



**Computer Science, Control and GeoInformation
XXIX Cycle Doctorate**

RFID Epidermal Technology for skin sensors with wireless reading

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Credits:

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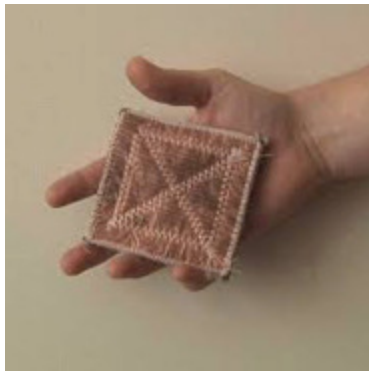




Wireless Bodycentric Systems

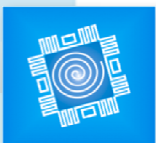


Samsung Introduces
Its First Wearable Glove,
Samsung Fingers



Huge scientific and industrial
growth in the last decade

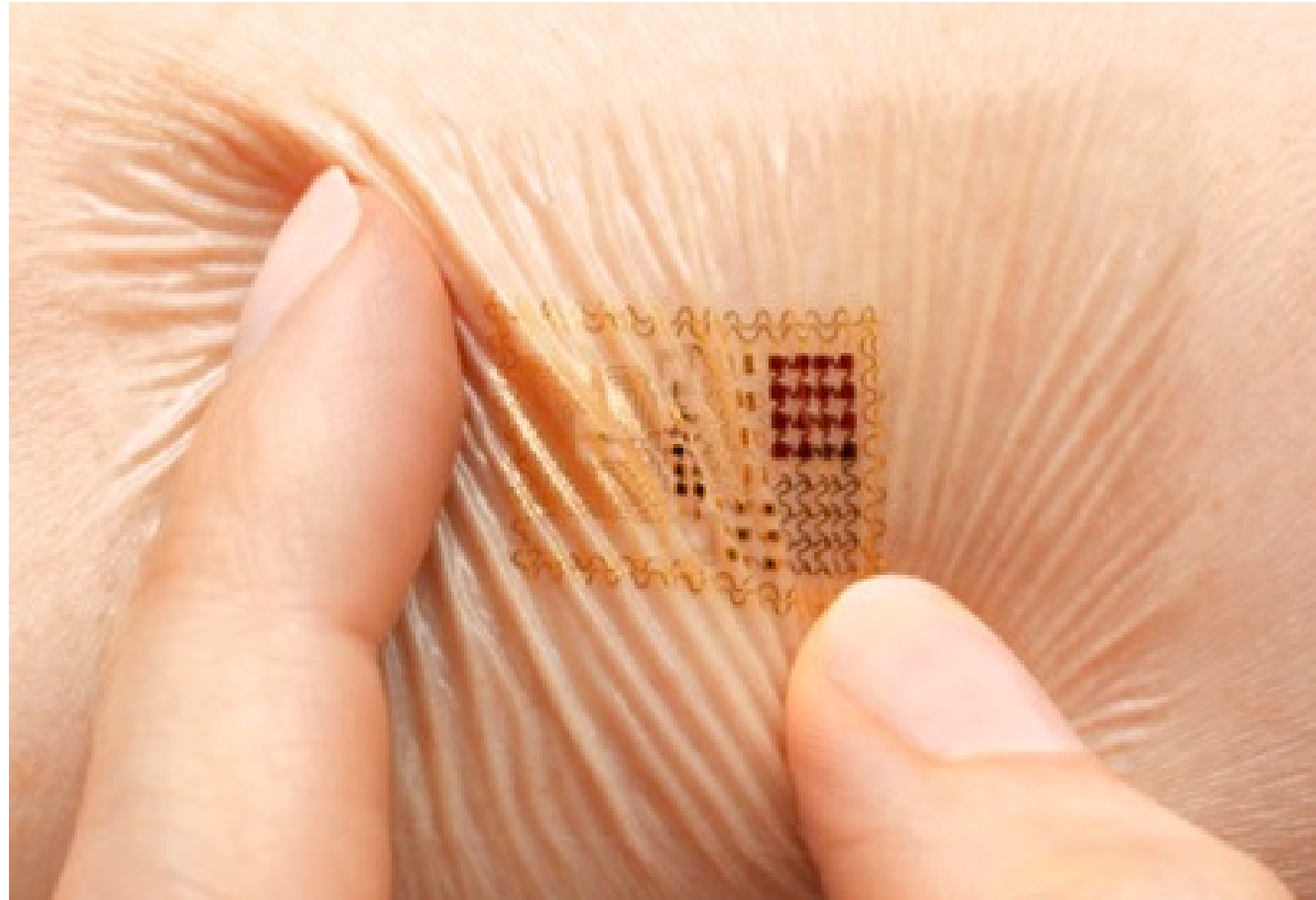
From Wearable to ...



... to Bio-integrated Electronics

KEYWORDS

- Skin
- Epidermal
- Flexible
- Stretchable
- Temporary
- Dissolvable
- Bio-resorbable
- Tattoo



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





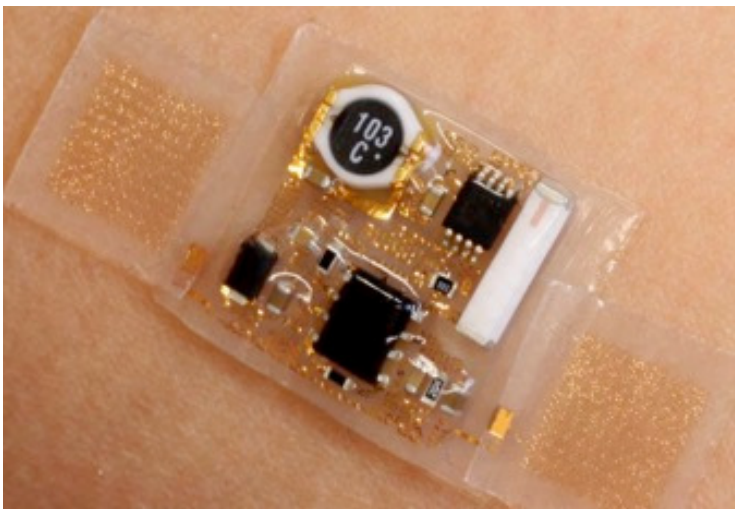
Powering & Communication



Local Battery



Wired Interfaces



Bulky electronics



Near-Contacting Reading
(HF-RFID 13.56 MHz)





Epidermal Electronics & RFID Tech

Radio Frequency Identification

UHF Band

860-960 MHz

> 1m

Direct Link



Backward Link

ID

Sensed Data



Epidermal Tag



Reader



Cloud

The last meters of Internet Of Things

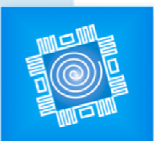


UHF Antenna



IC

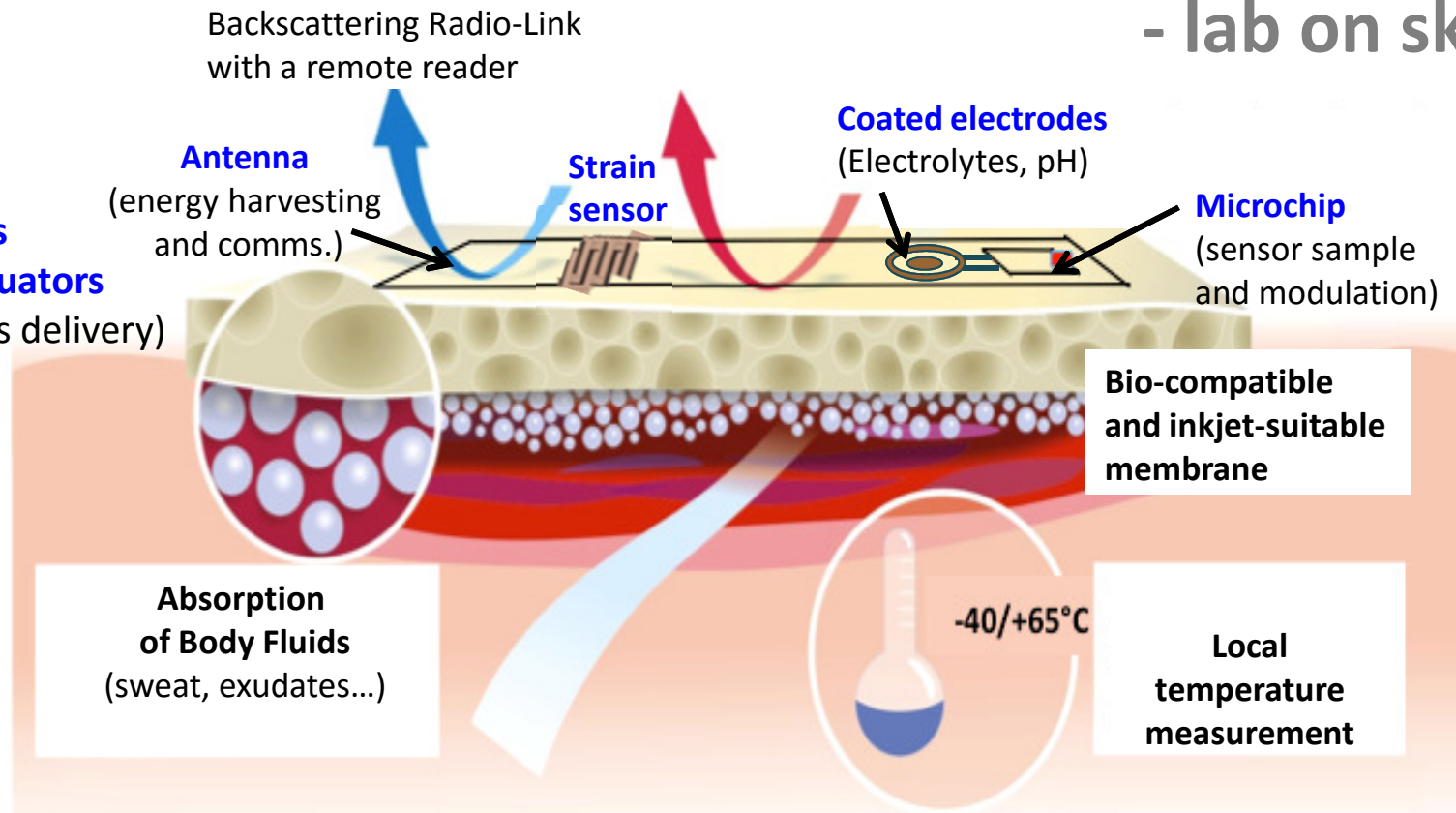
- ✓ Passive
- ✓ Remote Reading
- ✓ Easy integration
- ✓ Communication & Sensing



Concept: Epidermal Radio-Plaster

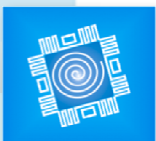
- lab on skin

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



CHALLENGES:

- Antenna has to play as sensor: radiator very close to high-loss body
- **Upper bound in antenna performance** (which is the best layout for skin antennas?)
- **Human Variability:** broadband and/or possible on-body retuning
- Metal Traces patterning over **biocompatible, flexible, ultra-thin substrates** (UHF RF properties?)



Target Application: Epidermal Temperature

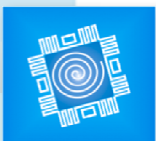
- **Wireless and continuous measurement of body surface temperature**
 - Fever rush
 - control and localization of Ebola/ SARS epidemics
 - infection around wounds and lesions
- **Variations of skin temperature are common indicators of brain activity and of particular psychological states.**
- **Indicator of Circadian system activity**



Epidermal RFID Thermometer

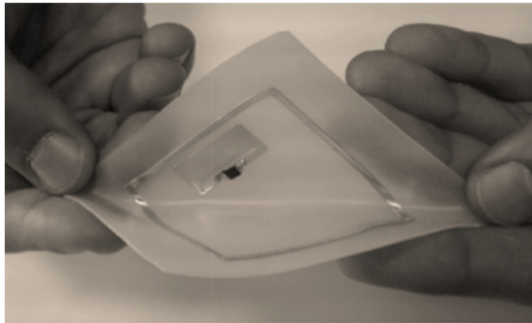
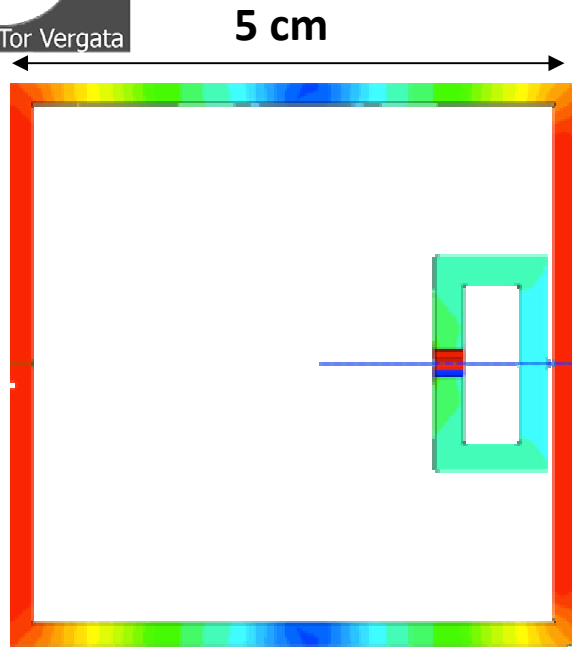
Contents

- Design of a **small-size UHF epidermal antenna** with on-body retuning mechanism
- Prototyping by different **manufacturing technologies**
- **Thermal characterization** of the RFID IC with temperature sensor
 - Sensor accuracy*
 - Time response*
- Evaluation of **communication and thermal performance** of the RFID epidermal thermometer in **realistic conditions**





Small-Size Epidermal Antenna

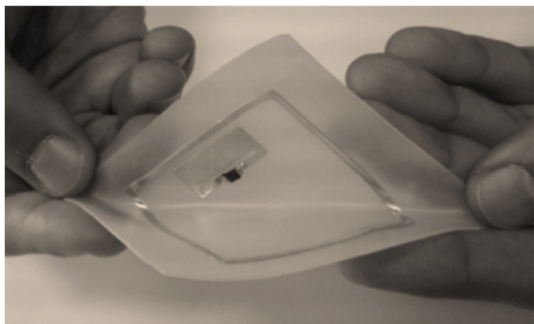
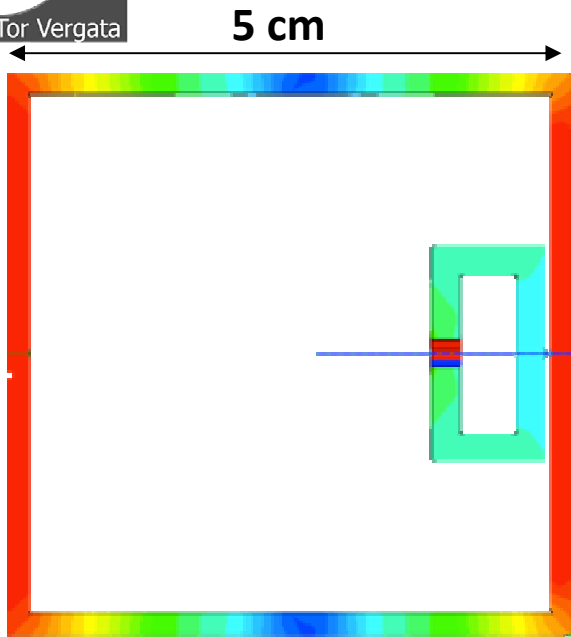


S. Amendola, S. Milici, and G. Marrocco
"Performance of Epidermal RFID Dual-loop
Tag and On-Skin Retuning", IEEE Trans. on
Antennas and Propagation, August 2015.

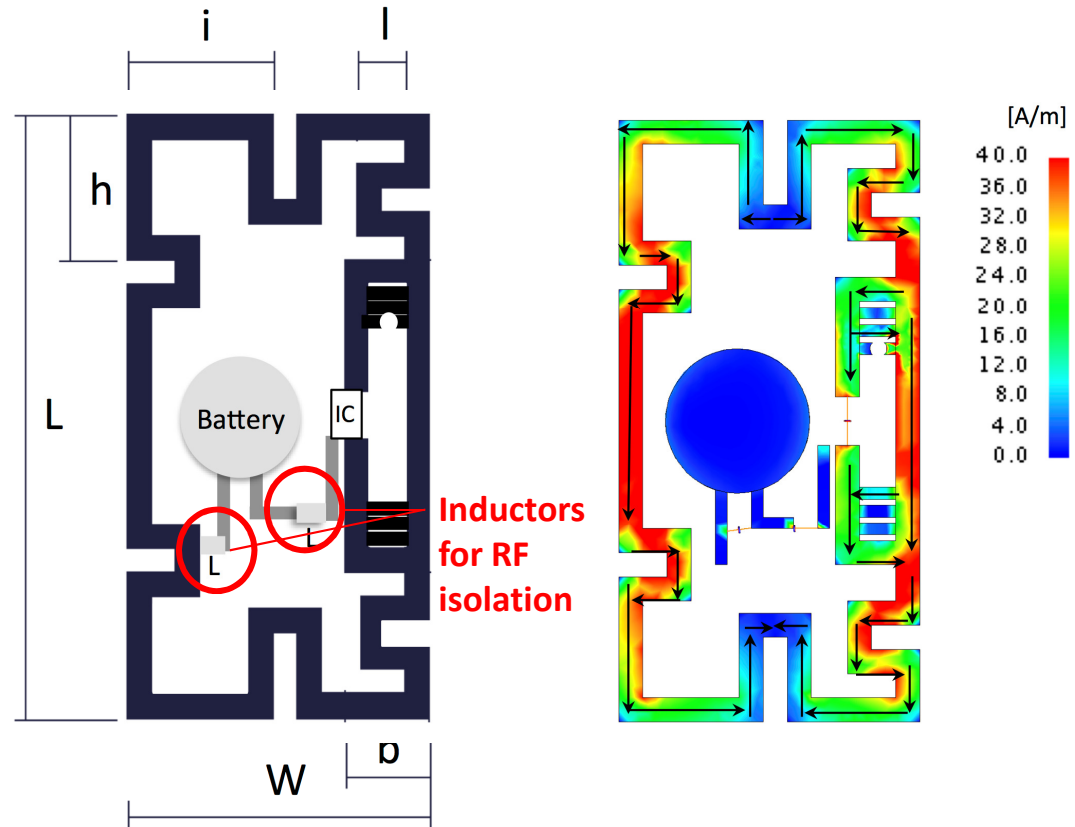




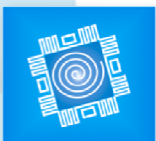
Small-Size Epidermal Antenna



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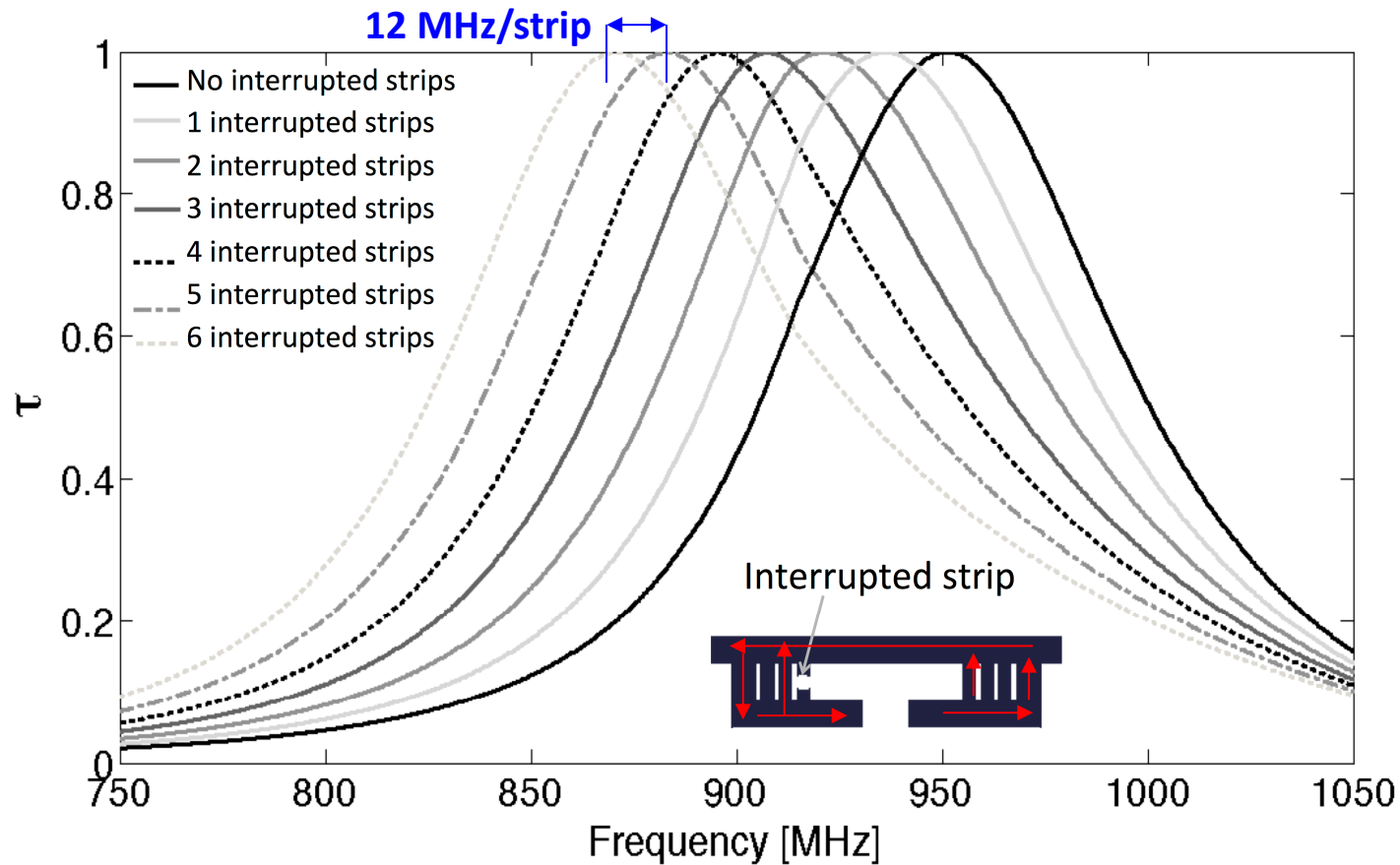
- Miniaturization of the “un-useful” traces
- Additional meandering to achieve stretching
- Performance unchanged ($G\tau_{\max} = -12$ dB, 870 MHz)
- **Battery Integration for improved the read range**



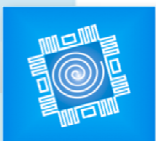


Small-Size Epidermal Antenna

On-body tuning method

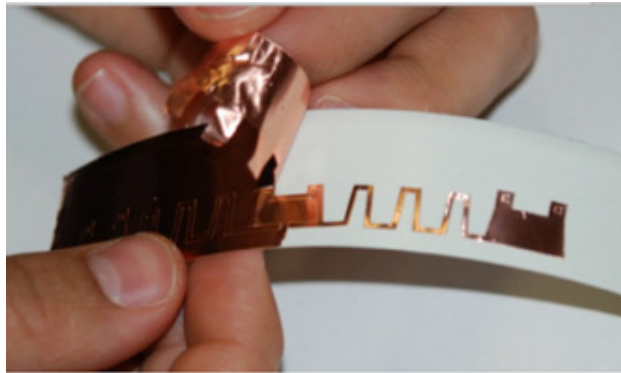


- Adapting the antenna to the specific placement over the body
- Shifting the working frequency in the European (866-869 MHz) or US (902-928 MHz) RFID bands





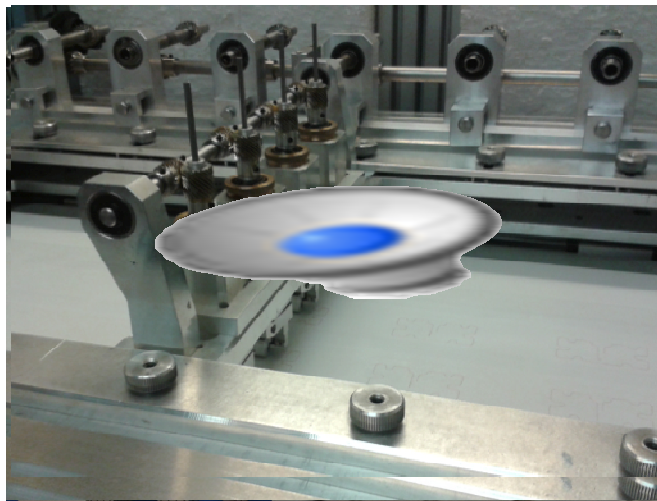
Manufacturing Technologies



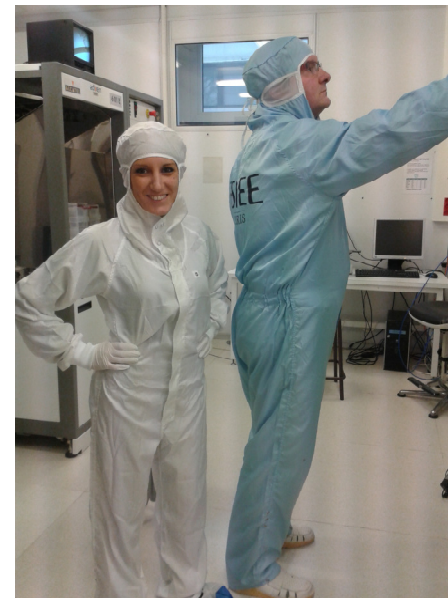
Carved adhesive copper



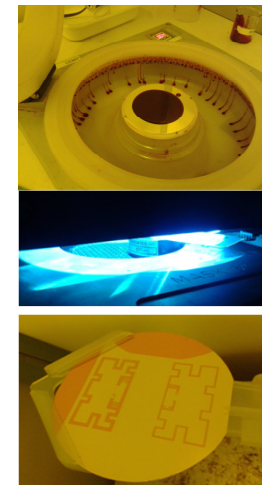
Inkjet printing by self-sintering ink



Coated Micro-wires



Microfabrication



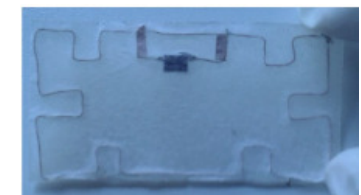
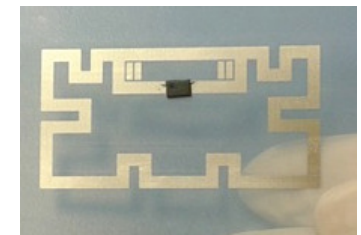
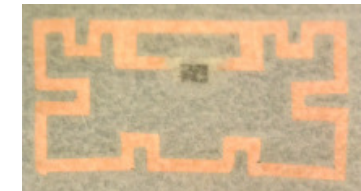
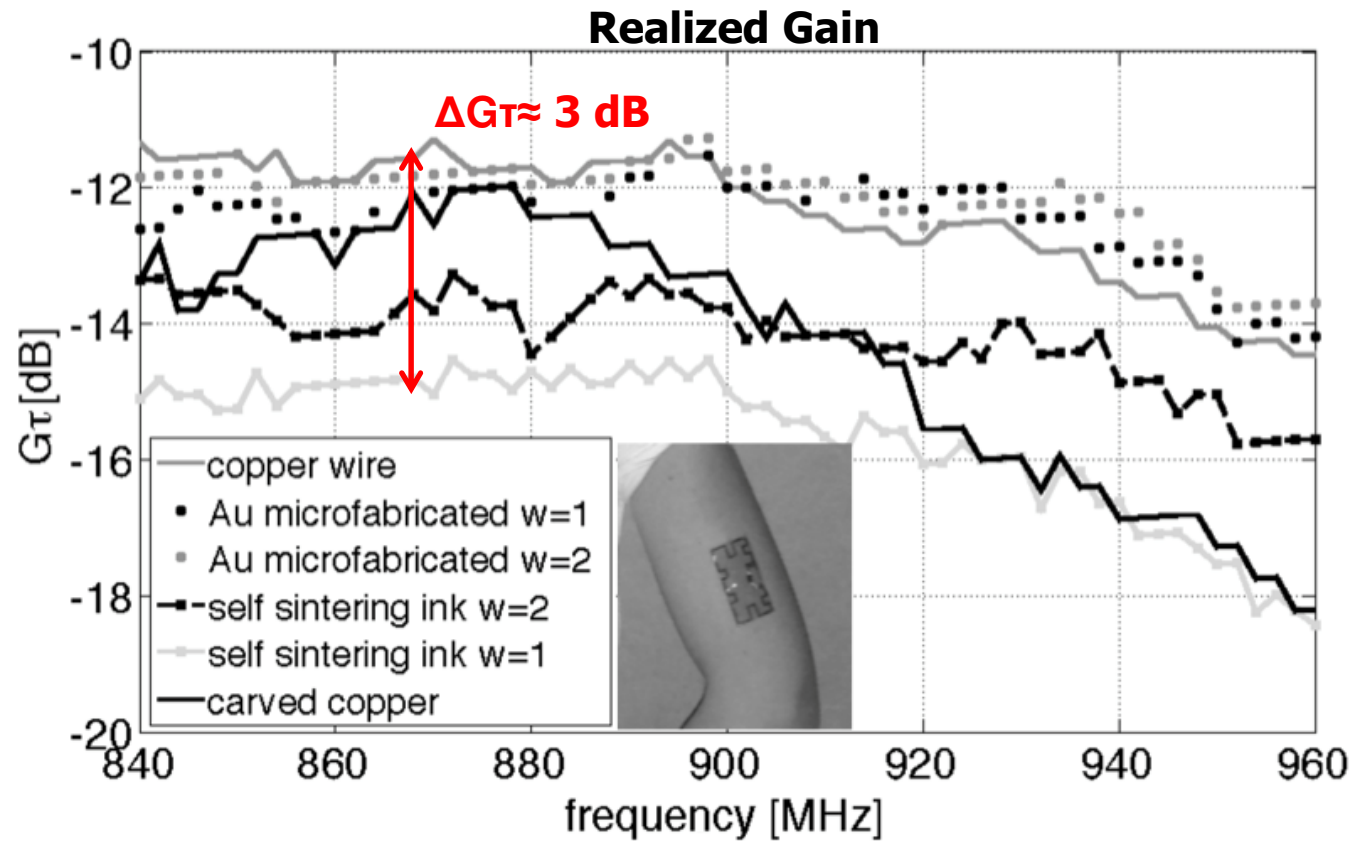
ESIEE
PARIS

Dec. 2015

WIPE
COST IC130



Communication Performance



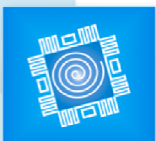
$0.5\text{m} < D_{\text{max}} \text{ (EIRP } 3.2\text{W)} < 2.3 \text{ m}$

Passive

(Forward-limited link)

Battery-Assisted

(Backward-limited link)

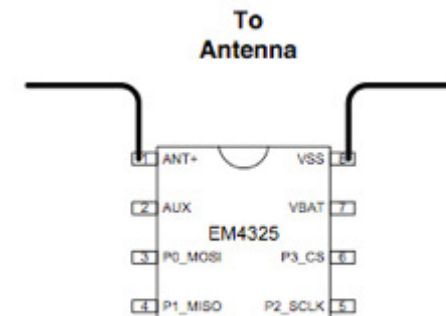
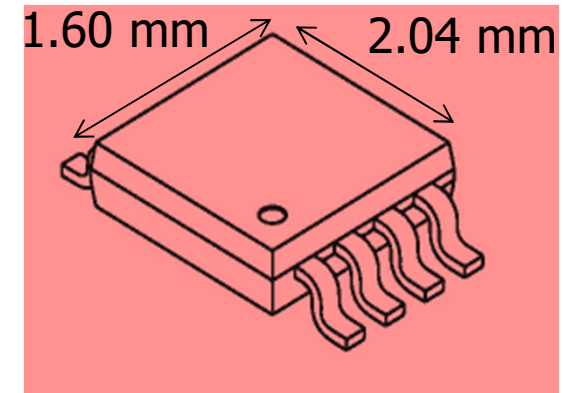




Temperature Sensor

- **On-chip integrated temperature measurement**
- Reduced power sensitivity w.r.t. *conventional* microchips
- Battery-less and Battery-assisted mode (extended read-range)
- Temperature Range: $-40^{\circ}\text{C} - +65^{\circ}\text{C}$ (passive mode)
- Resolution: 0.25°C
- **Single-point calibrated 5°C (!!!)**
Mean accuracy of $\pm 1.0^{\circ}\text{C}$

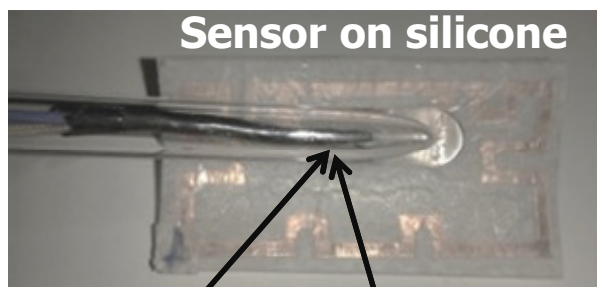
Improved accuracy may be achieved by **re-calibrating the temperature sensor** in the final epidermal tag form factor within the physiological temperature range





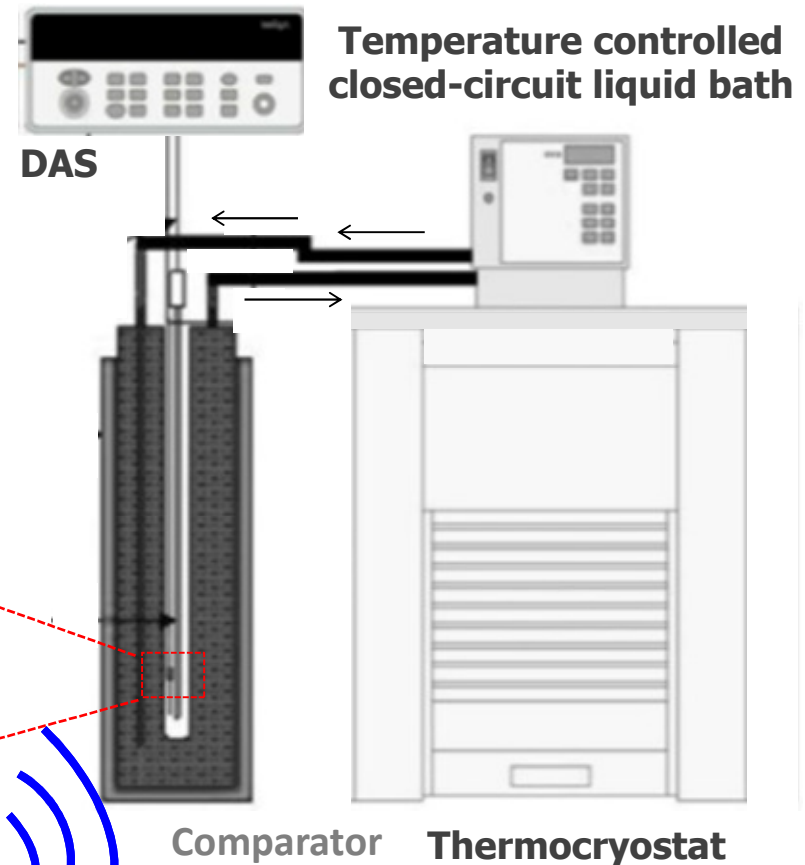
Temperature Sensor Calibration

- **Stationary measurements** in calibration Bath providing a very stable and uniform temperature environment
- Certified Platinum Thermoresistance (PTR25) as reference
- **Multi-Point Thermal Calibration** (from -5° to 60° C, 5° steps)



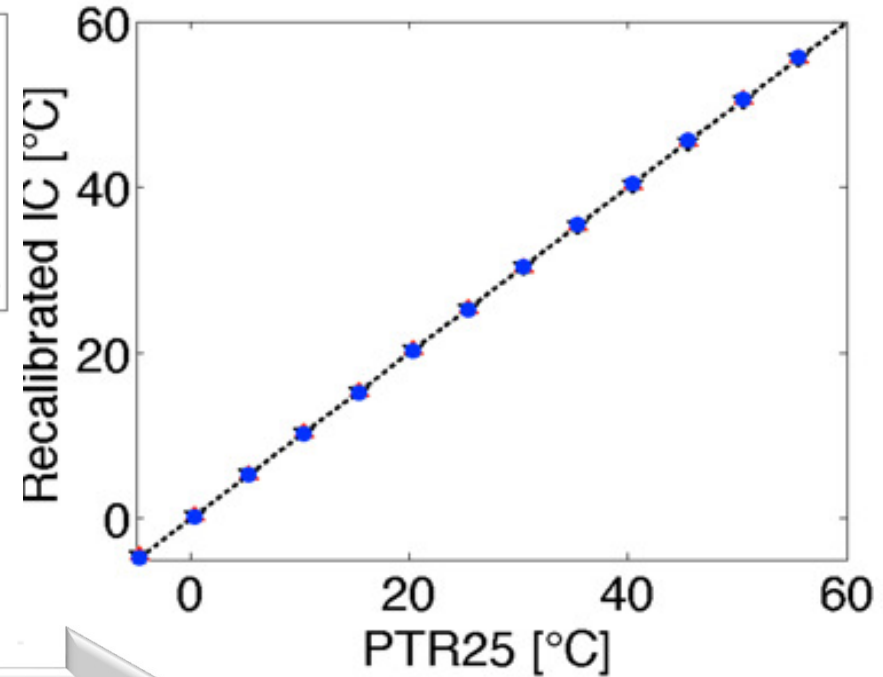
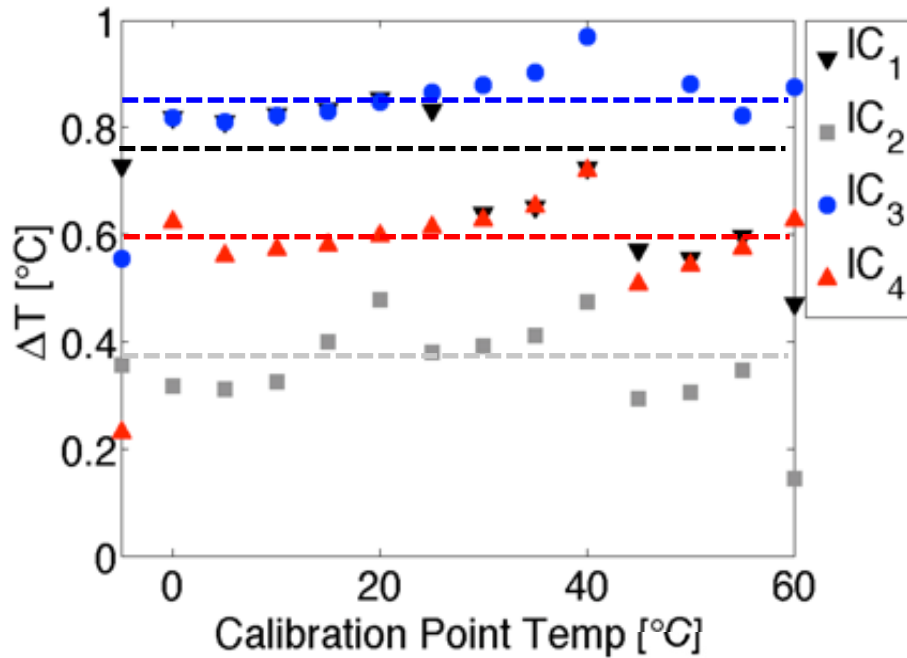
PTR25

RFID IC





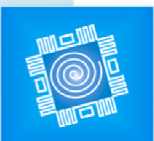
Temperature Sensor Calibration



Uniform calibration

Accuracy below resolution

- The mean error between spans in the range $0.35^{\circ} C < \Delta T < 0.85^{\circ} C$.
- Epidermal thermometers should be **individually** re-calibrated (few-points calibration)
- **Total uncertainty** (ISO-GUM) is $0.18^{\circ} C$, much lower than that declared by the manufacturer
- Calibration offset can be written inside the microchip memory

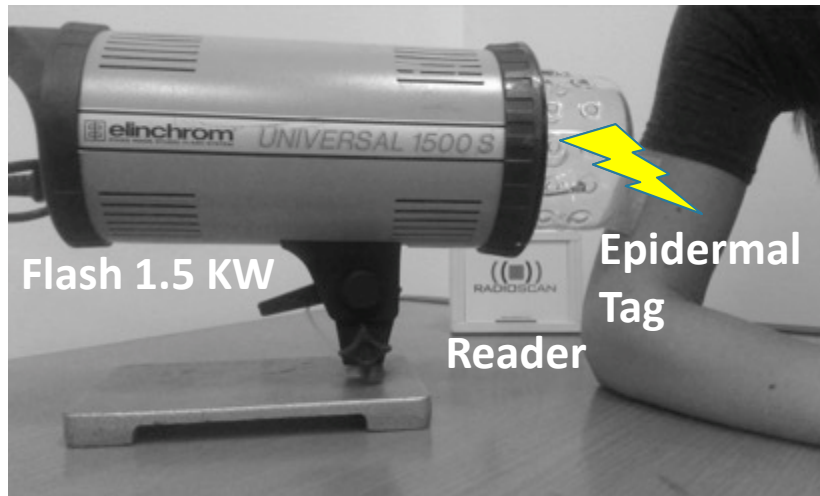




Temperature Sensor

Time Response

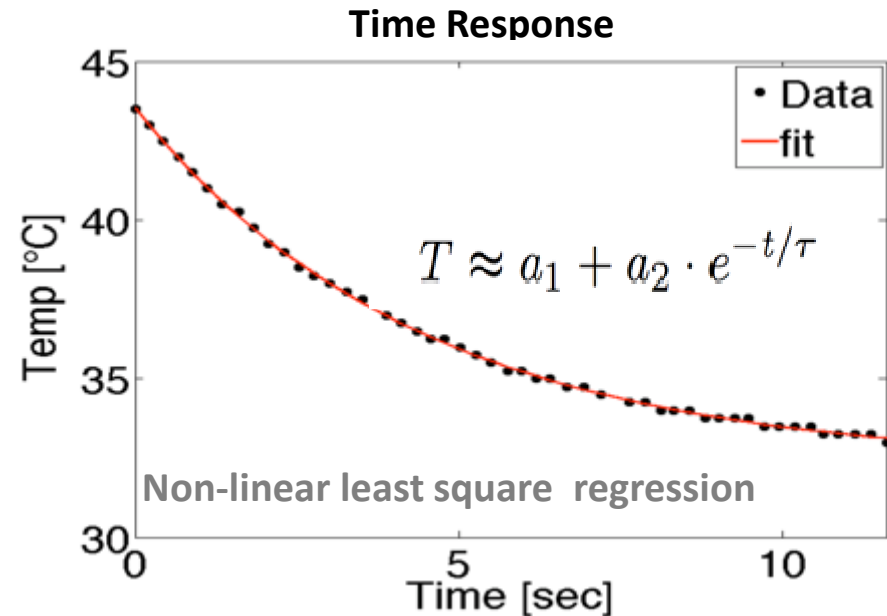
Impulsive Heating (Flash-Method)



Time response depends on the heat capacity and the conductivity of the human skin and on the substrate layer (here 25 μm Tegaderm[®])

Stable temperature data can be read **20 seconds** (5τ) after the placement onto the body.

Time constant fully compatible with the physio/pathological time variations of skin temperature



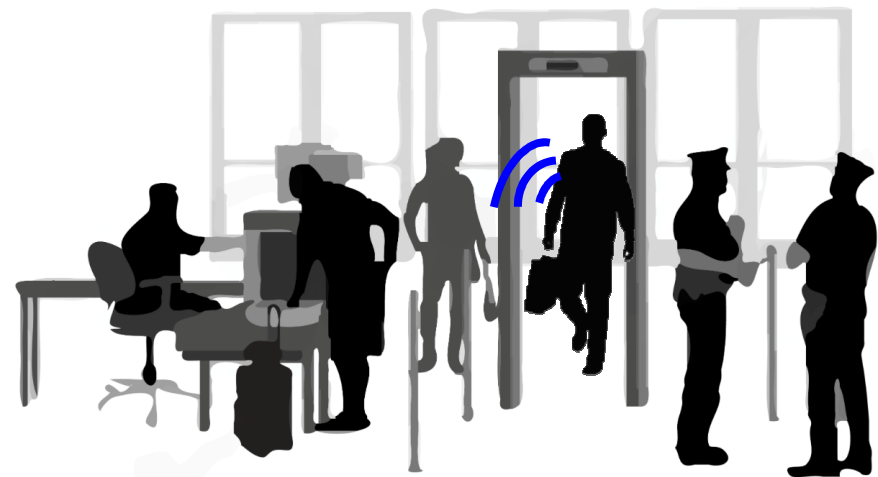
Tag Position	τ (sec)
Air	6.5 ± 0.2
Liquid Phantom	6.1 ± 0.1
On-Body	4.3 ± 0.2





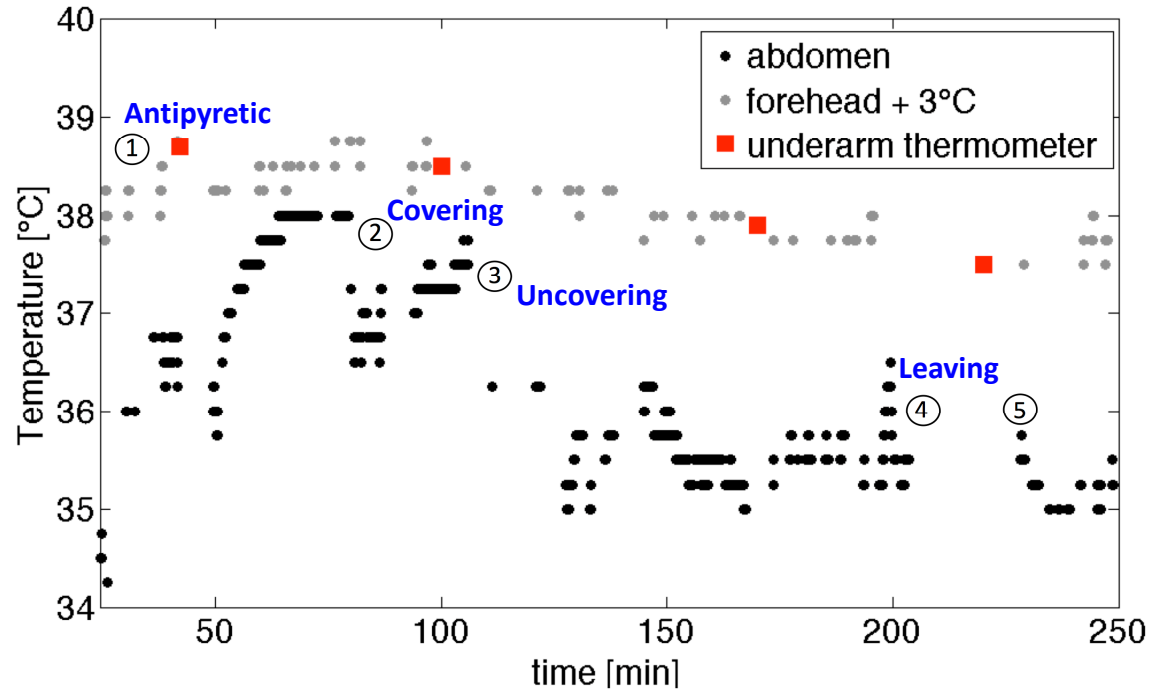
Sensor Experimentation in realistic conditions

➤ The establishment of a robust communication link is a critical issue





Manual Temperature reading



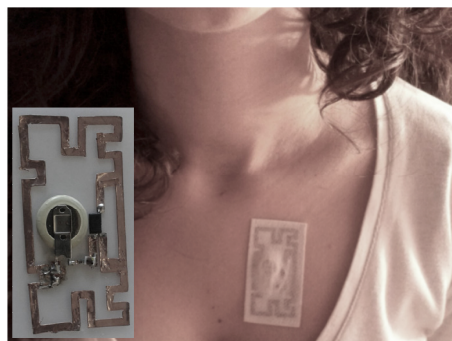
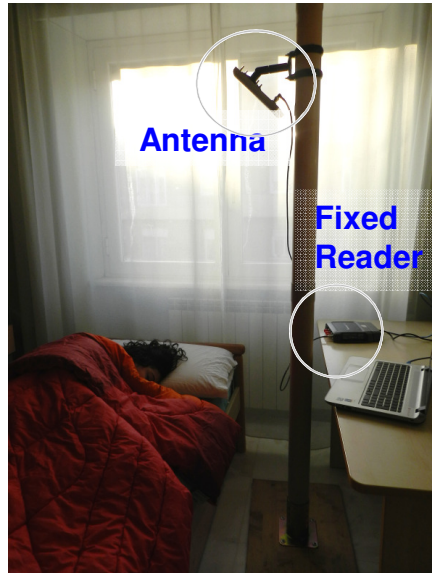
- **Abdominal temperature** does not correlate with the core one because of **time-variant ambient conditions**
- After 3 ° C offset compensation, data non-invasively measured over the **forehead** provide an acceptable **estimate of the central temperature**

25 years old female down with the flu

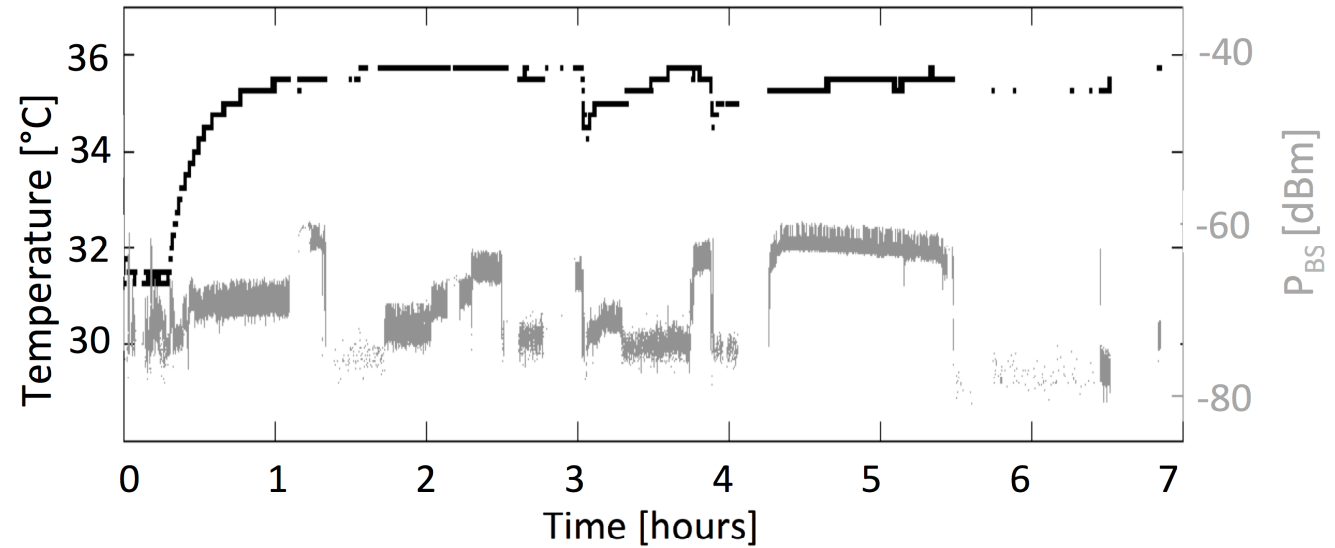




Overnight temperature monitoring



BAP sensor



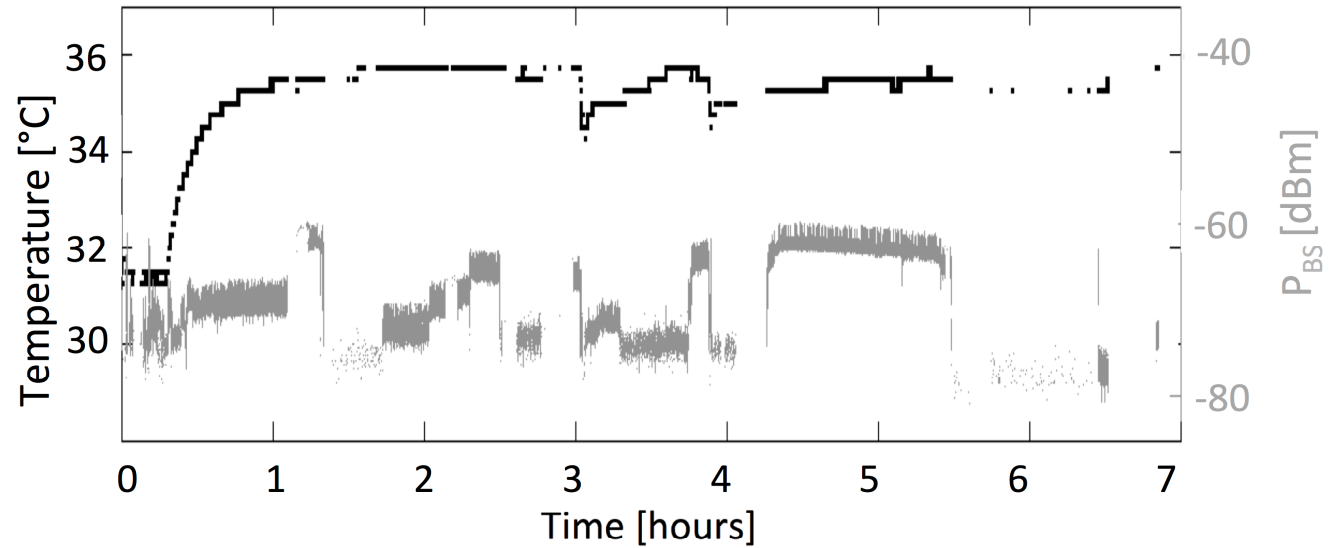
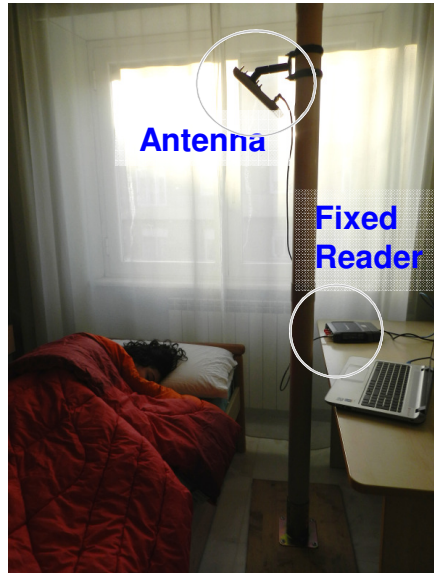
Temperature and Backscattered Power can be correlated:

- removing measurement artifacts
- Interpreting temperature variations related to subject's position changes.





Overnight temperature monitoring



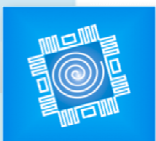
Reliability of the wireless link

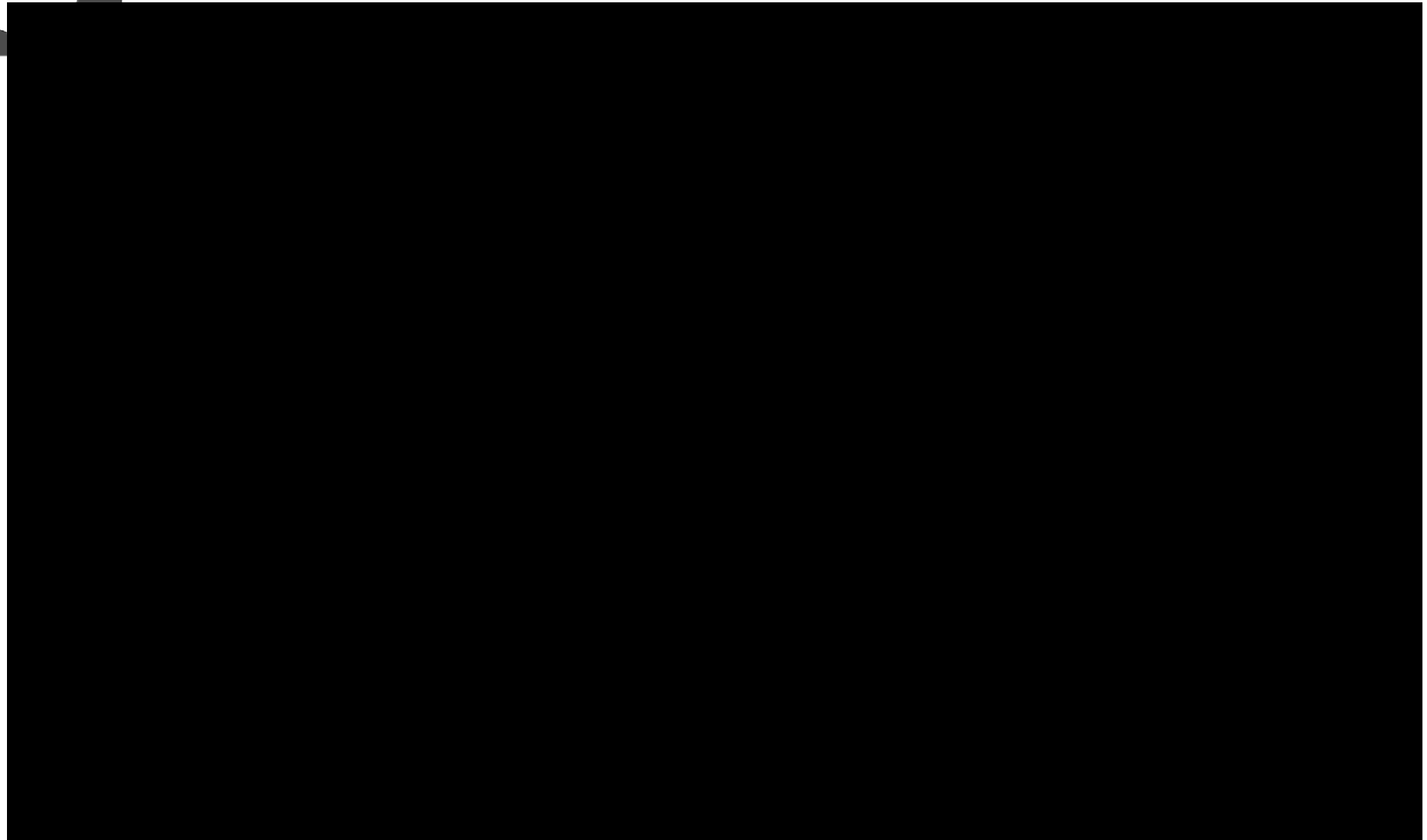
	5min	10min	15min	20min	30 min
1 st night	12%	8%	6%	5%	2%
2 nd night	10%	8%	4%	1%	0%
3 rd night	20%	15%	14%	12%	9%
4 nd night	20%	14%	8%	4%	0%

Interruptions longer than 15 min occurred in average for less than the 8% of the total observation time



BAP sensor







On-flight screening across gates

Identification & Temperature Sensing of moving people

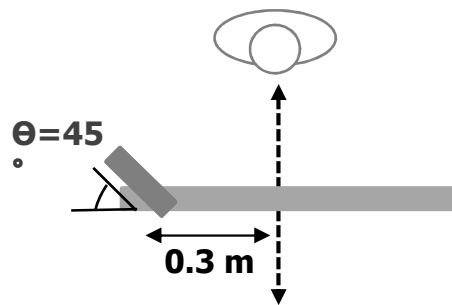
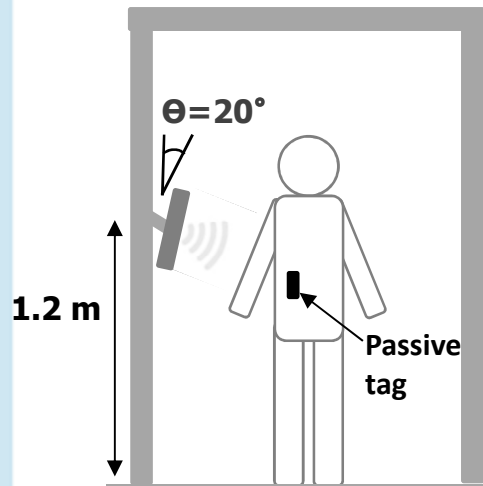


Since the outbreak of recent epidemics public health authorities have been looking for a **fast, easy, non-invasive, and reliable method** to early detect and isolate suspected cases of infection **in high-risk groups...**

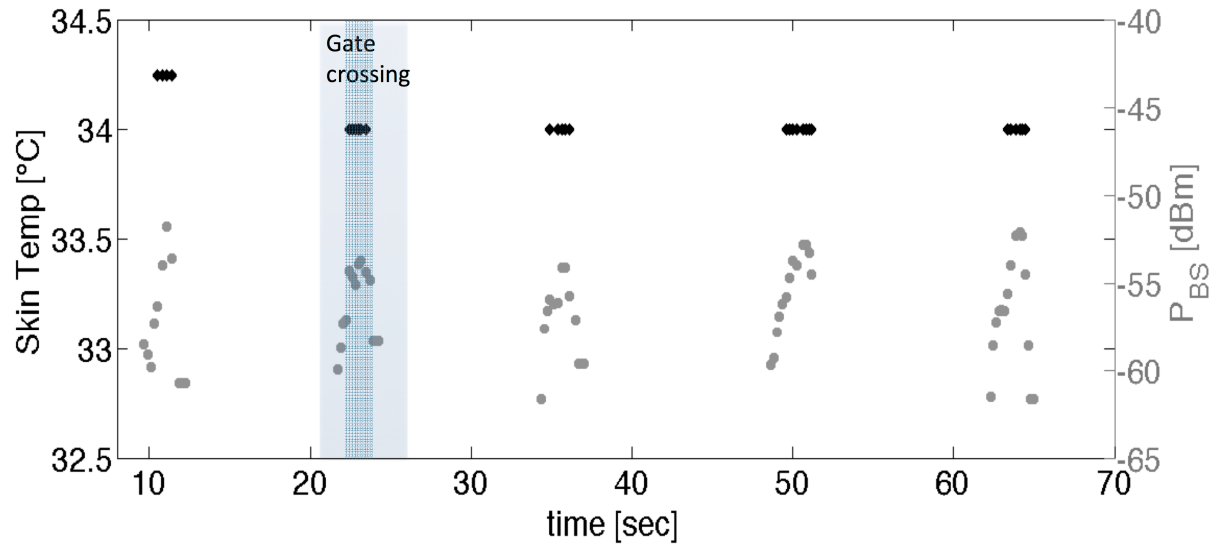




On-flight screening across gates



Cyclic gate crossing with a controlled gait cadence



$P_{chip,labeling} = -8.3$ dBm

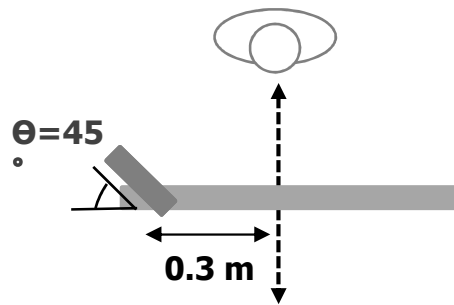
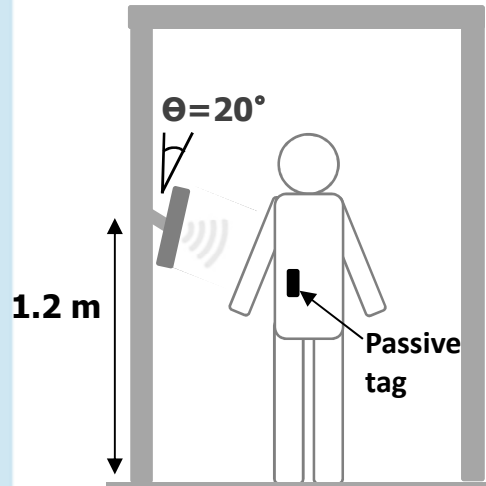
$P_{chip,sensing} = -4.5$ dBm

The system fails temperature sampling at the borders of the identification interval due to the higher power required for sensing



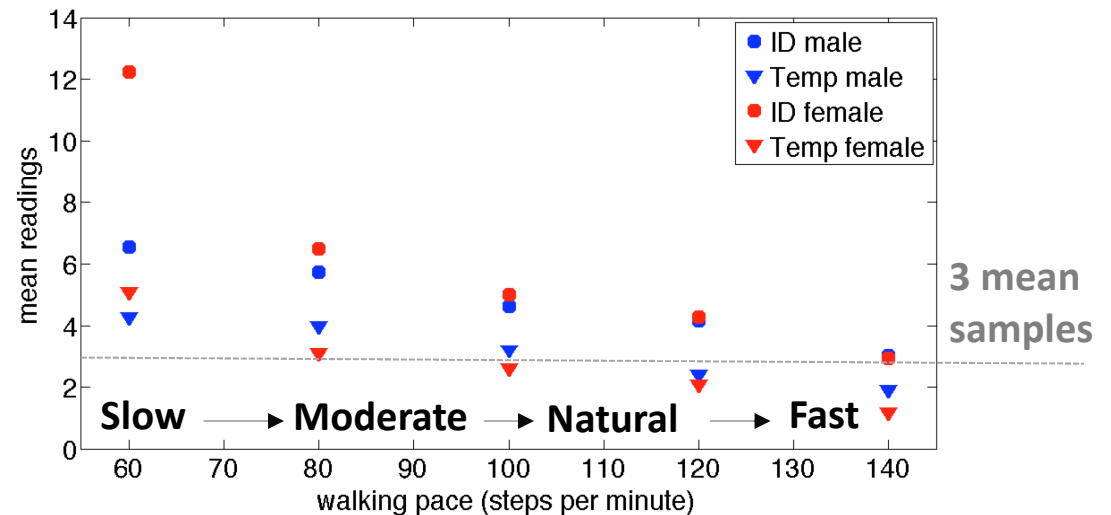
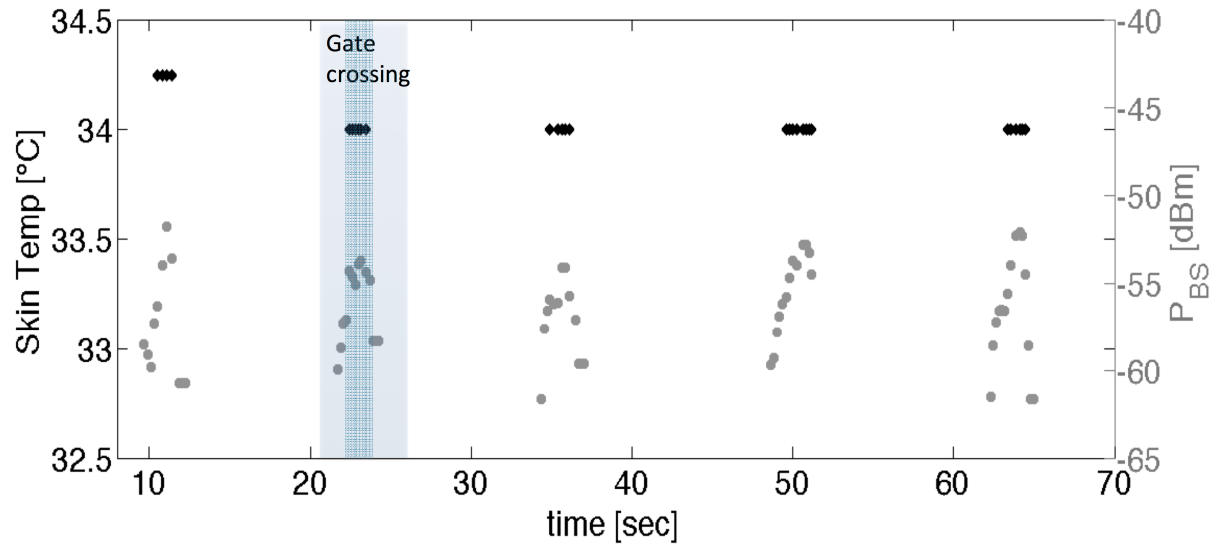


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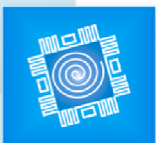
Improve reading reliability:
Multiple reader antennas
Near-field focused UHF antennas

Cyclic gate crossing with a controlled gait cadence





Video





Conclusions

- The **epidermal RFID thermometer** is a potential key element of the **IoT physical layer** for personal healthcare and security in *Smart Environments*
 - The small-size UHF epidermal antenna embedded in medical plasters is **readable from 0.7 m** (passive mode) **up to 2.3 m** (battery-assisted mode, lifespan 3 years)
 - After uniform recalibration, the sensor accuracy satisfies the target values for standard thermometers (0.2° C - 0.5° C).
 - Stable temperature readings are **collected after 20 sec** if the sensor is properly attached to the, in absence of localized heat flows (possible mitigation by insulating coating).
 - Temperature/behavior correlations are possible for high-level data processing.

Next...

Clinical Experimentation, Tor Vergata Hospital

