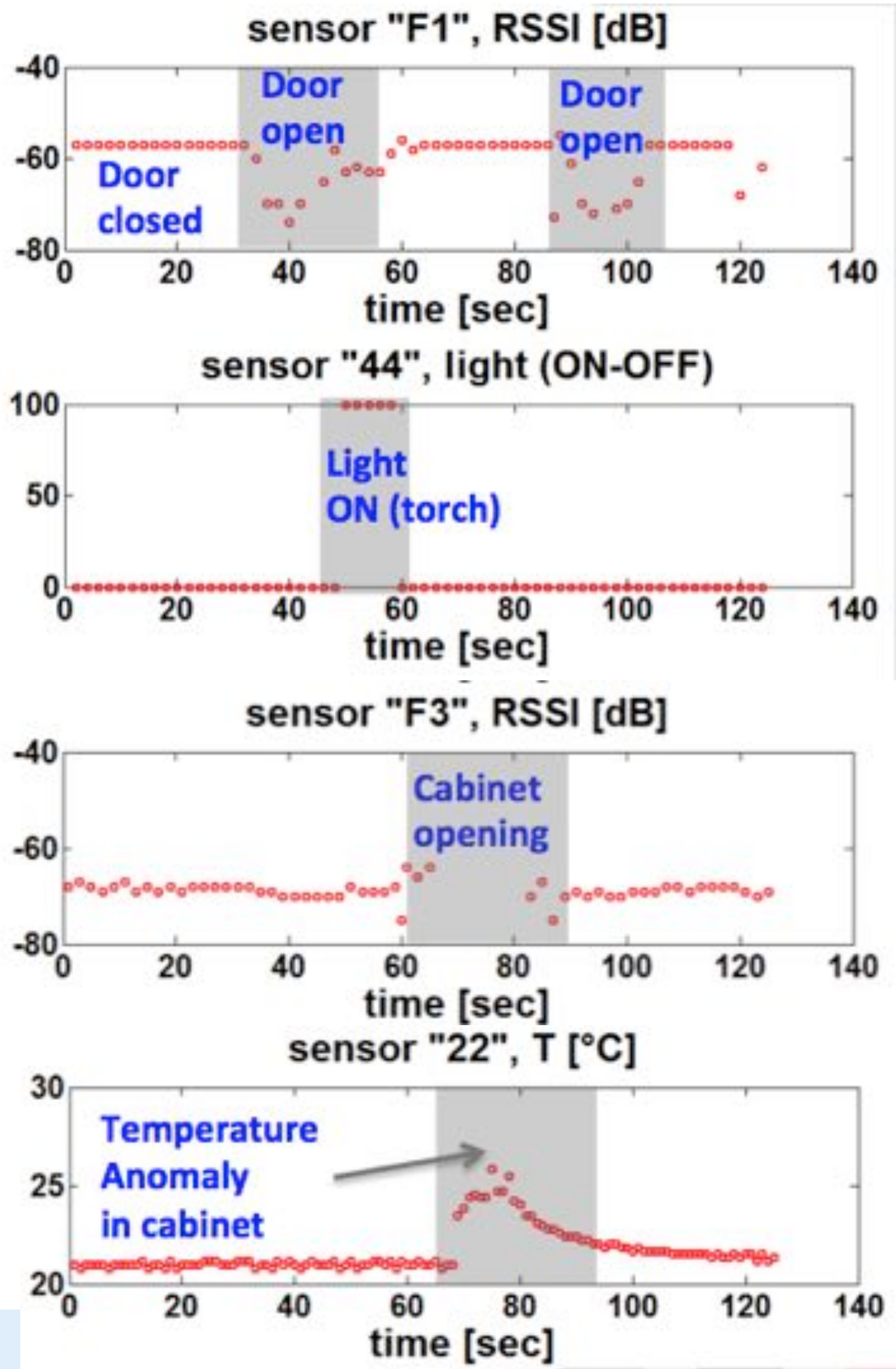
1. Door open: somebody inside
2. Badge detection: the system recognizes the technician
3. The technician turns on the light
4. The technician opens a cabinet
5. The technician get close the exit door and turns-off the light; the system records the exit



Un-authorized



a b c d



Human-based Semantic Analysis

1. Open door: somebody inside
2. No badge detection: the person is not authorized and may be classified as *intruder*
3. The intruder turns on the light for a short time: maybe uses a torch
4. The intruder opens a cabinet
5. The temperature inside the cabinet increases: possible manumission
6. The intruder opens the door and exits.

That's all !

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www.pervasive.ing.uniroma.it

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Original videos at ➔ www.pervasive.ing.uniroma.it