EPFL

EDMI Microsystems and Microelectronics

MICRO-614: Electrochemical Nano-Bio-Sensing and Bio/CMOS interfaces

Lecture #15

Portable, Implantable, and Wearable Devices,…& Beyond!!!

Glucometer on iPhone

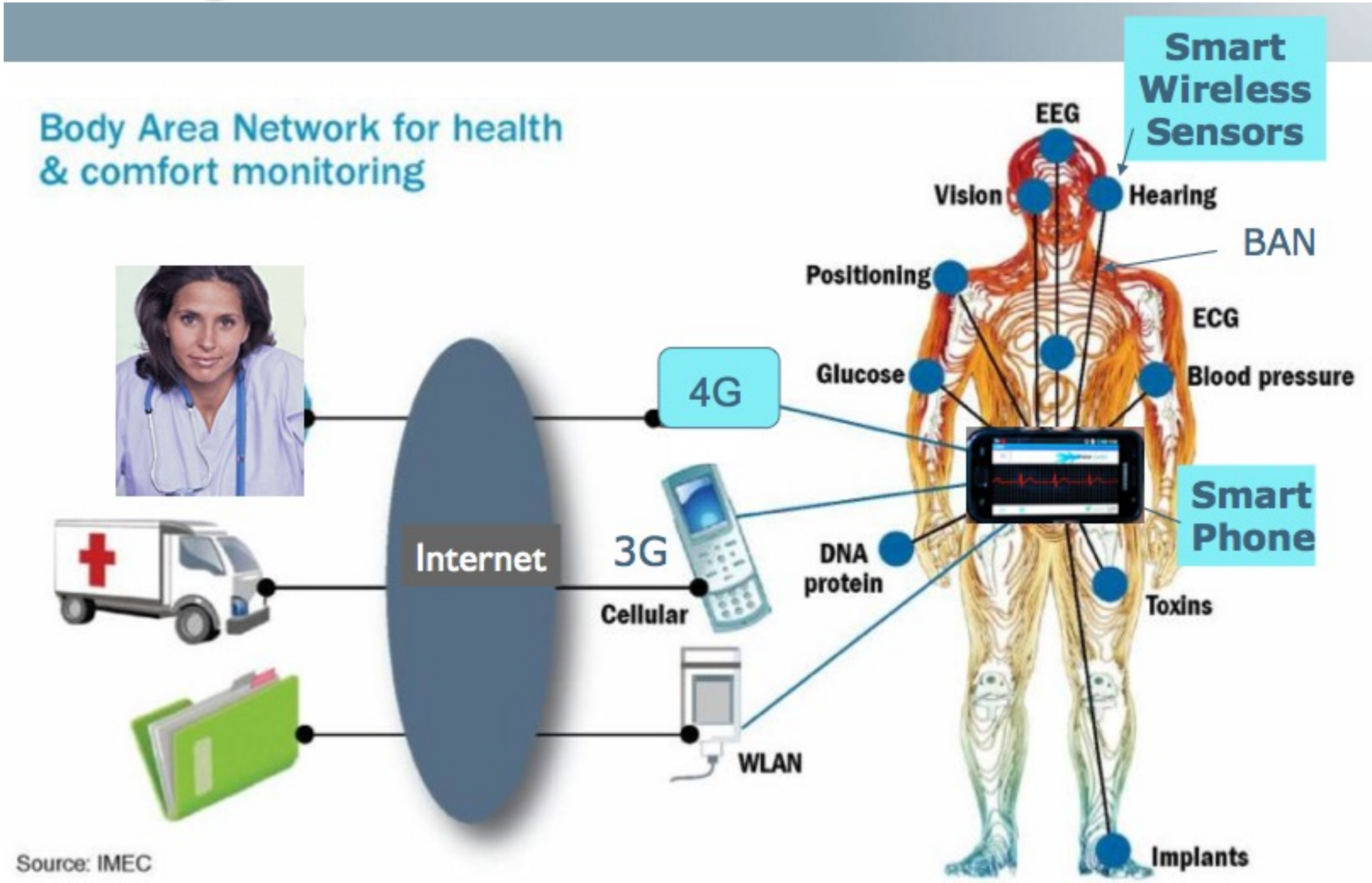
Wearable Glucometer by Abbot

An Unser's interface

Wearable Devices expected by 2030

From 3 billion in 2025, Research Nester estimates that, there will be 26 billion connected IoT devices by 2030

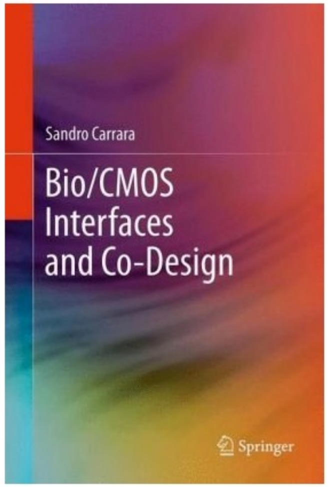
Fully-Connected Human++



Courtesy, Hugo De Man (IMEC)

Toward innovative systems we need:

1. Fully integration of Biomolecules to assure specificity
2. Fully integration of Nano-structures to assure sensitivity
3. Proper CMOS frontends to assure



(i) Precise Current measurements,

(ii) Multiplexing for multi-metabolites,

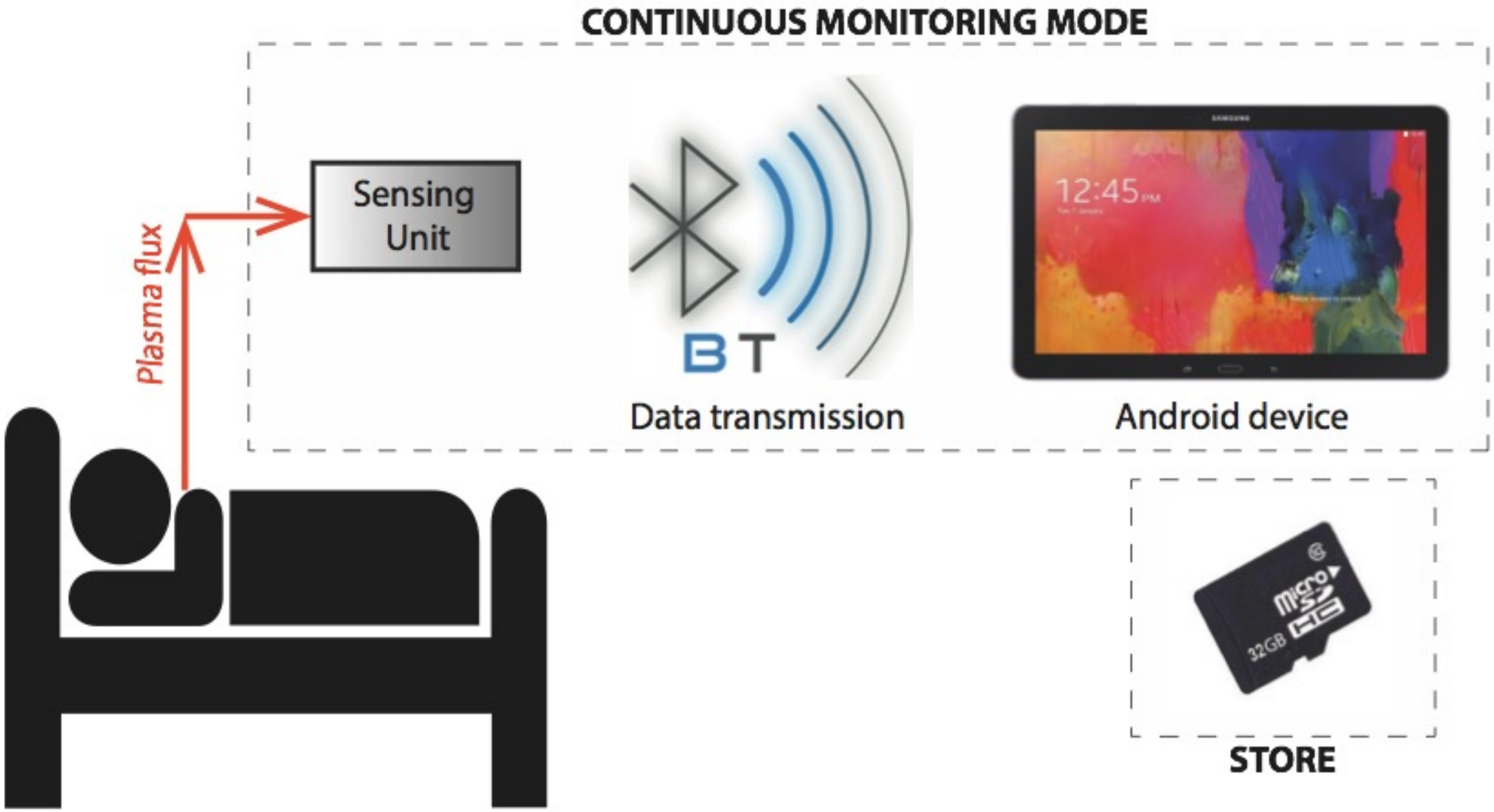
(iii) Reliability in Temperature and pH

Bio/Nano/CMOS Co-design !

Portable, Implantable, 'n' Wearable

Monitoring scenarios

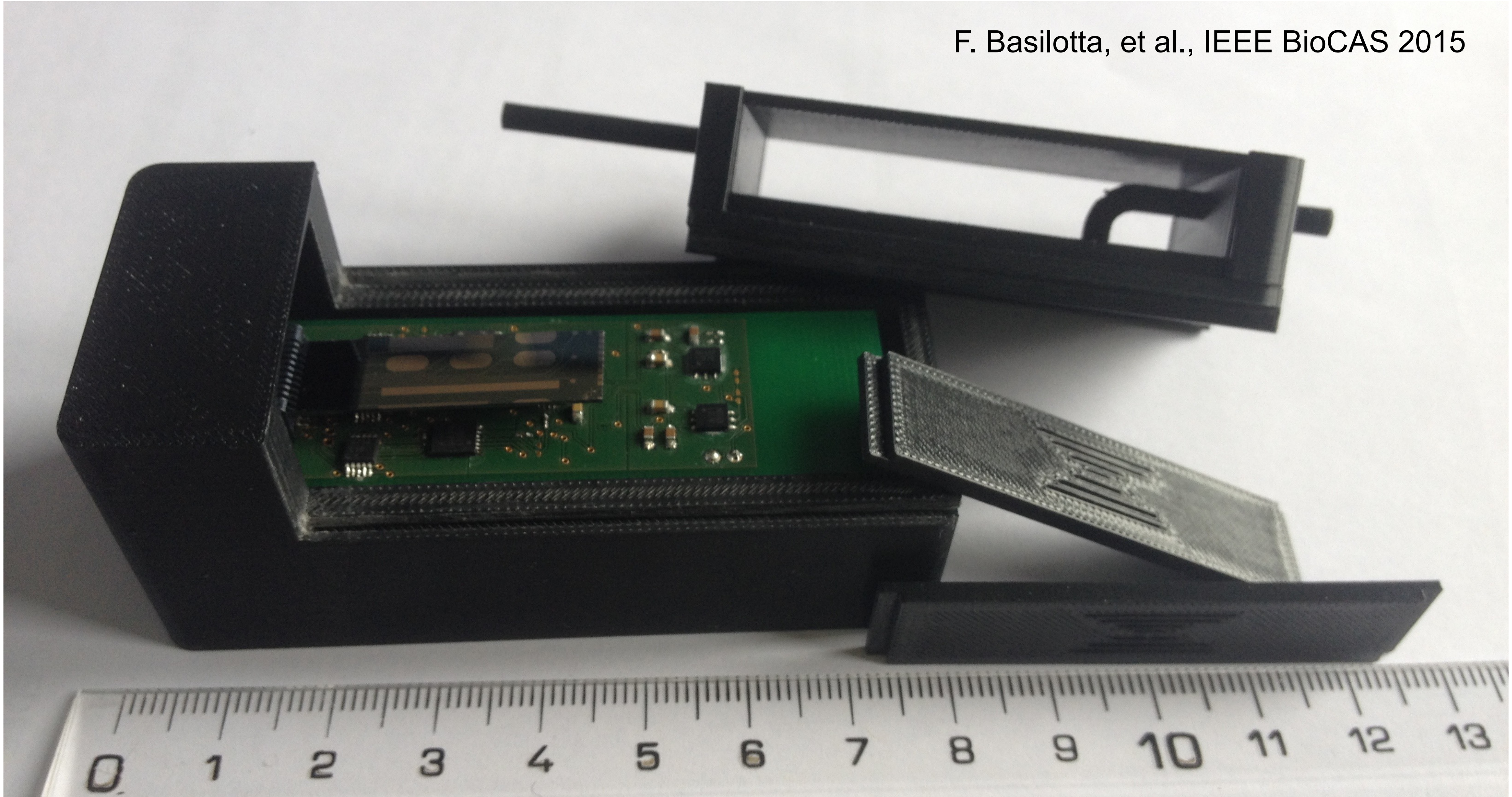
Portable: e.g., Intensive Care Units



F. Stradolini, et al., IEEE Sensors Journal 16(2016) 3163 - 3170

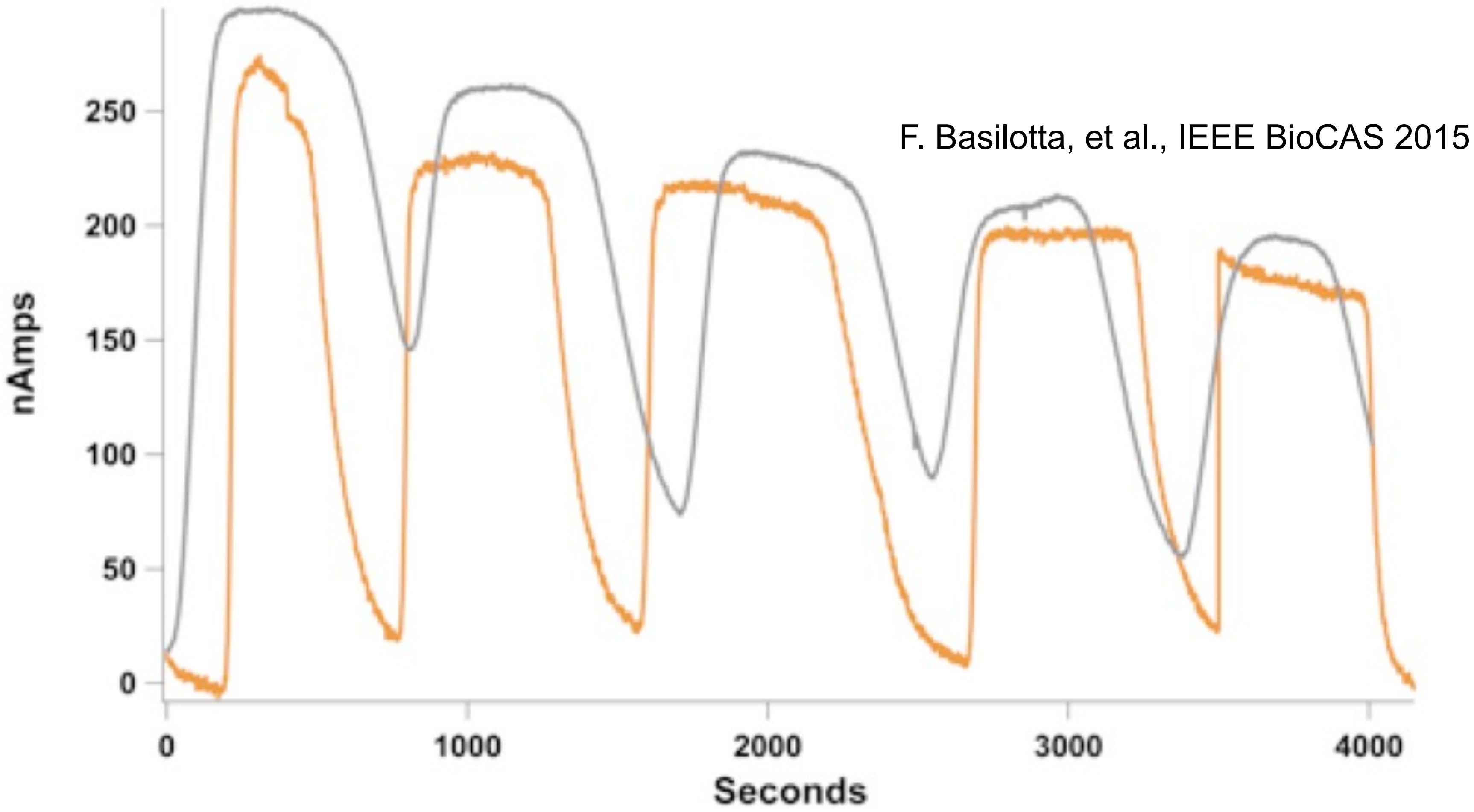
Monitoring scenario where the main parameters of the patient are continuously displayed on an Android mobile device

Monitoring in Intensive Care Units



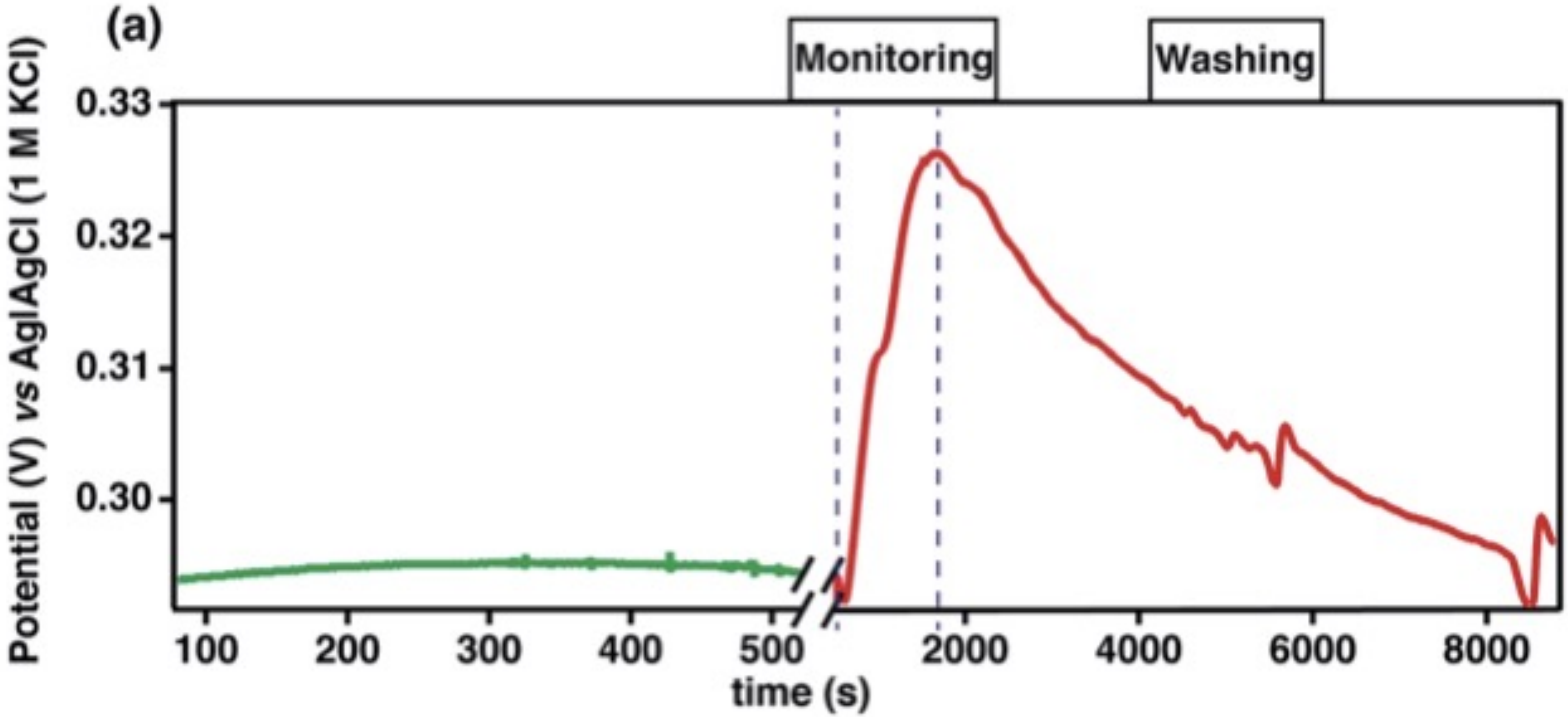
The whole system with the Android™ interface that allows connectivity too

Glucose and Lactate in flux



Chronoamperometry for glucose (grey) and lactate (orange) acquired with the fluidic system

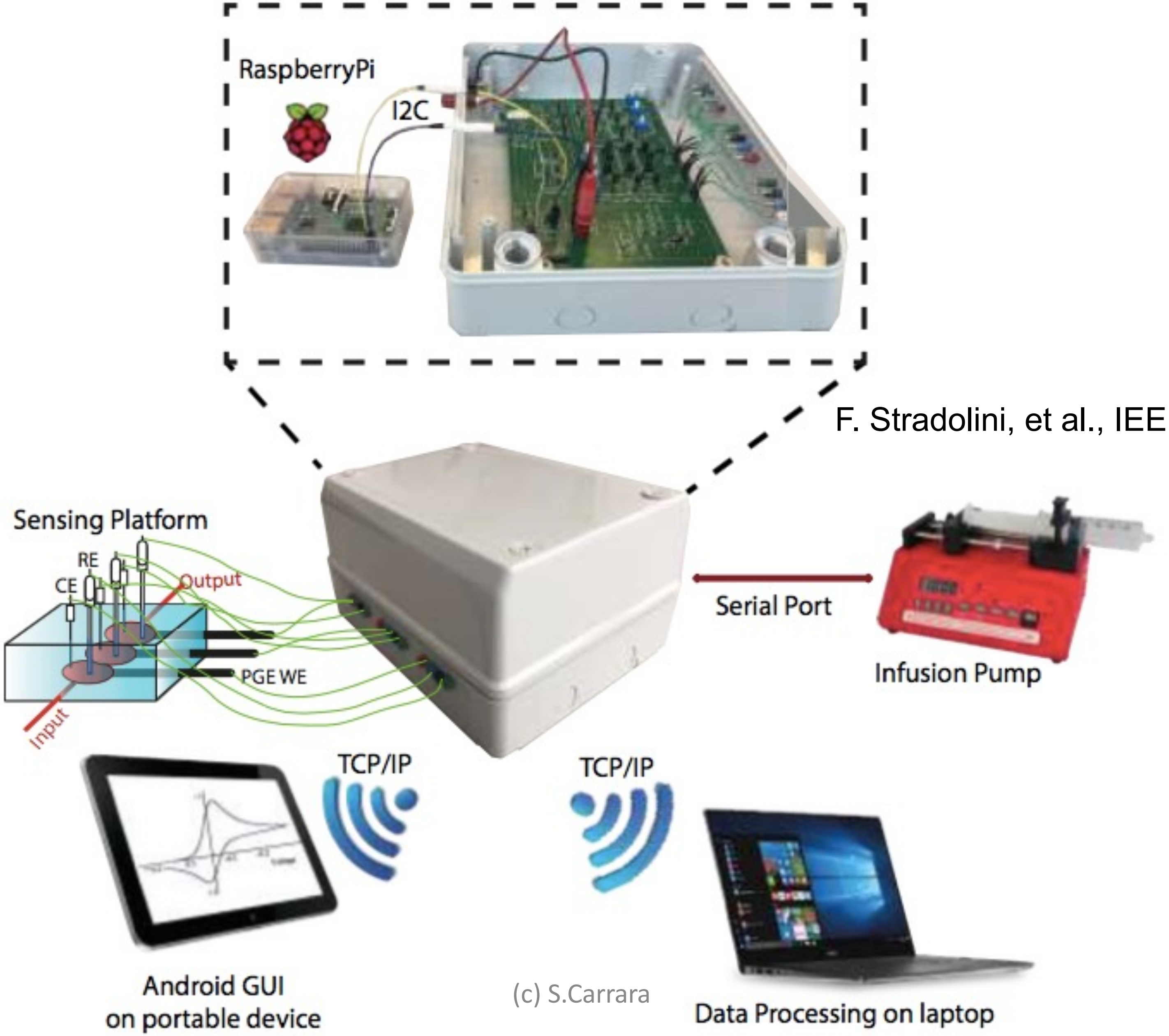
Emulation of Organs Failure



I. Taurino, et al., RSC Advances 6(2016) 40517-40526

K^+ acquisitions during cell' osmotic chock

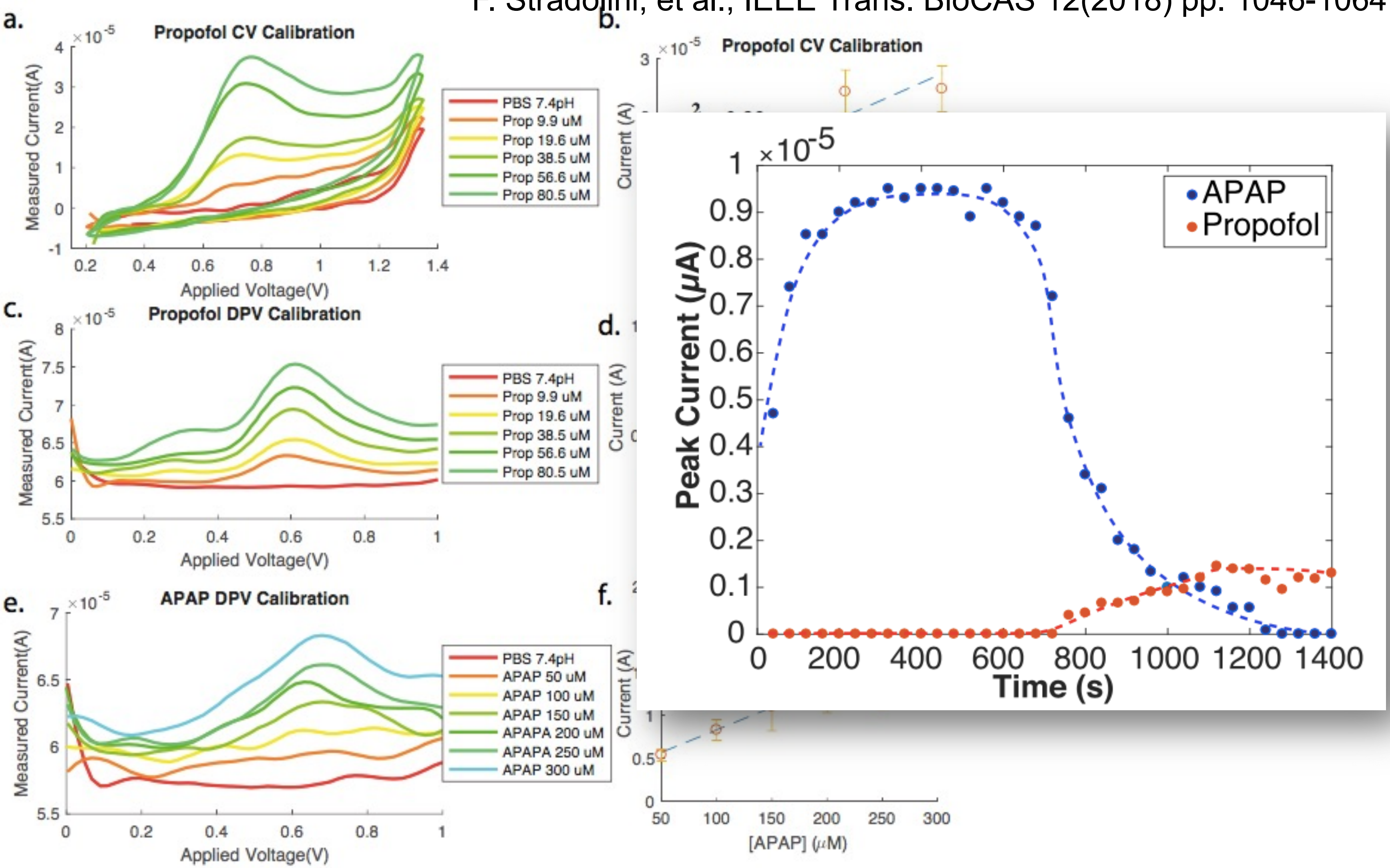
Monitoring and Injection in Surgery



F. Stradolini, et al., IEEE NGCAS 2017

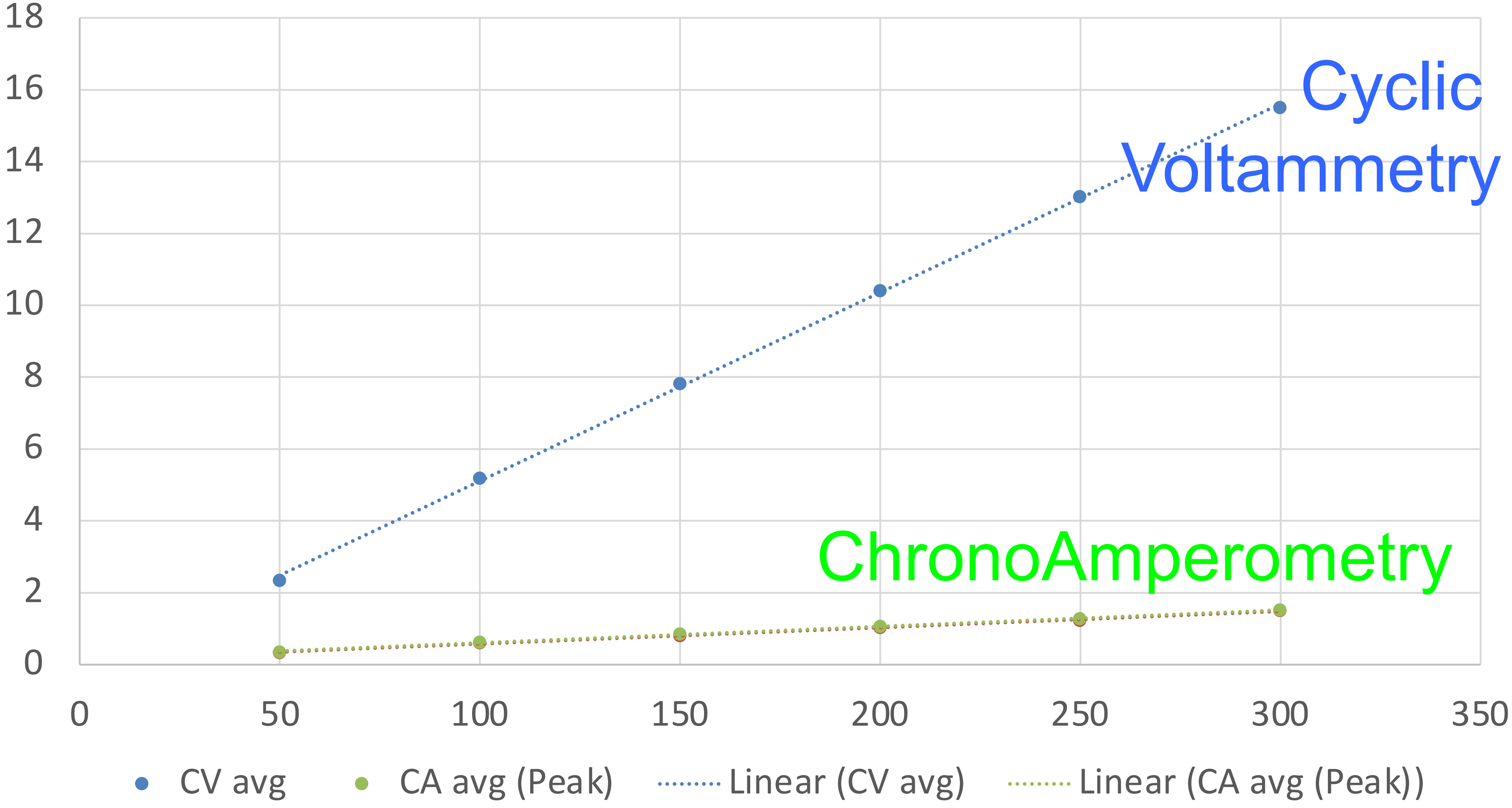
Detection of Anaesthetics

F. Stradolini, et al., IEEE Trans. BioCAS 12(2018) pp. 1046-1064



Sensors for Propofol, Paracetamol, and Midazolam have been successfully developed and tested

Chrono vs Cyclic: which best?



Paracetamol detection in
Chronoamperometry or in Cyclic Voltammetry

Lab vs Field: what change?

Stirring vs Non-Stirring

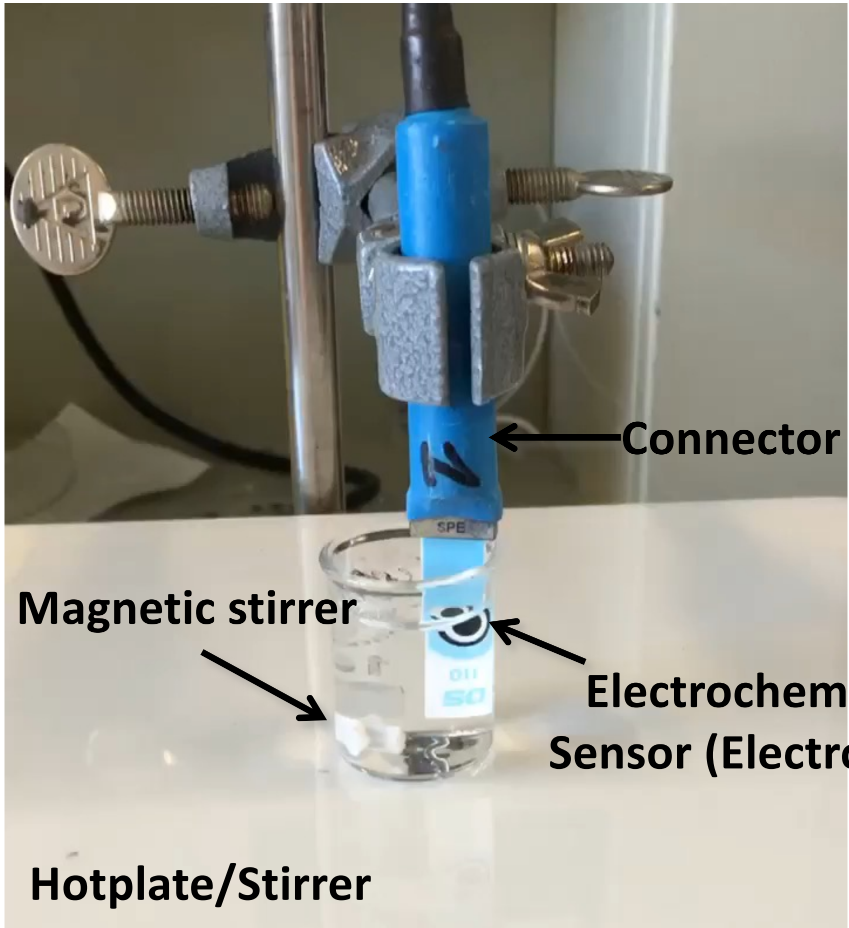
Usually, all the papers about electrochemistry we find in literature are showing data acquired with a Stirrer that assure best conditions with respect diffusion phenomena.

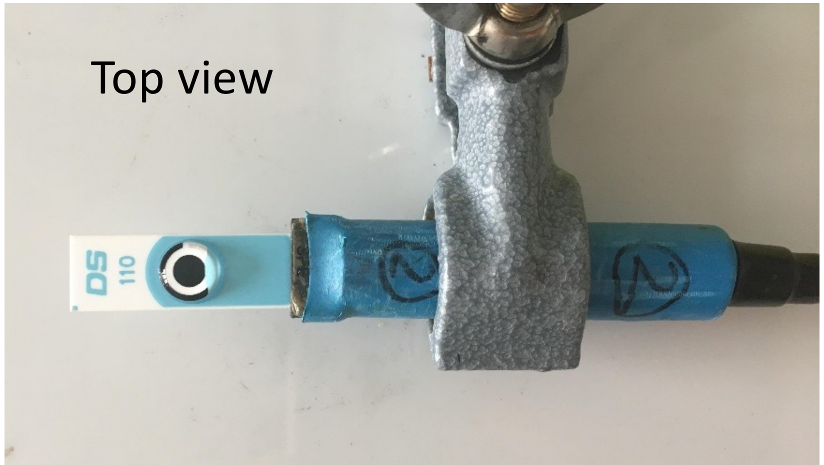
Does any conclusion we read on those papers be applied, for example, to measure on-the-skin?

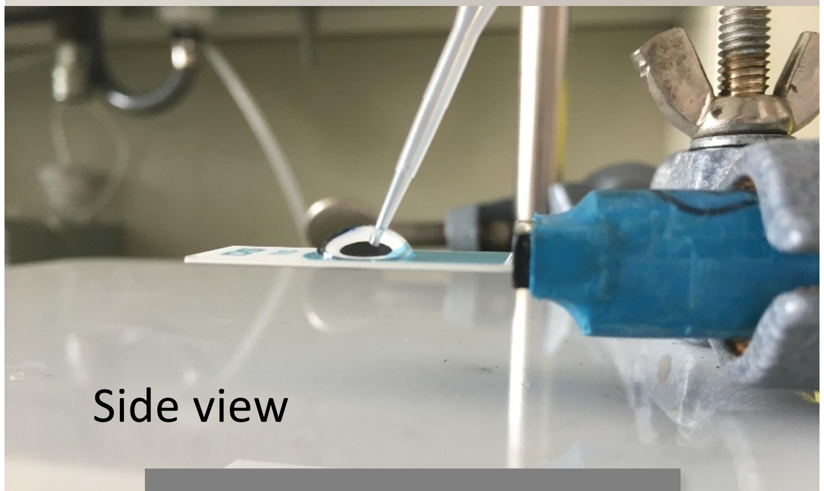
The Stirrer

Reality vs Ideality

Stirring vs non-Stirring



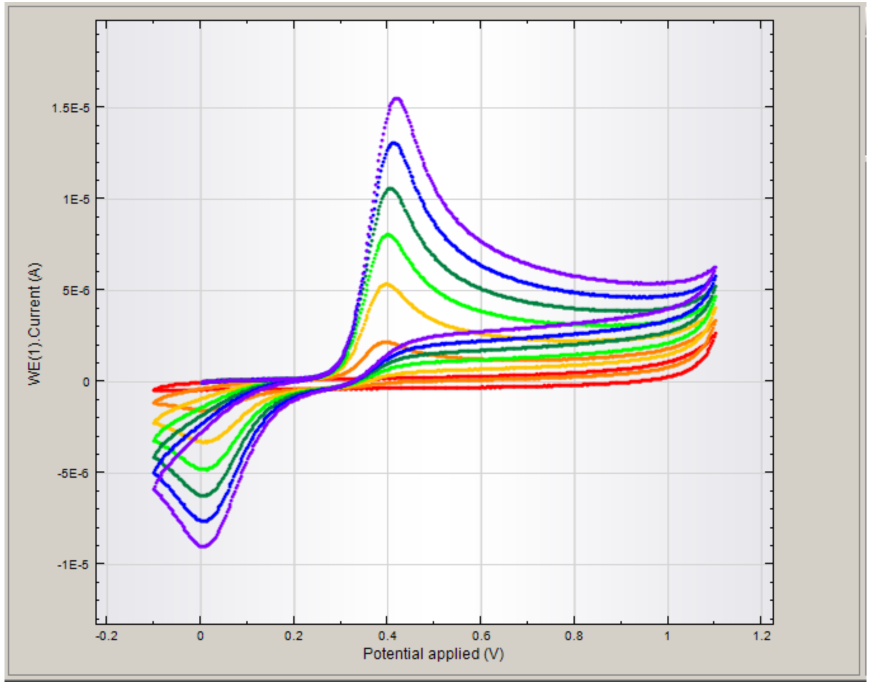


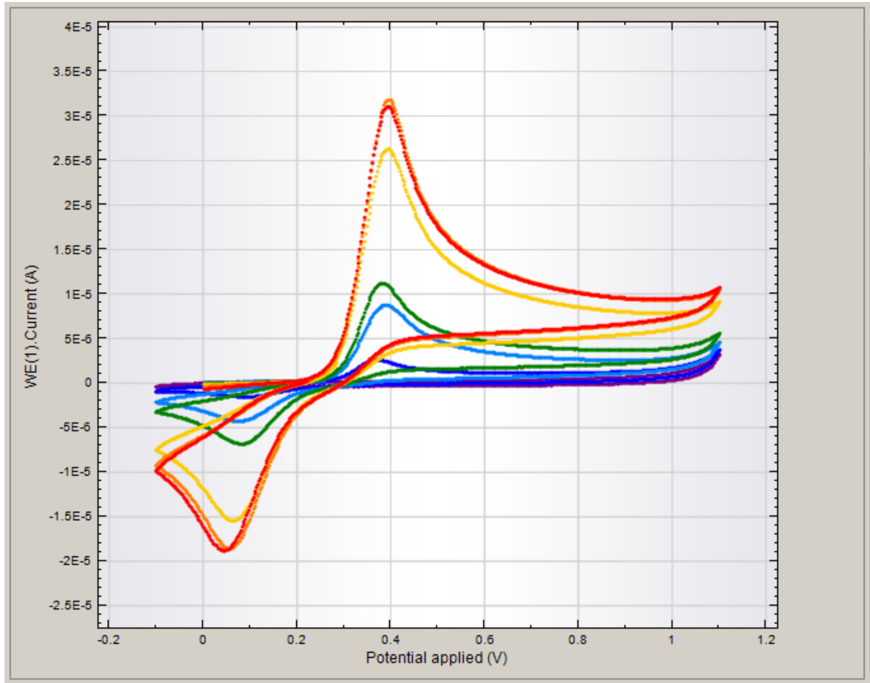


Water drop setup

Cyclic Voltammetry

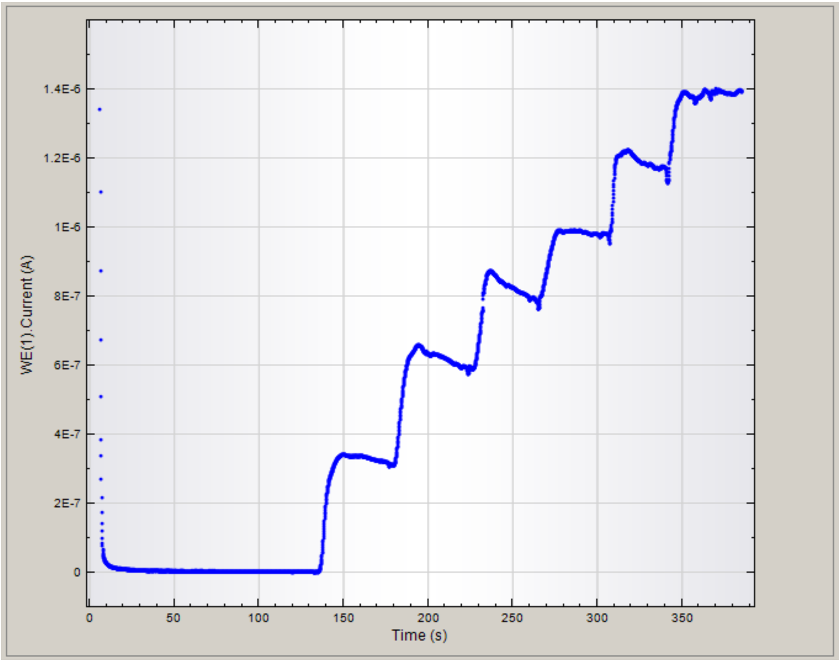
Stirring vs non-Stirring

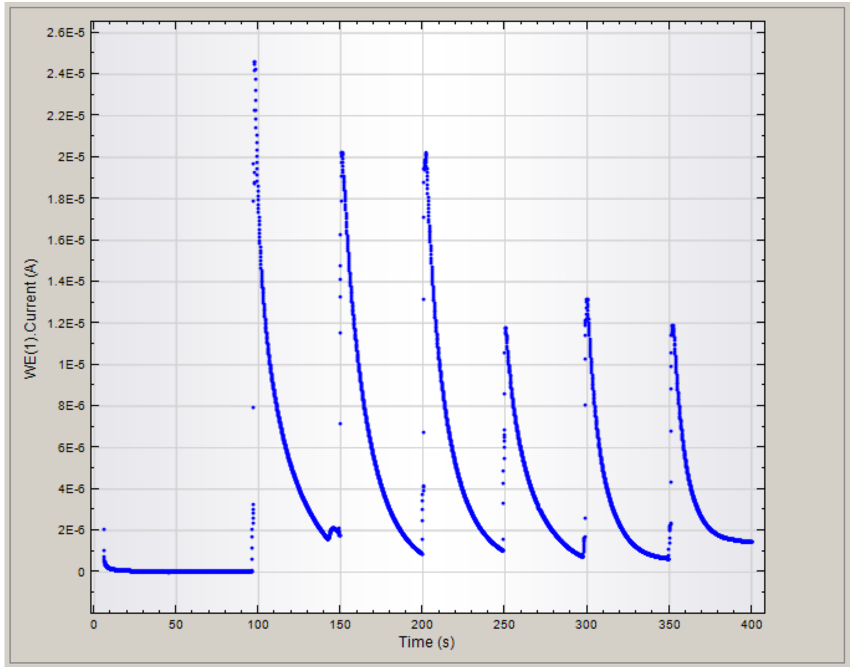




Chronoamperometry

Stirring vs non-Stirring





APAP 0-300 uM at 0.4V, acquisition each 50 sec. in both the cases

CV vs CA

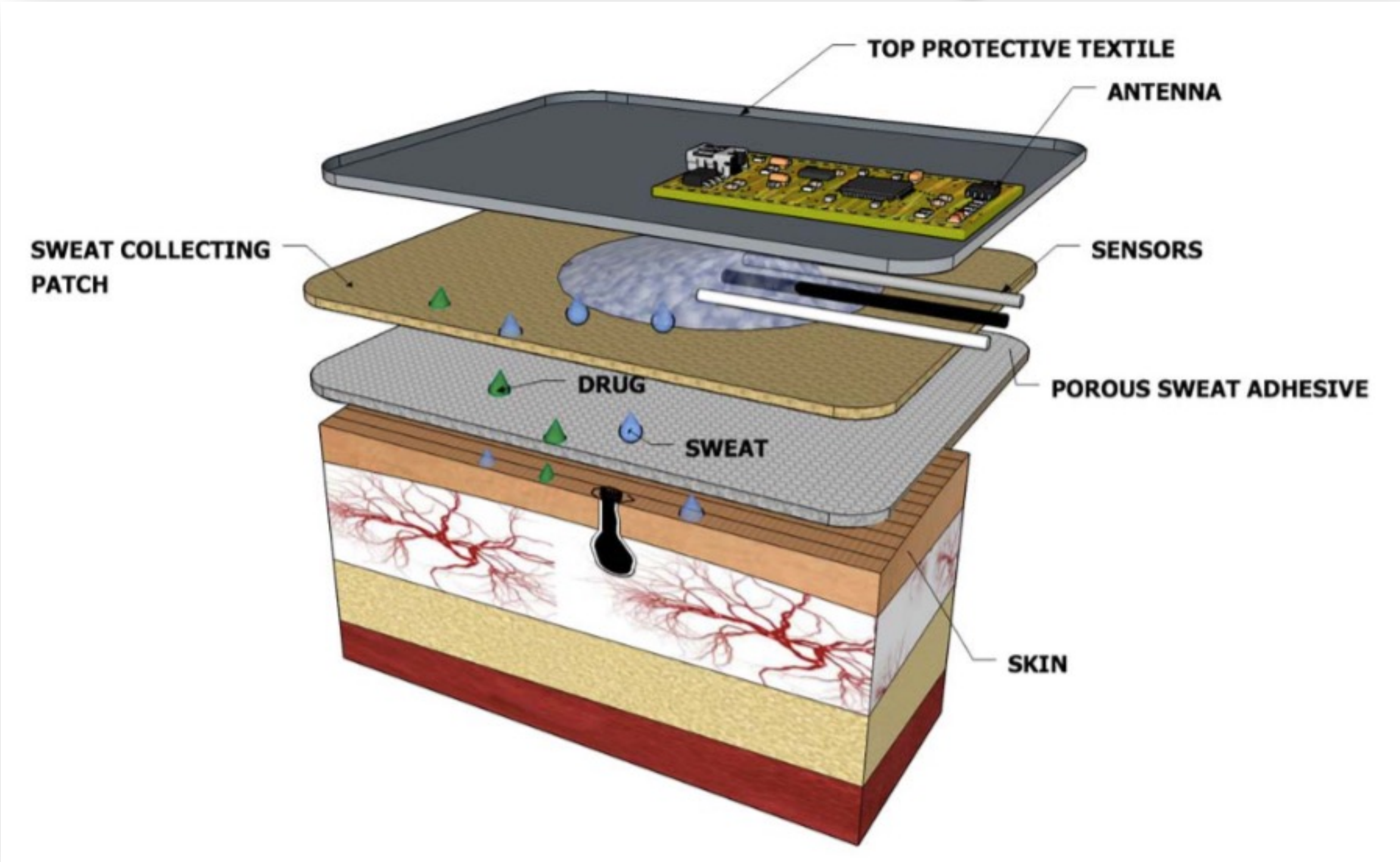
Stirring vs non-Stirring

	Stirring	Water drop
Sensitivity in CV	2.62	0.13
Sensitivity in CA	0.0045	0.012
Overall SD	low	high

In CV, both sensitivity and standard division in normal experiment are better than water drop. Therefore, the ***limitation of detection of water drop experiment is worst*** (higher) ***than normal experiment***.

In CA, result is almost the same as CV but sensitivity is higher in water drop experiment. Maybe because of the injection position.

Wearable Monitoring Devices



T.Kilic, al. et S.Carrara / ICECS 2016

Metabolites Monitoring on the skin

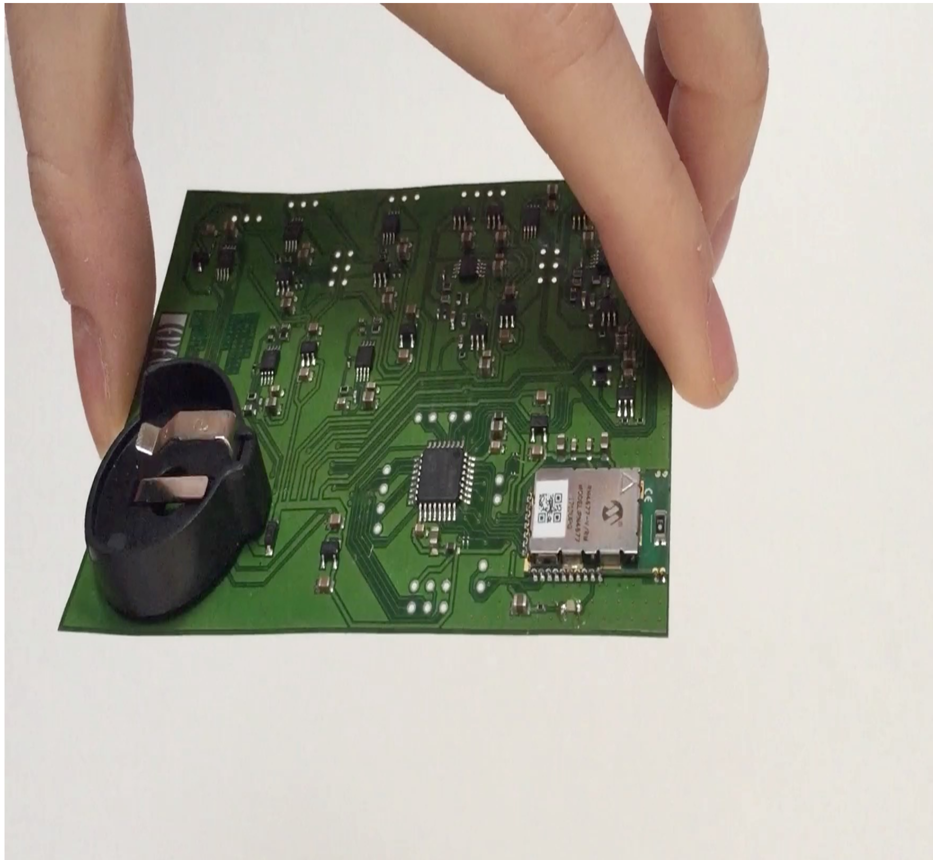
Metabolites on the skin

I.Ny Hanitra, et al., IEEE MeMeA 2018

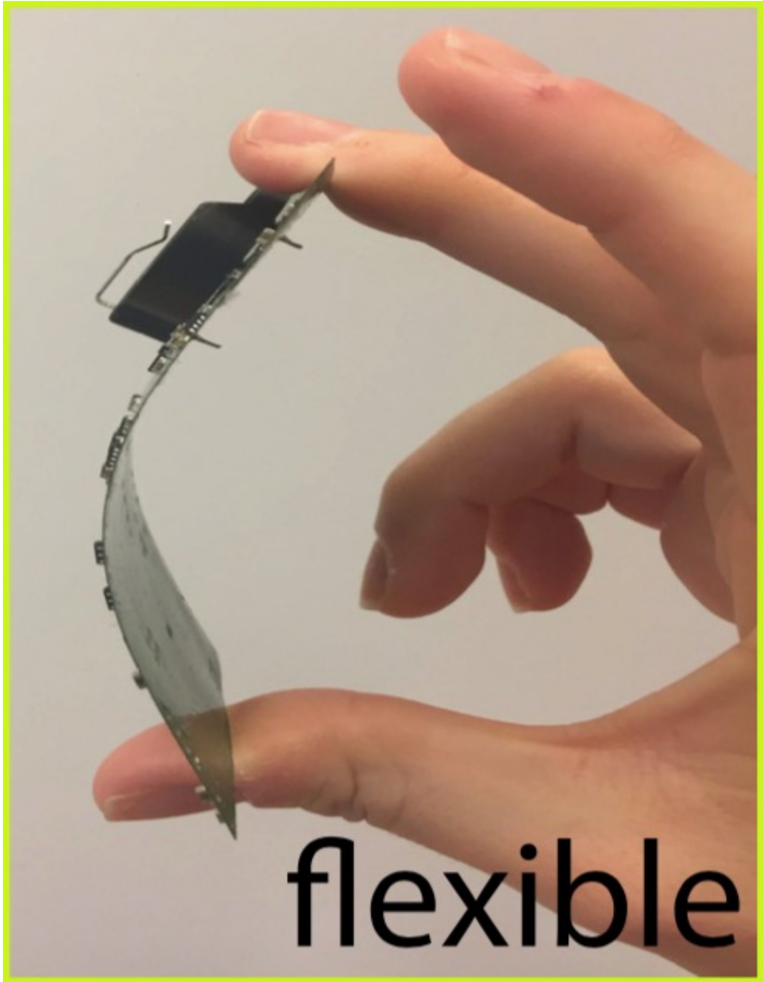
Wearable Sensors

Wearable Electronics

Flexible Electronics



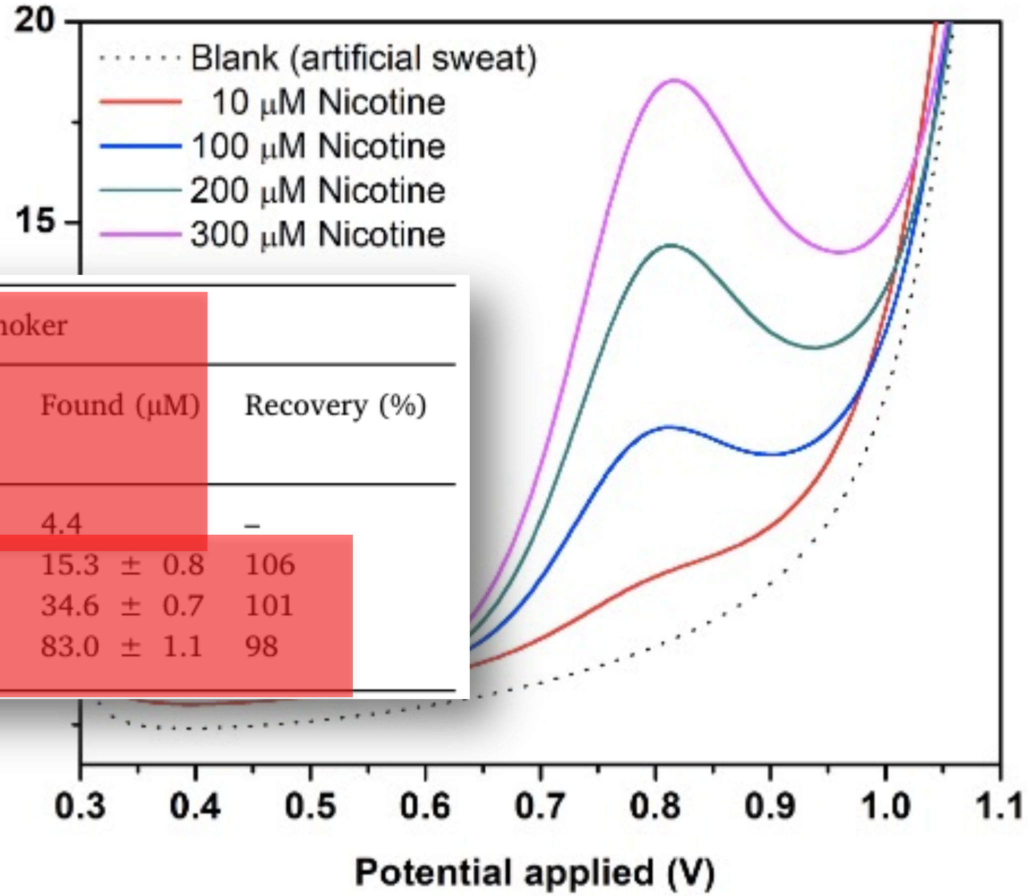
I.Ny Hanitra, et al., IEEE MeMeA 2018



The Detection system has been realized
on flexible PCB

Nicotine @ Wearable

E. Mehmeti, al. et S.Carrara / Microchemical Journal 158(2020) 105155

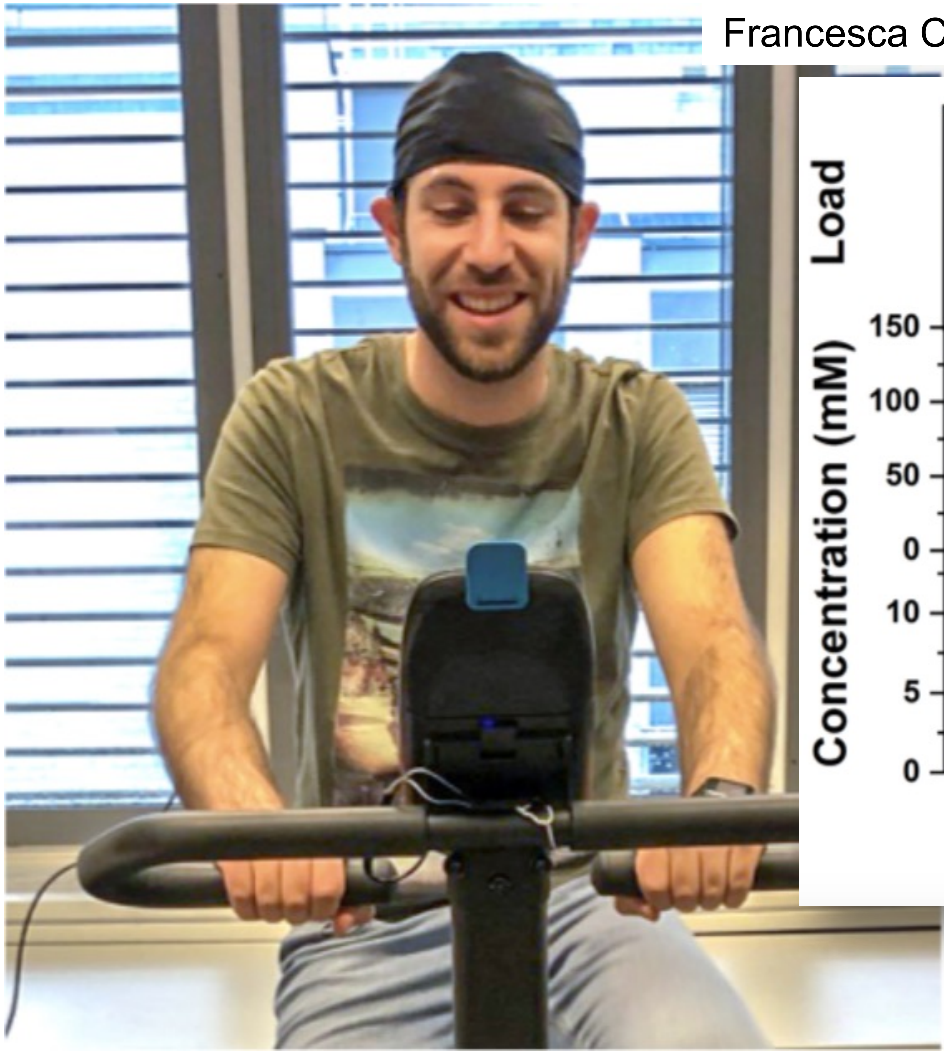


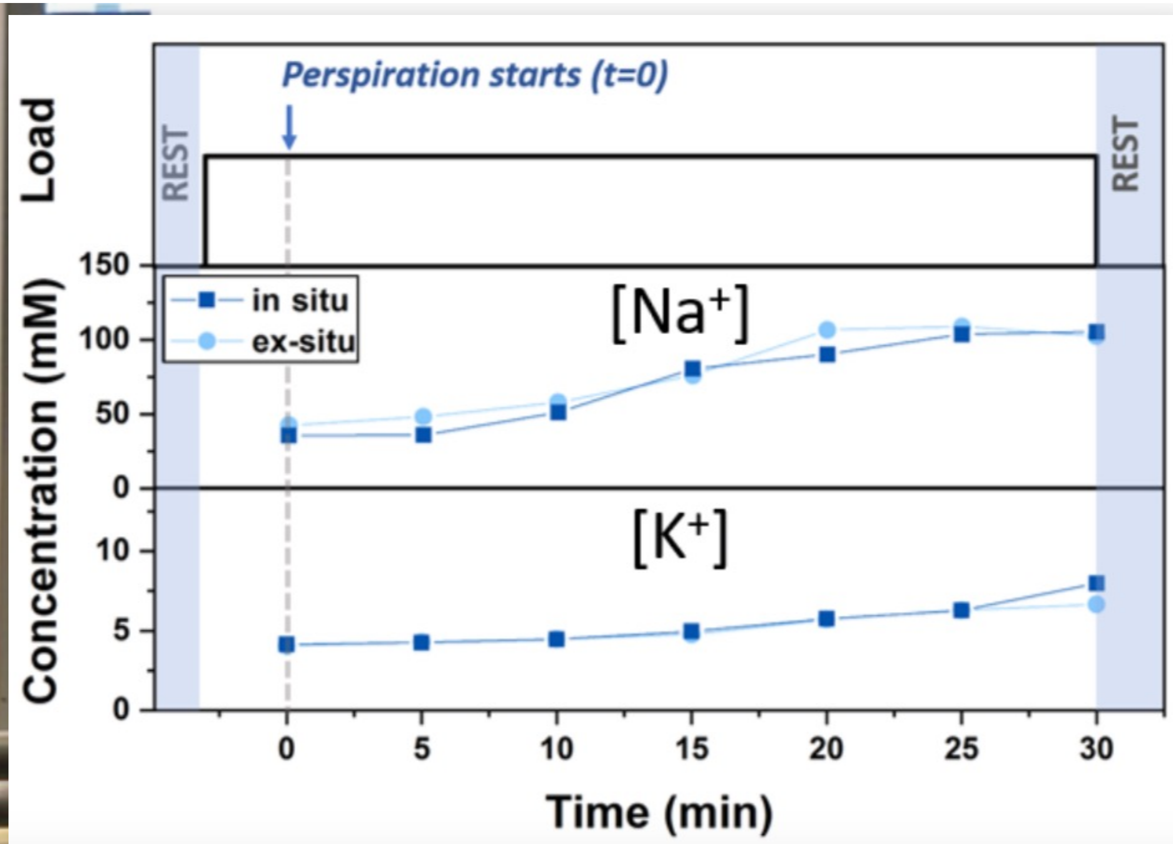
Heavy Smoker			Light Smoker		
Added (μM)	Found (μM)	Recovery (%)	Added (μM)	Found (μM)	Recovery (%)
–	23.4	–	–	4.4	–
10.0	32.3 ± 0.2	97	10.0	15.3 ± 0.8	106
30.0	54.1 ± 0.3	101	30.0	34.6 ± 0.7	101
80.0	106.3 ± 0.9	103	80.0	83.0 ± 1.1	98

The Detection of Nicotine on the skin of heavy and light smokers

Na^+ & K^+ @ Wearable

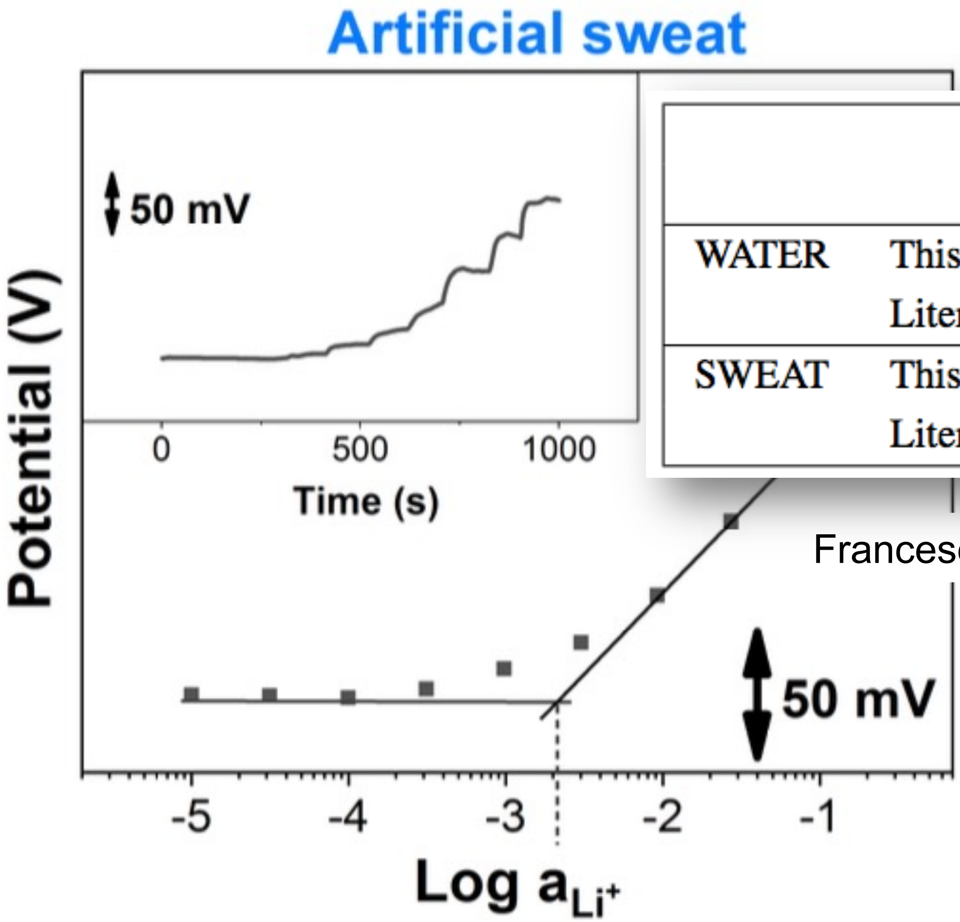
Francesca Criscuolo, al. et / Sensors And Actuator B, 2020 submitted





The Detection of ions in sportsmen

Li^+ @ Wearable

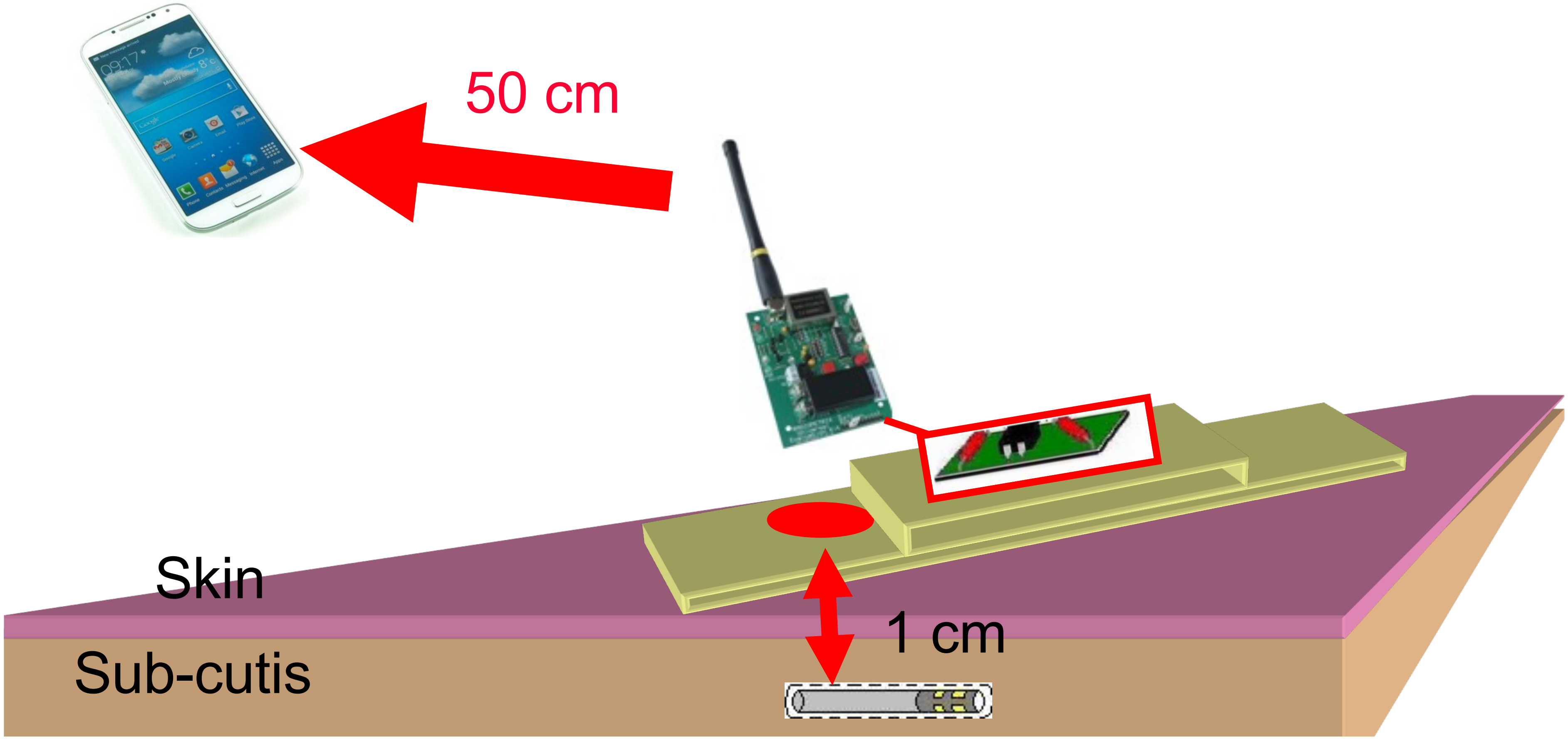


		sensitivity [mV/decade]	LOD (M)
WATER	This work (flexible)	**59.6** ± 1.5	(**5.9** ± 2.6) × 10^{-5}
	Literature (rigid) [27]	**58.7** ± 0.8	(**1.3** ± 0.4) × 10^{-5}
SWEAT	This work (flexible)	**56.8** ± 3.9	(**1.7** ± 0.6) × 10^{-3}
	Literature (rigid) [31]	**57.6** ± 2.1	(**1.4** ± 0.2) × 10^{-3}

Francesca Criscuolo, al. et / IEEE Sensors Journal, 2020 in press

Non-invasive monitoring of Lithium as Drug in Bipolar Disorder

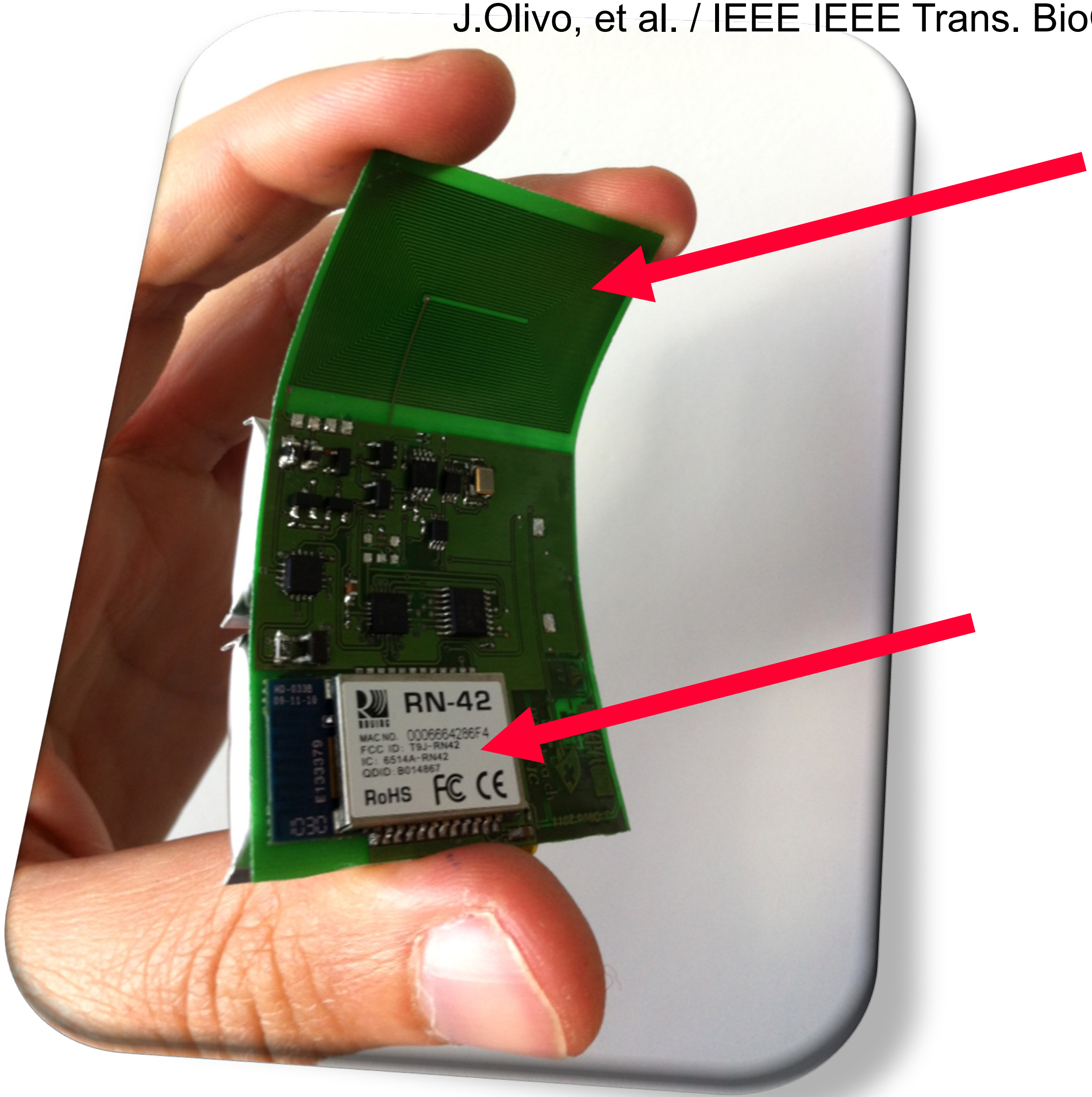
Under-the-Skin Devices & Wearable



An antenna very close to the chip is required for the remote powering

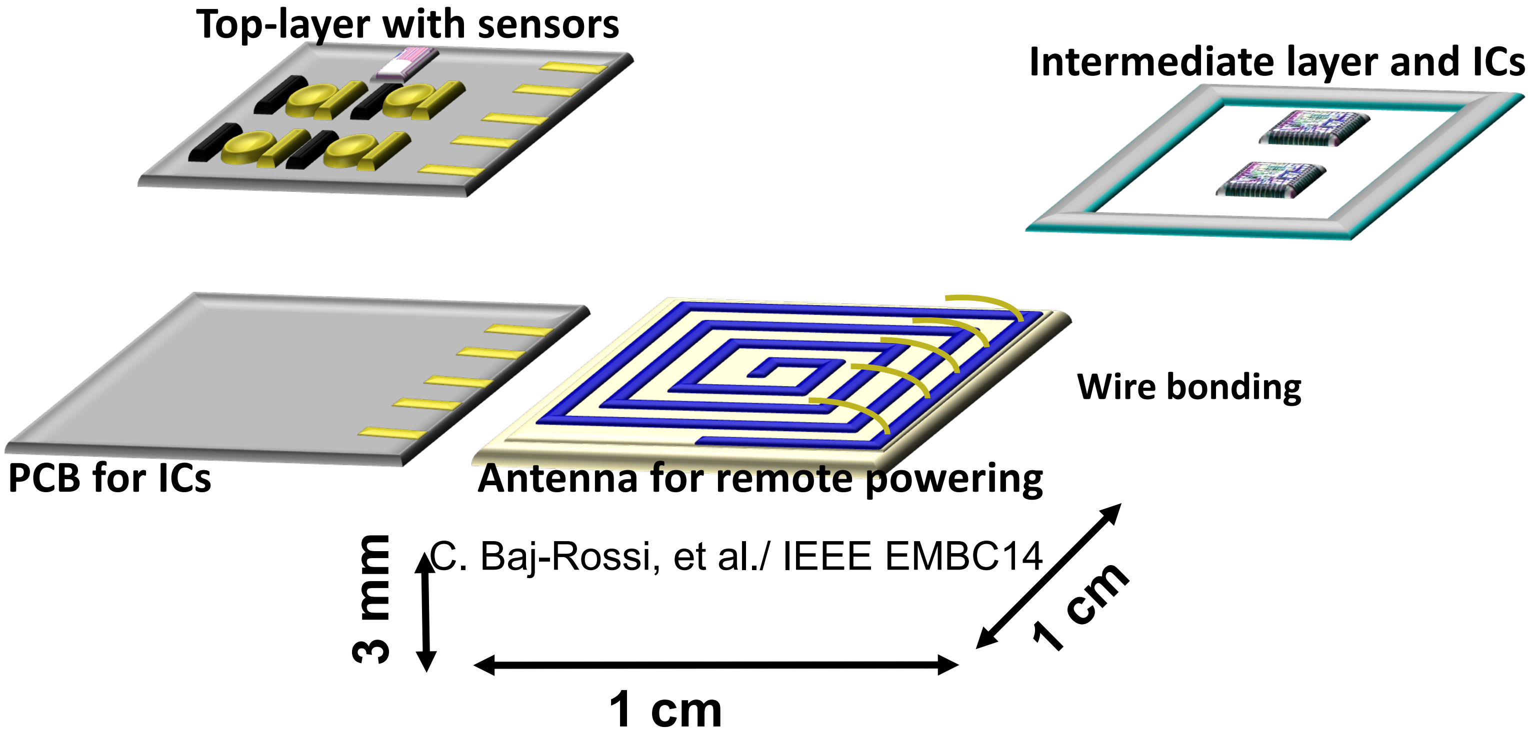
The Realized Remote Powering Patch

J.Olivo, et al. / IEEE IEEE Trans. BioCAS 7(2013) pp. 536-547



The patch has been realized with off-the-shelf components

Under-the-Skin Device: button' size



C. Baj-Rossi, et al./ IEEE EMBC14

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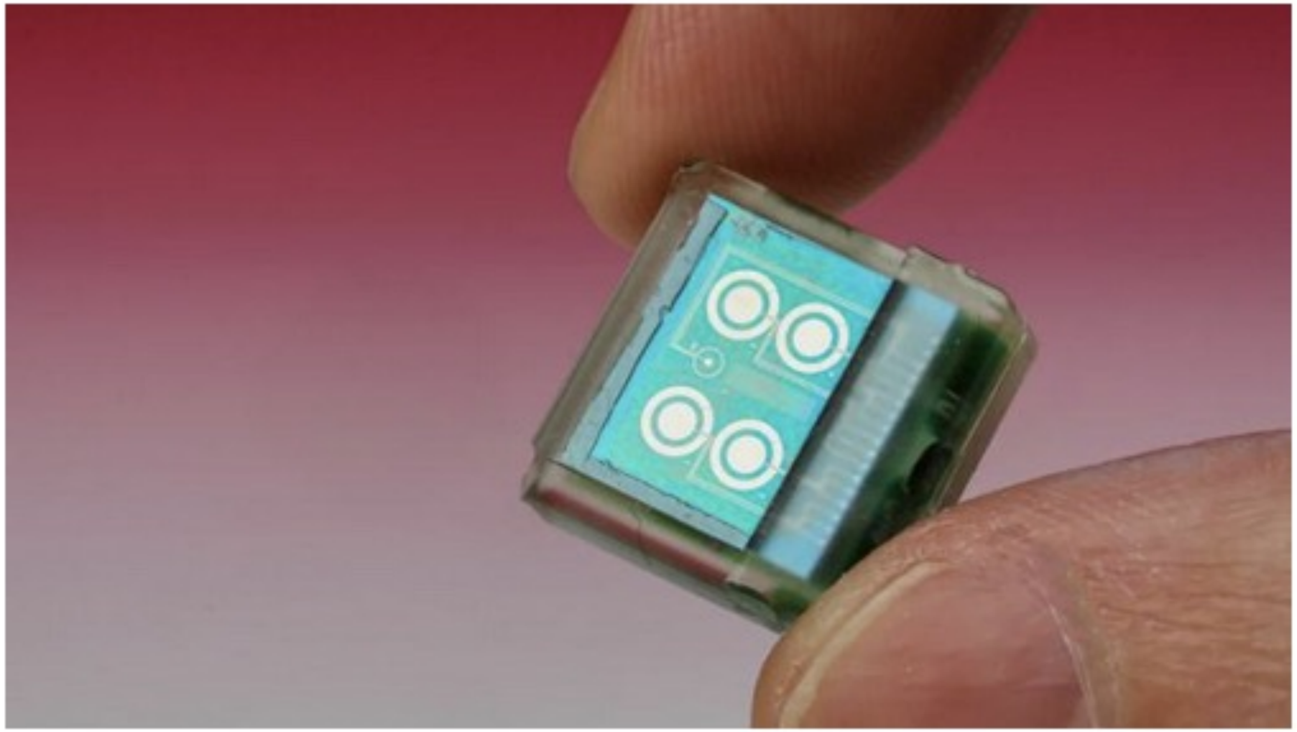
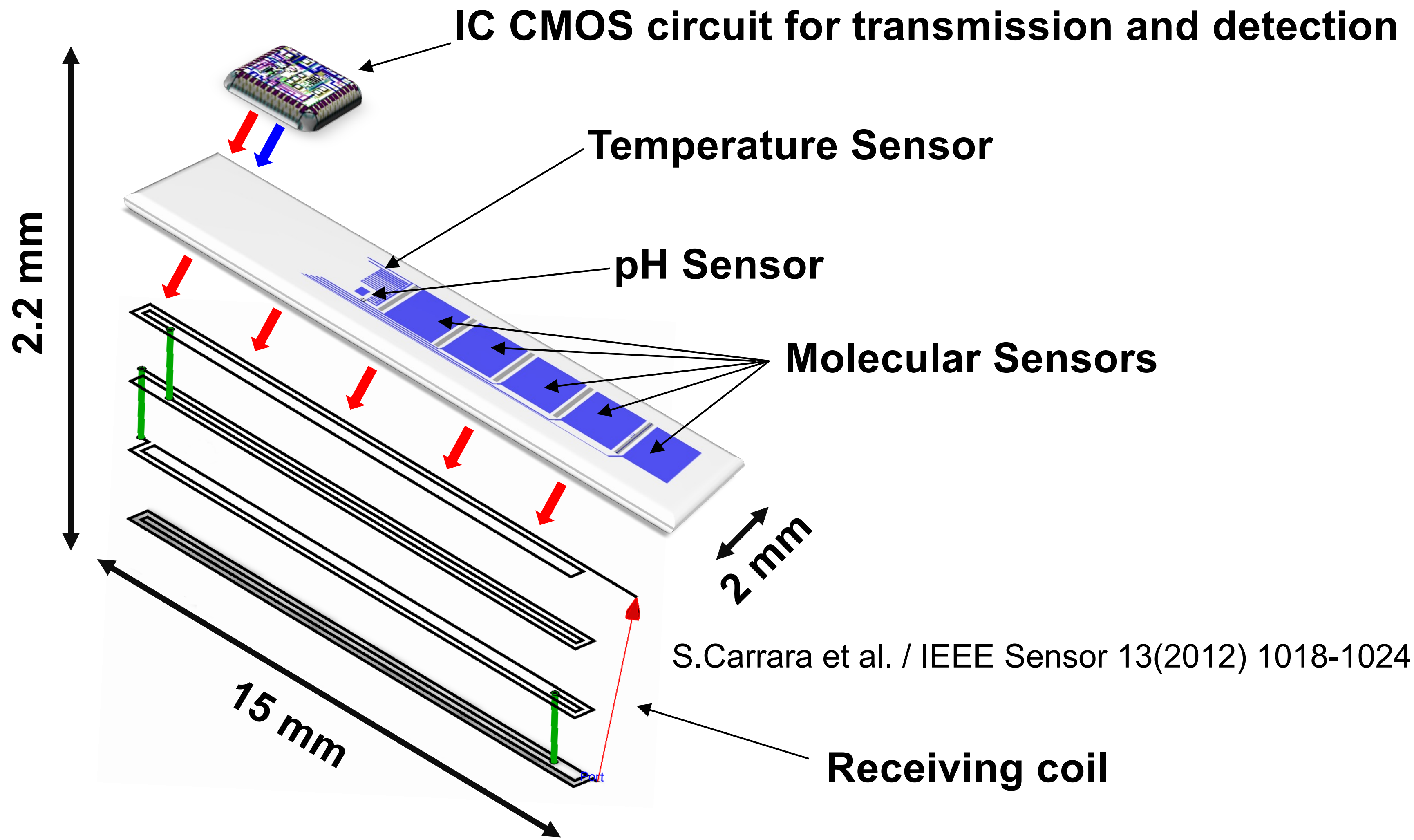


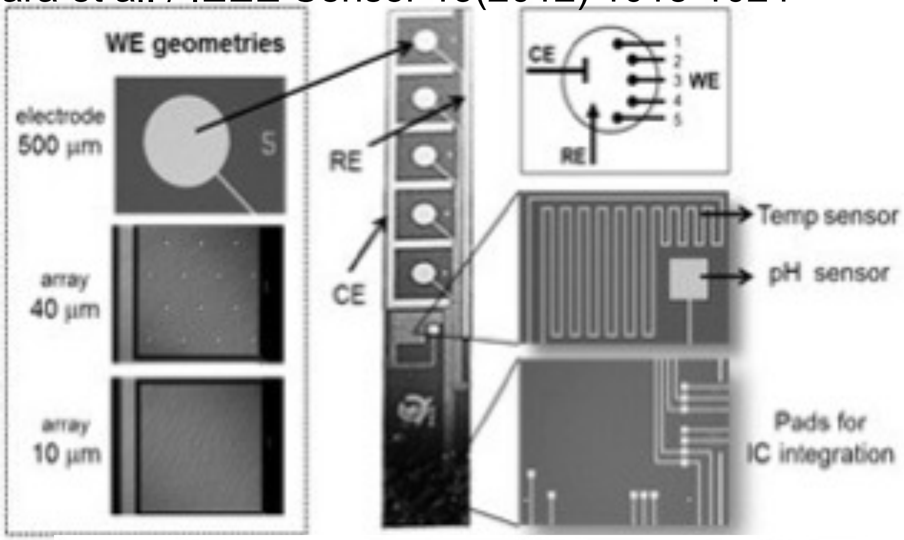
Under-the-Skin Device: needle' size

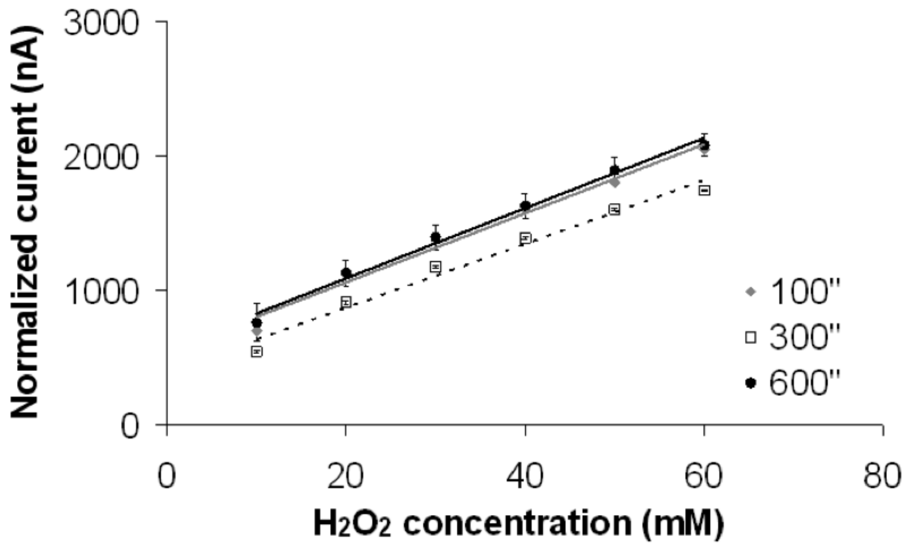


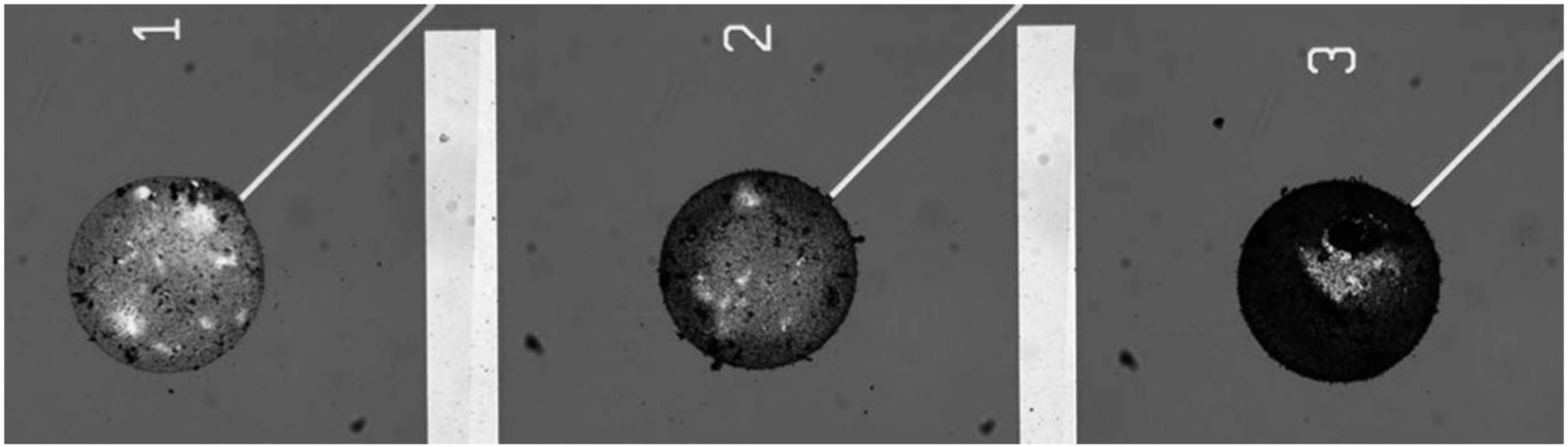
Minimally invasive with size within that of a surgery needle

Nano-Bio-Sensors by Electrodeposition

S.Carrara et al. / IEEE Sensor 13(2012) 1018-1024

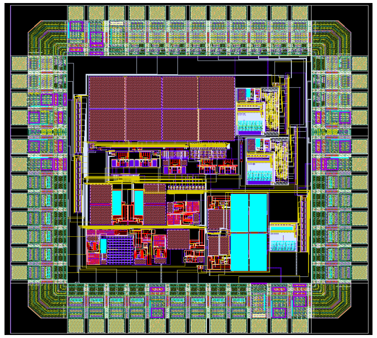




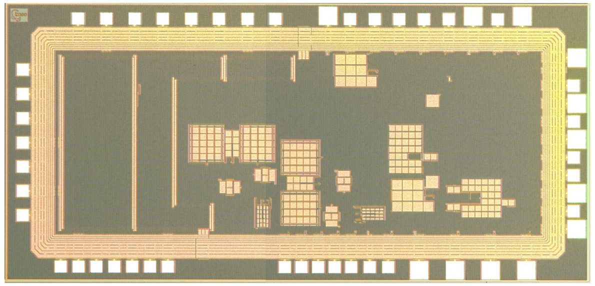


Different amount by different deposition times

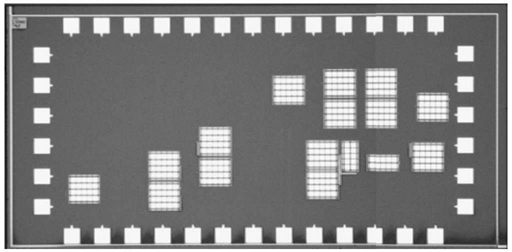
Some Realized CMOS Frontends



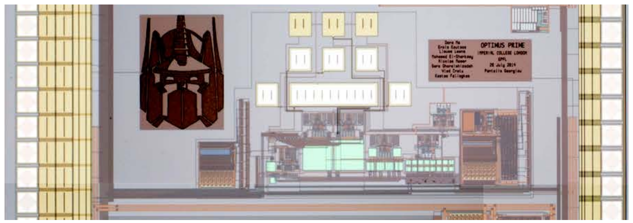
Chip # 1 UMC 0.18
IEEE Trans. BioCAS
8(2014) pp. 891-898



Chip # 3 UMC 0.18
IEEE Trans. BioCAS
10(2016) pp. 955-962



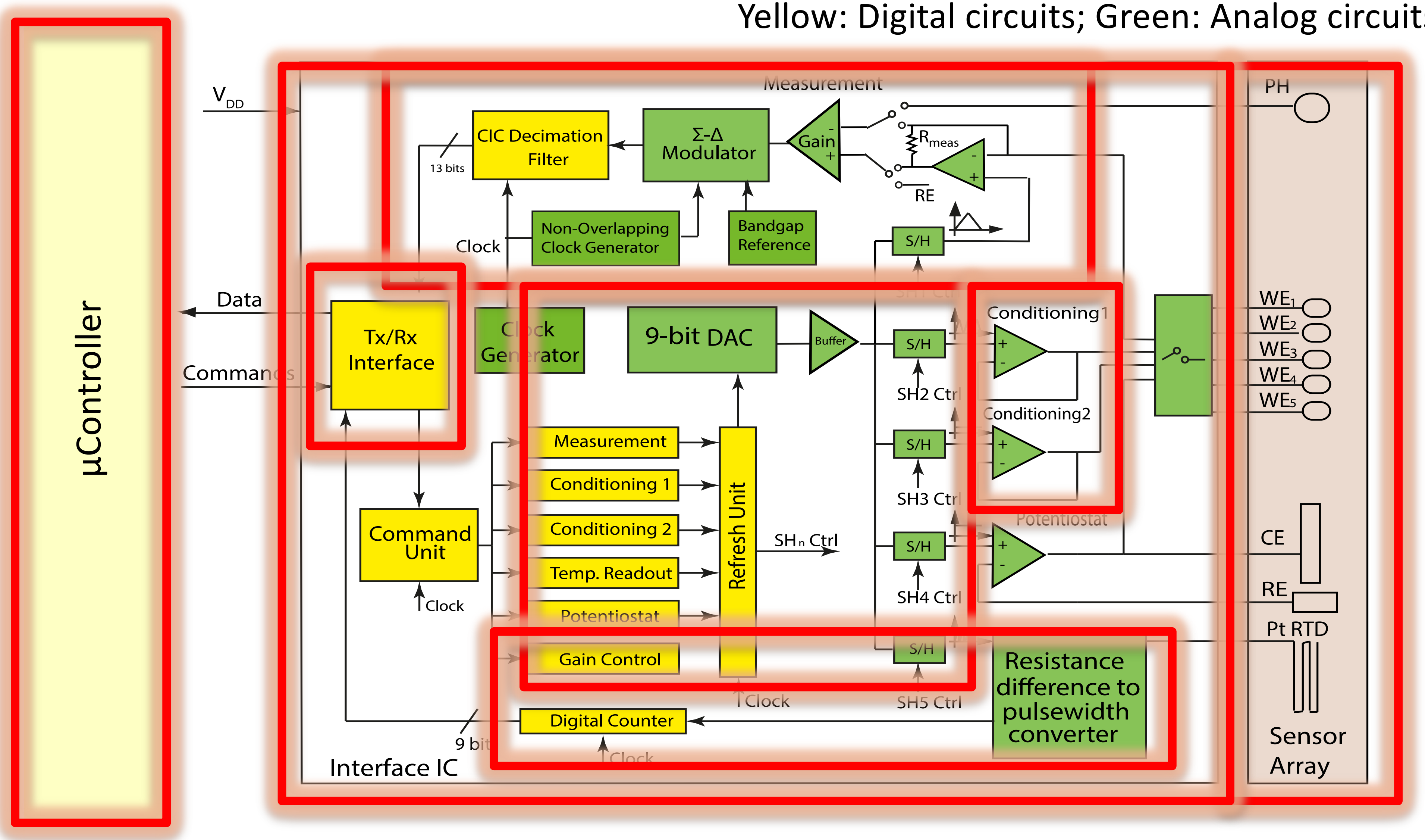
Chip # 2 UMC 0.18
IEEE Sensors Journal
15(2015) pp. 417-424



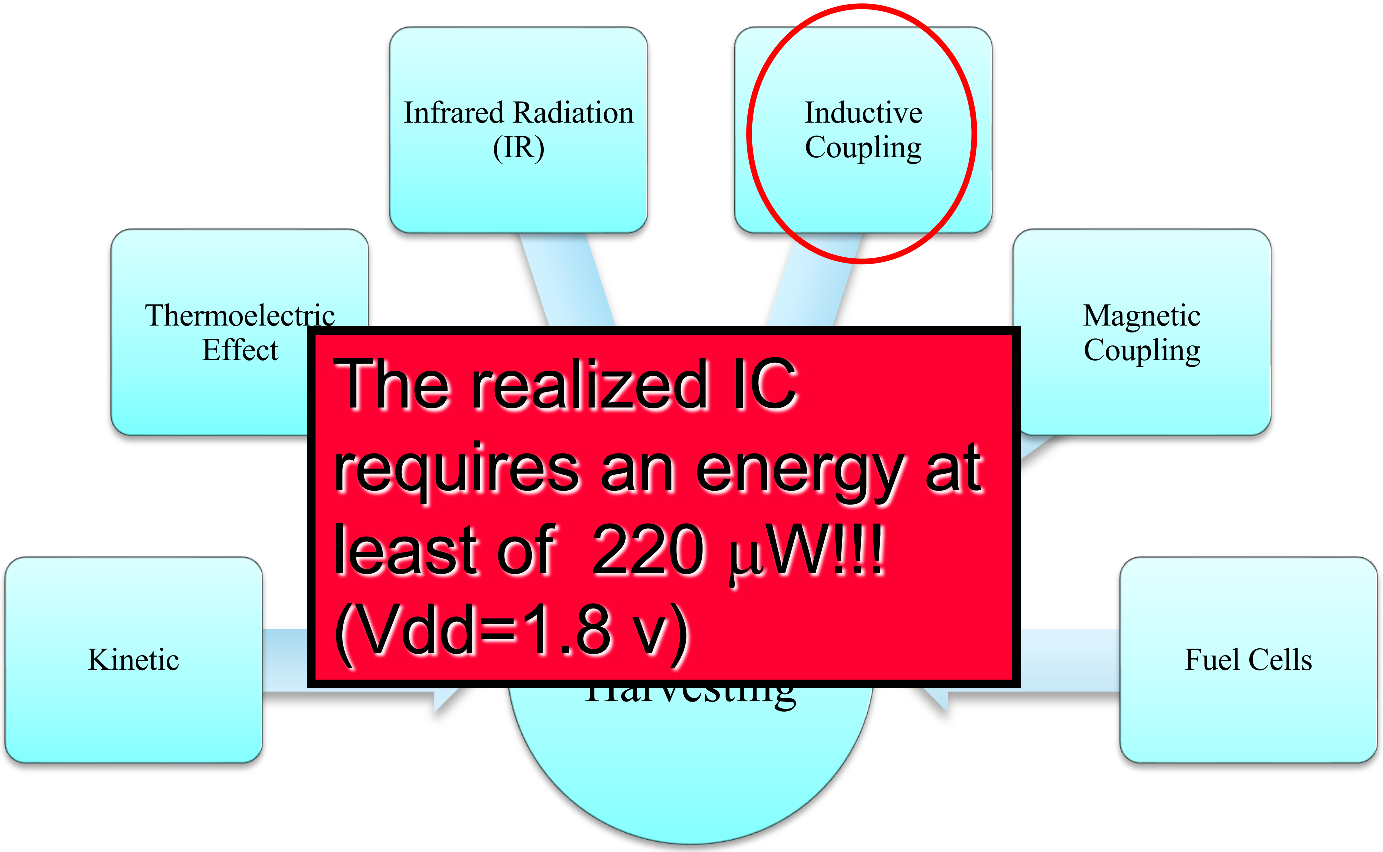
Chip # 4 AMS 0.35
IEEE Trans. BioCAS
11(2017) pp. 1148-1159

The IC Frontend

Yellow: Digital circuits; Green: Analog circuits



Energy Scavenging Strategies



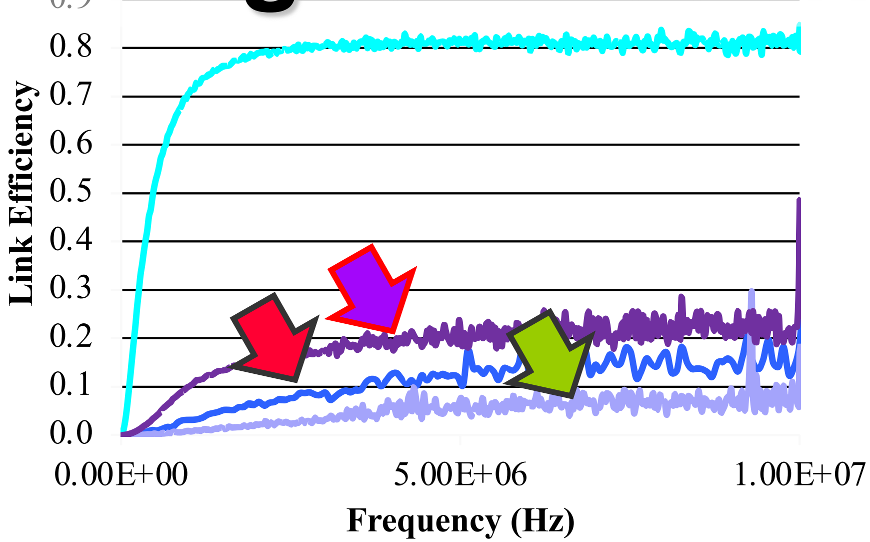
Inductive Coupling

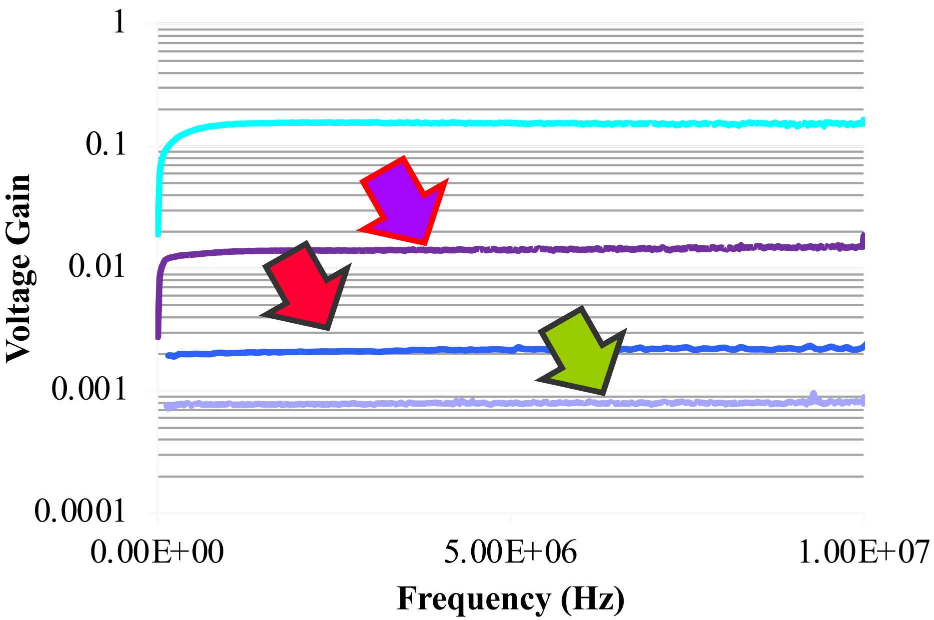
Ref.	Coil Area (λ = 10 mm²)	Carrier Frequency	Data Transmission	Bit Rate	Power Consumption	Efficiency	Distance	Measurement Site	Implantation Site
[8]	Tx: 7.8 λ Rx: 1.7 λ	4 MHz	twd Int.: PWM-ASK twd Ext.: ASK	twd Ext.:125 kbps	10 mW		5 mm	Air	Neural Recording System
[9]	Tx: 196.3 λ Rx: 31.4 λ	4 MHz	twd Ext.: LSK	5 kbps	6 mW		25 mm	Water Bearing Colloids	Various
[10]	Tx: 13200 λ Rx: 25.2 λ	1 MHz			150 mW	1% (min)	205 mm	PVC Barrel	Stomach
[11]	Tx: 184.9 λ Rx: 10 λ	1 MHz			10 mW	18.9% (max)	5 mm	Air	Cerebral Cortex
[12]	Tx: 282.7 λ Rx: 31.4 λ	0.7 MHz	twd Int.: ASK twd Ext.: LSK	twd Int.: 60 kbps twd Ext.: 60 kbps	50 mW	36% (max)	30 mm		Orthopaedic Implant
[13]	Tx: 31.4 λ Rx: 5 λ	10 MHz	twd Int.: ASK twd Ext.: BPSK	twd Int.: 120 kbps twd Ext.: 234 kbps	22.5 mW in vitro ≈ 19 mW in vivo		15 mm	Rabbit	Muscles
[14]	Tx: 196.3 λ Rx: 3.5 λ	5 MHz	twd Int.: OOK	100 kbps	5 mW		40 mm		Neural Stimulator
[15]	≈ Rx: 112.5 λ	6.78 MHz	twd Int.: OOK twd Ext.: LSK	twd Ext.:200 kbps	120 mW	20% (max)	25 mm	Dog Shoulder	Muscolar Stimulator
[18]	Tx: 40 λ Rx: 0.4 λ	915 MHz			0.14 mW	0.06%	15 mm	Bovine Muscle	Various

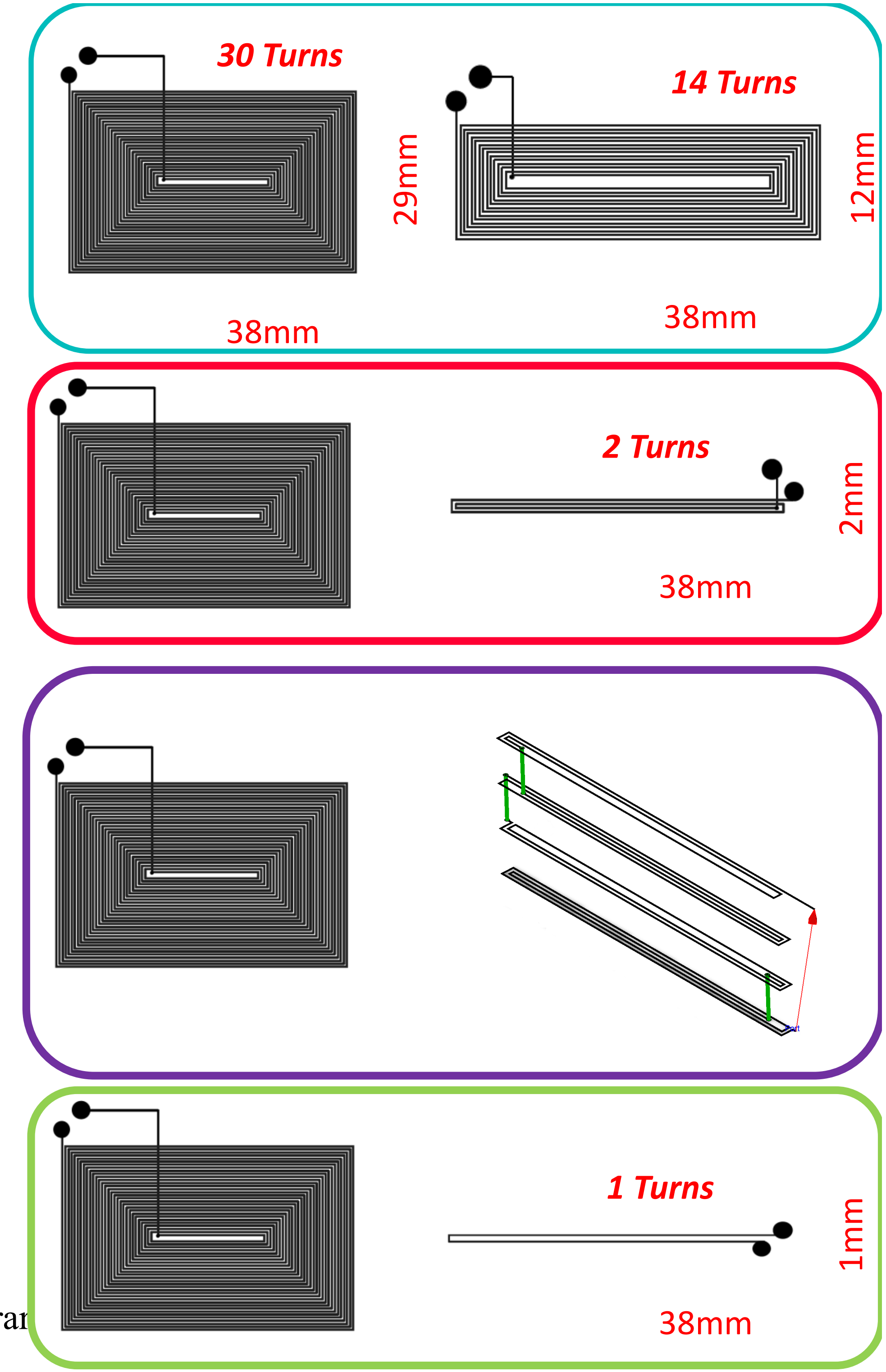
!

[8] T.Akin et al., "A wireless implantable multichannel digital neural recording system for a micromachined sieve electrode", *IEEE J. Solid-State Circ.*, vol.33, pp. 109-118, Jan 1998
[9] C.Sauer et al., "Power Harvesting and Telemetry in CMOS for Implanted Devices", *IEEE Trans on Circuits and Systems*, vol.52, n.12, pp.2605-2618, 2005
[10] B. Lenaerts et. al., "An inductive power link for a wireless endoscope", *Biosensors and Bioelectronics*, vol.22, pp. 1390-1395, 2007
[11] K.M. Silay et. al., "Load Optimization of an Inductive Power Link for Remote Powering of Biomedical Implants", *IEEE Proc. of International Symposium on Circuits and Systems 2009*, pp. 533-536, May 2009.
[12] B. Lenaerts et. al., "An inductive power system with integrated bi-directional data-transmission", *Sensors and Actuators A*, vol. 115, pp.221-229, 2004
[13] J. Parramon et al., "ASIC-based batteryless implantable telemetry microsystem for recording purposes", *Eng. in Med. and Bio. Soc.*, In *Proc. of the 19th Annual Int. Conf.*, vol.5, pp. 2225-2228, 1997.
[14] G. Gudnason et al., "A Chip for an Implantable Neural Stimulator", *Analog Integrated Circuits and Signal Processing*, vol.22, pp.81-89, 1999
[15] B. Smith et al., "An externally powered, multichannel, implantable stimulator-telemeter for control of paralyzed muscle", *IEEE Trans. on Biomed. Eng.*, vol.45, pp.463-475, 1998
[18] A.S.Y. Poon et al., "A mm-sized Implantable Power Receiver with Adaptative Link Compensation", Stanford University

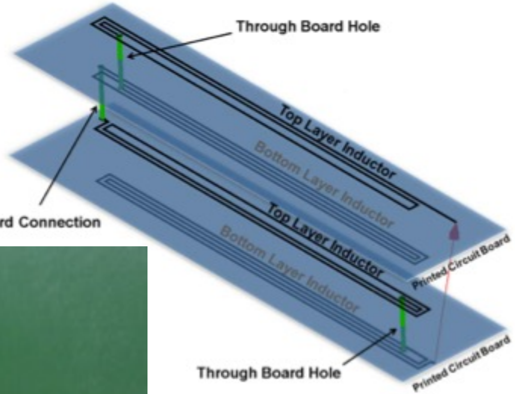
Measures on the Designed Inductors



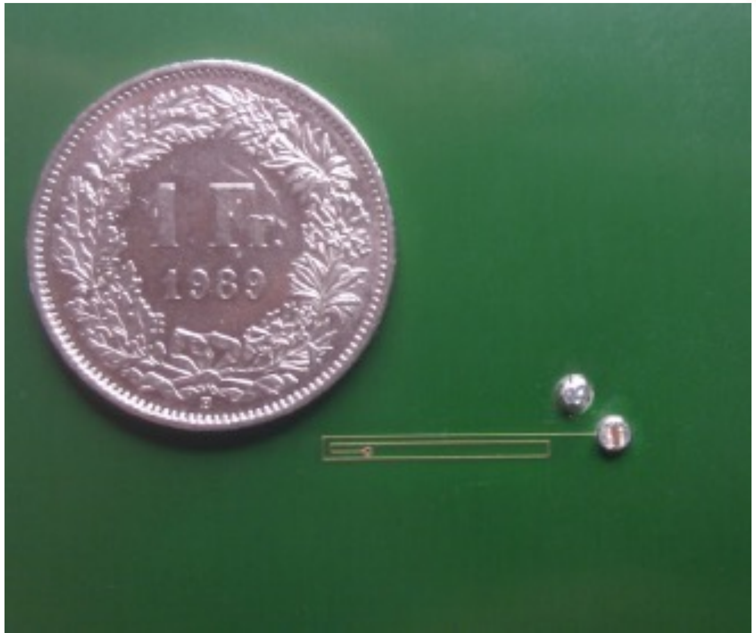




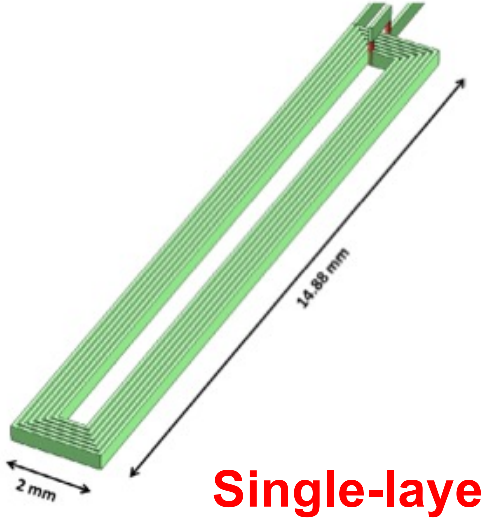
The Tiny Spiral Inductors



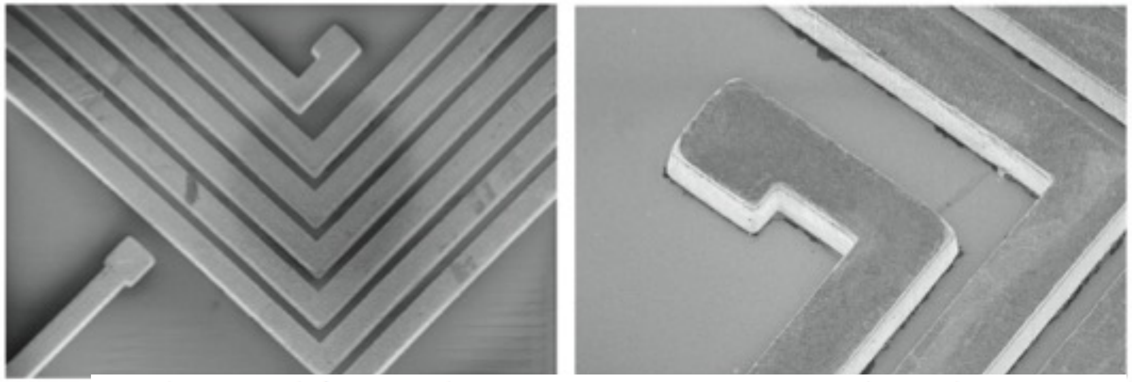
Multi-layer on PCB



S. Carrara et al. / IEEE Sensors Conf. 2012



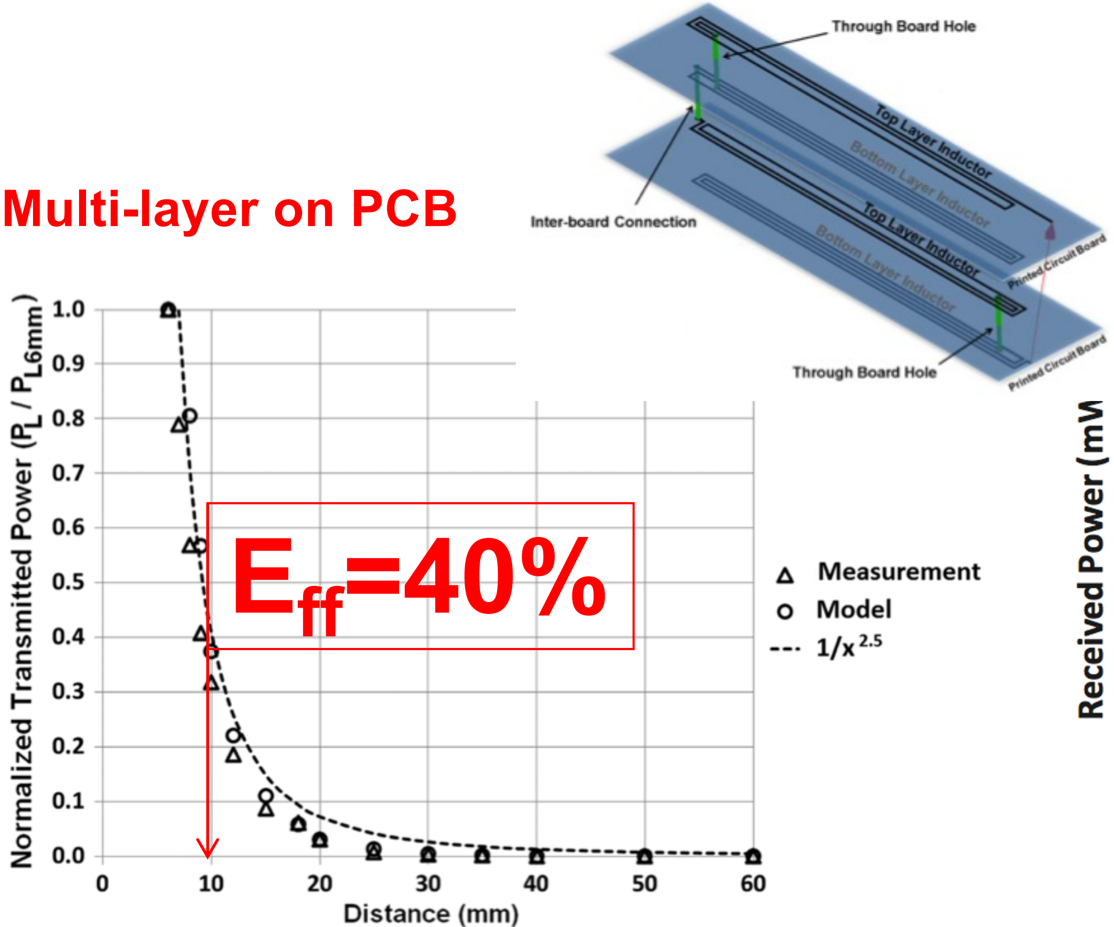
Single-layer on Si



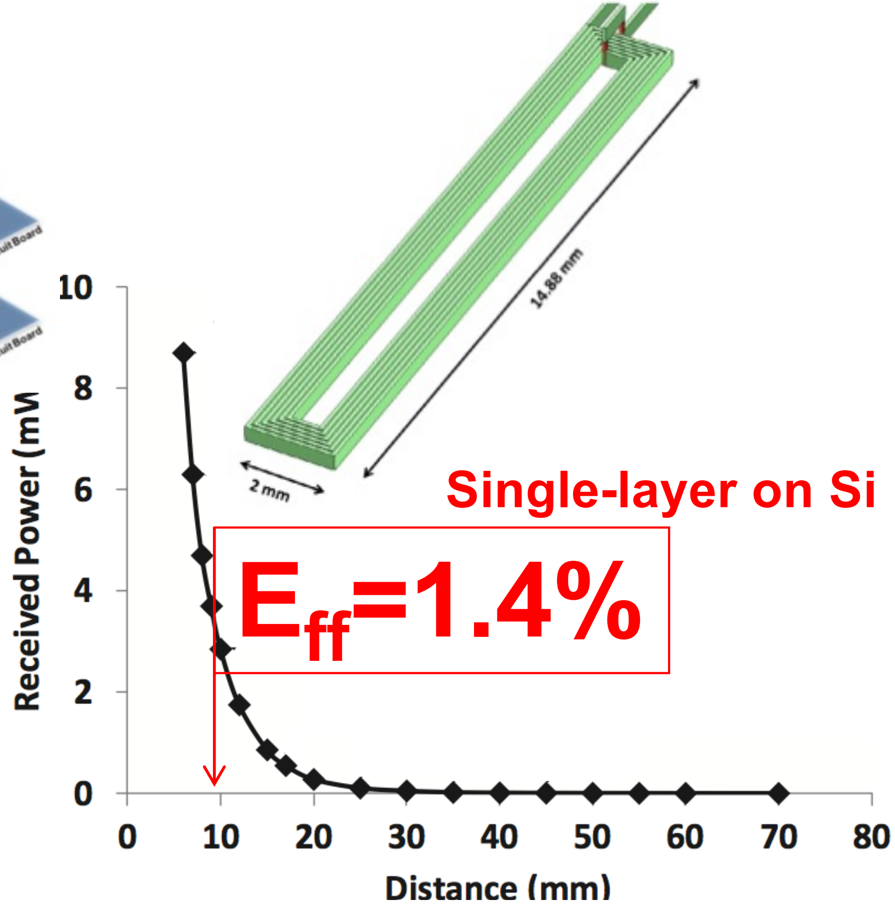
J. Olivo et al. / Microelectronic Engineering 113 (2014) 130–135

Two versions of the antenna have been fabricated and tested

The Tiny Spiral Inductors on Air



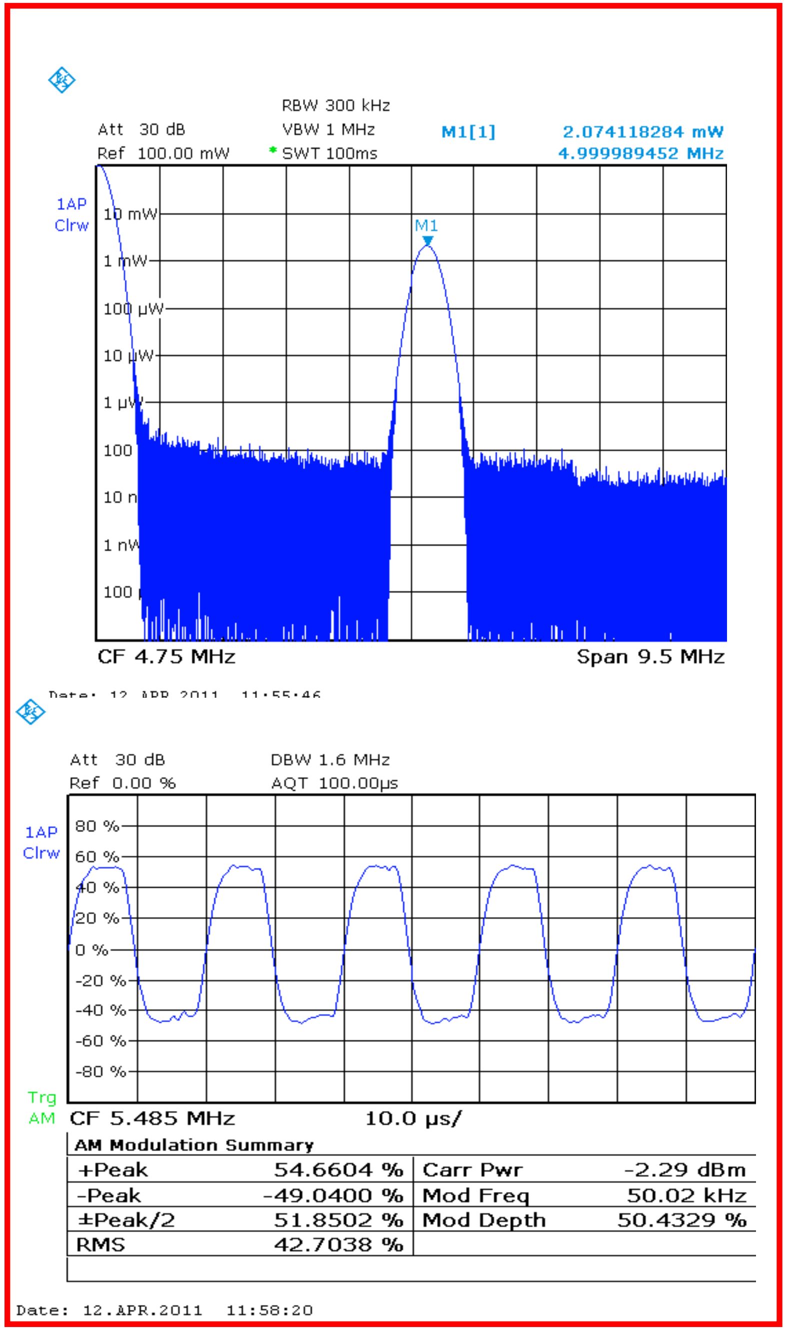
J.Olivo, S. Carrara, G.Demicheli / IEEE TBCAS 2013

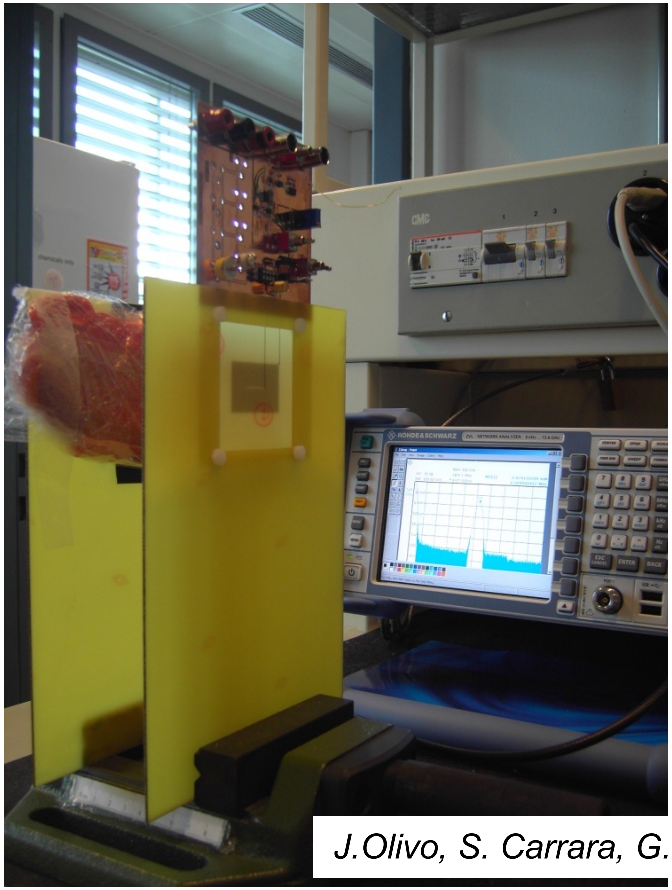


J. Olivo et al. / Microelectronic Engineering 113 (2014) 130–135

Two versions of the antenna have been fabricated and tested

The Multi-layer Inductor on Tissue

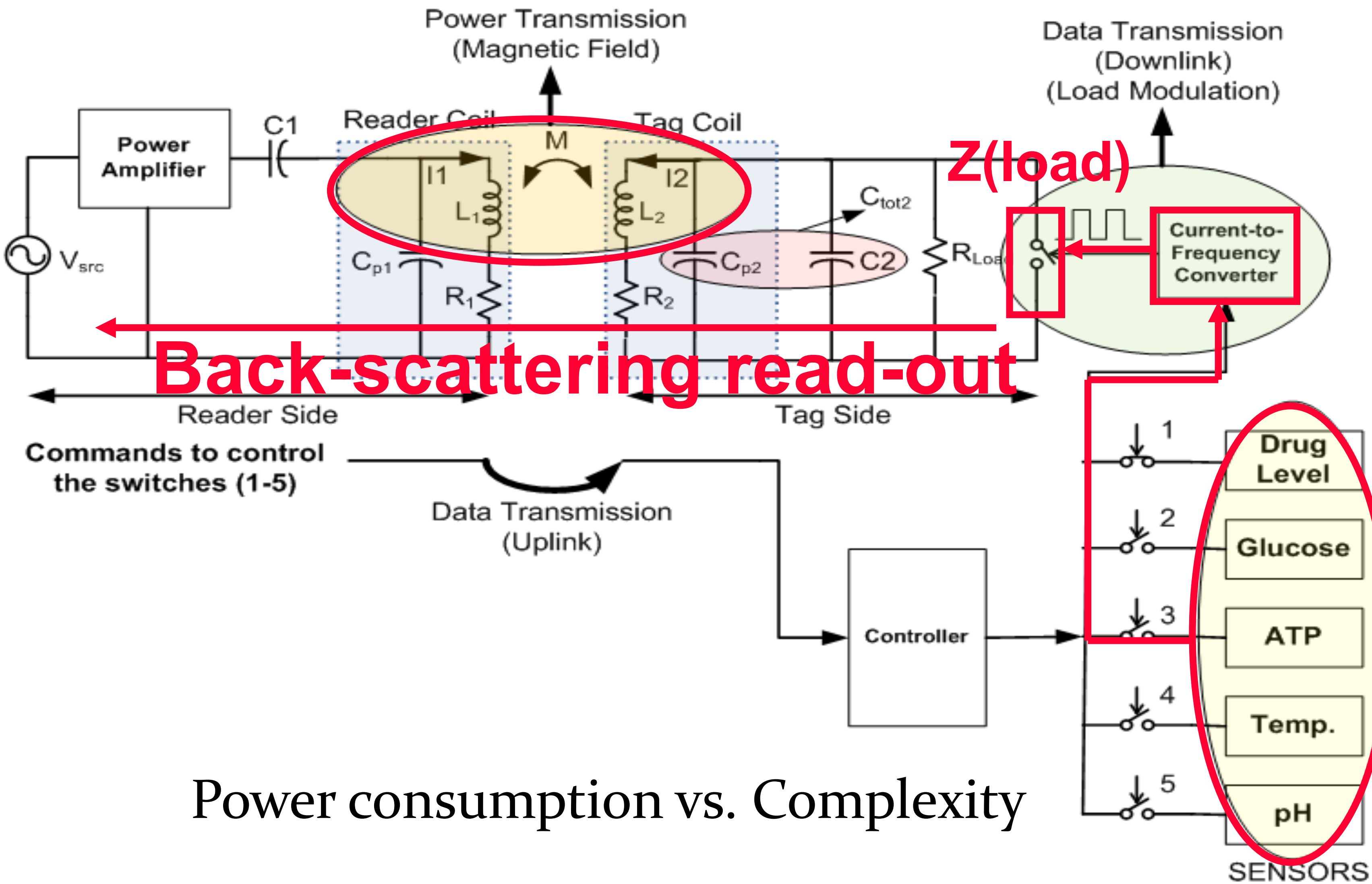




J.Olivo, S. Carrara, G.Demicheli / IEEE TBCAS 2013

- 2.09 mW (25mm – Bovine Tissue) - THD 2.08%
- 3.6 mW (14mm – Bovine Tissue) - THD 2.27%
- Communication is achieved at 100 kbps

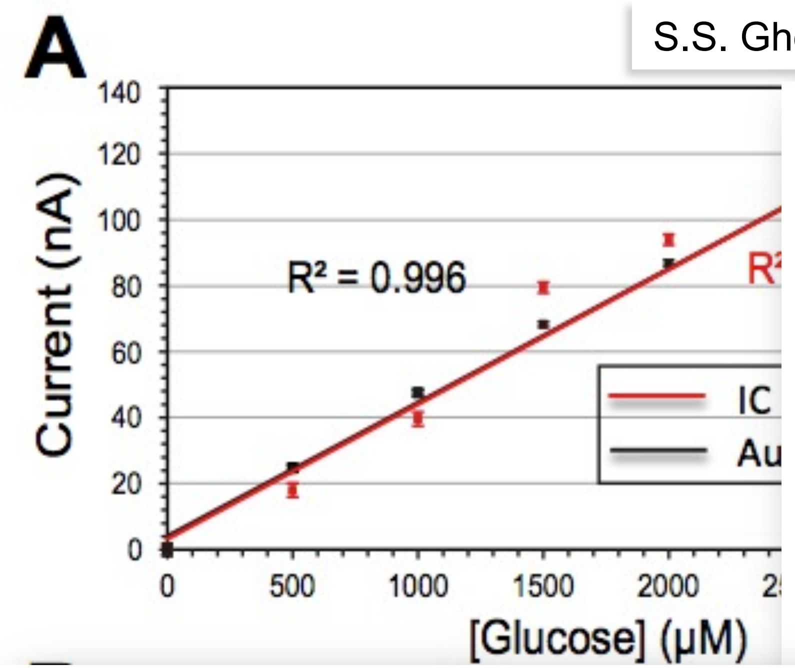
Data Transmission

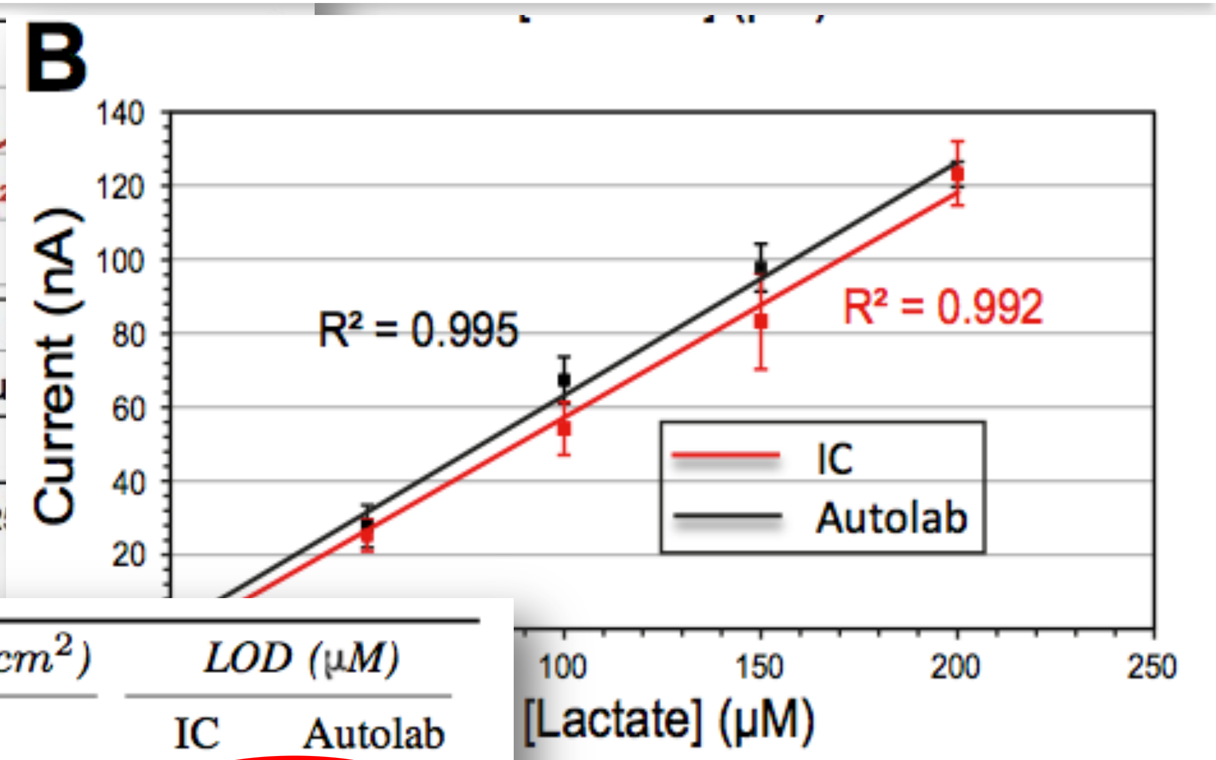


Power consumption vs. Complexity

The IC Potentiostat

S.S. Ghoreishizadeh, al., S. Carrara & G. De Micheli / IEEE TBCAS, 2013



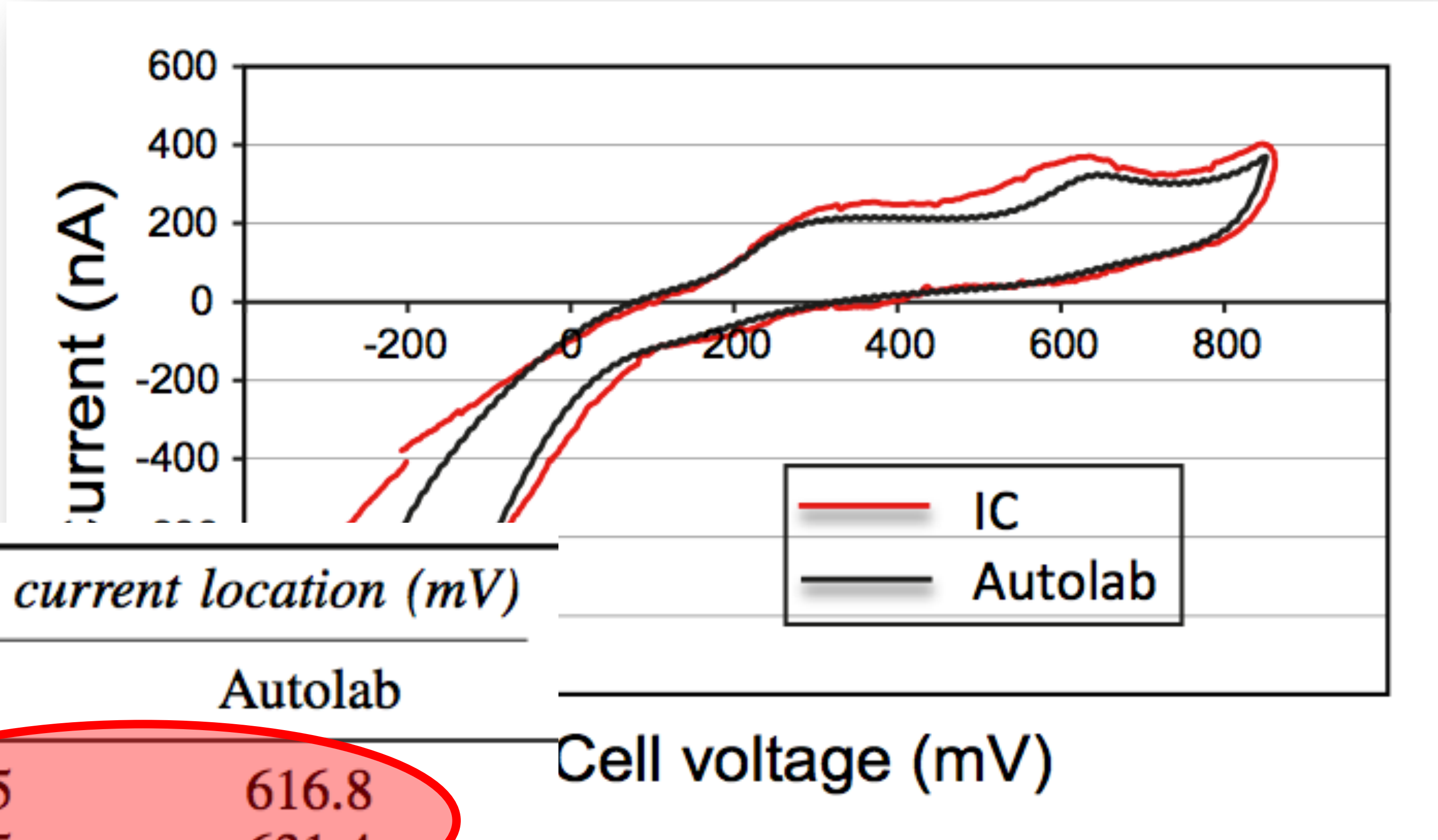


Metabolite	*Sensitivity* $(\mu A/mM \times cm^2)$ IC	Autolab	*LOD* (μM) IC	Autolab
Glucose	27.2	27.3	87.9	17.5
Lactate	285.7	391.3	21.4	4.1

The integrated potentiostat works quite well with respect the well-know and costly lab-one by Autolab

The IC Potentiostat

S.S. Ghoreishizadeh, al., S. Carrara & G. De Micheli / IEEE TBCAS, 2013

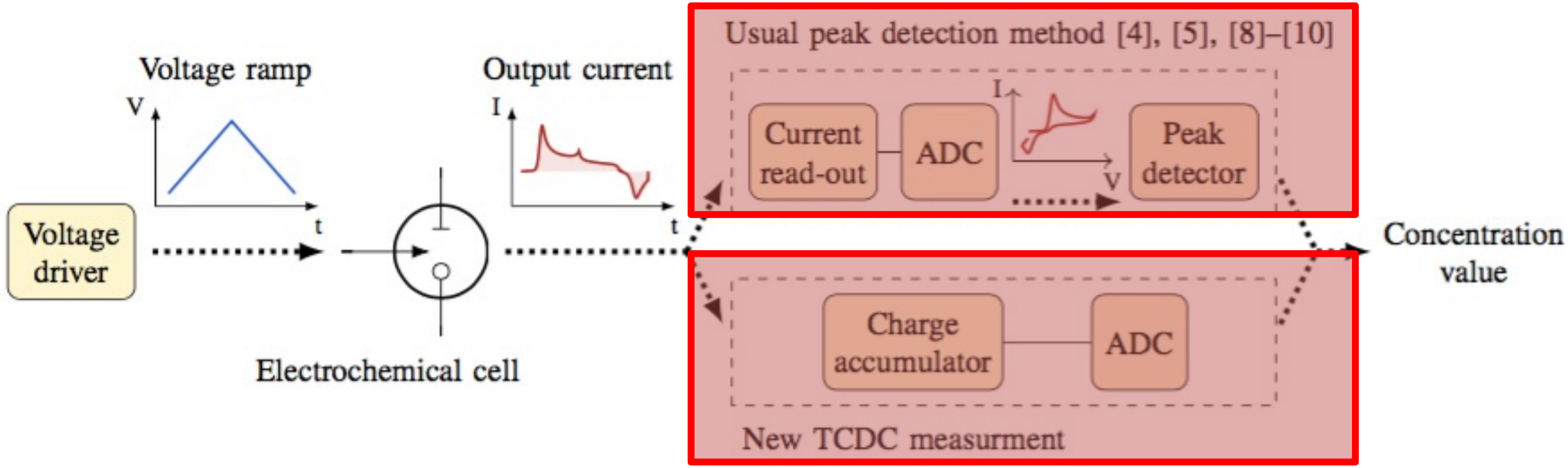


	Peak current location (mV)	
[Etoposide]	IC	Autolab
200 μM	612.5	616.8
400 μM	609.5	631.4

The integrated potentiostat works quite well with respect the well-know and costly lab-one by Autolab

Peak estimation on I_w @ WE

S.Aiassa et al. / IEEE MeMeA 2020



New Measurement Method in Drug Sensing by Direct Total-Charge Detection in Voltammetry

Peak estimation on I_w @ WE

S.Aiassa et al. / IEEE MeMeA 2020

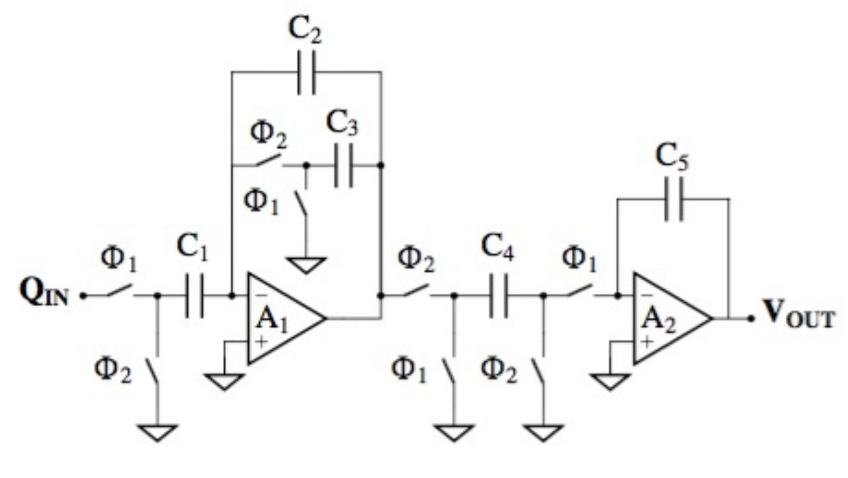
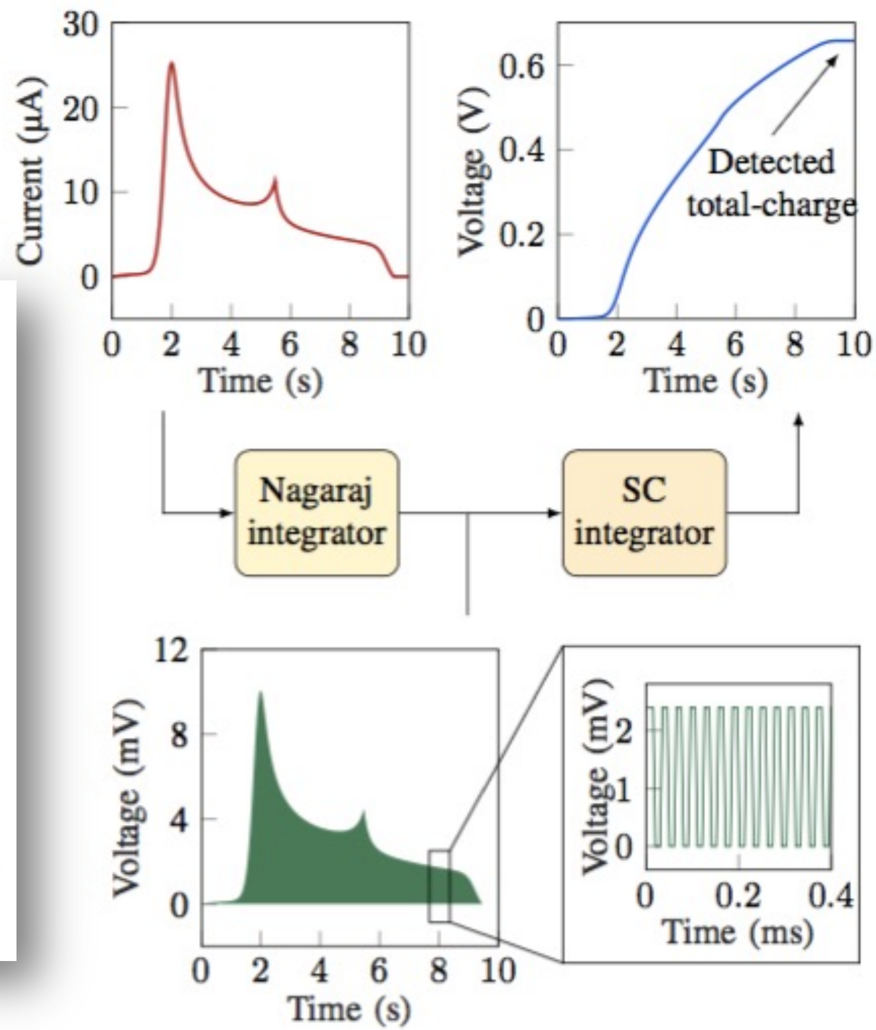


Fig. 2: TCDC instrumentation. The Nagaraj integrator (A_1) and the SC integrator (A_2) accumulate and convert the total input charge into the output voltage, during the two non-overlapped clock phase (Φ_1, Φ_2)



New Measurement Method in Drug Sensing by Direct Total-Charge Detection in Voltammetry

Injectable with biocompatible packaging

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20 March 2013 Last updated at 01:49 GMT

4.3K Share

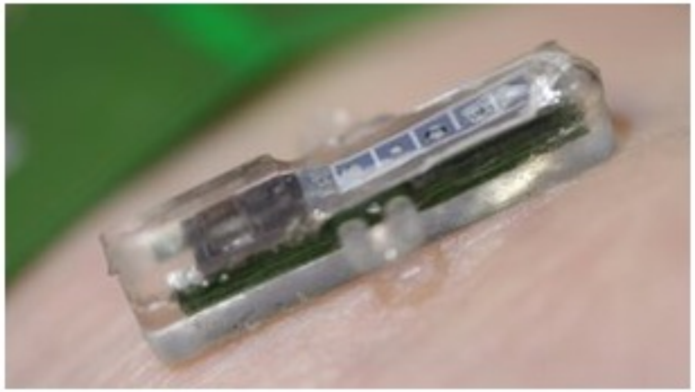
'Under the skin' blood-testing device developed

By Michelle Roberts
Health editor, BBC News online

Scientists say they have developed a tiny blood-testing device that sits under the skin and gives instant results via a mobile phone.

The Swiss team say the wireless prototype - half an inch (14mm) long - can simultaneously check for up to five different substances in the blood.

The data is sent to the doctor using radiowaves and Bluetooth technology.



The device sits under the skin and takes multiple readings

Syringe-injectable electronics: Reveal LINQ™

Mark Phelps by Medtronic, and the Reveal LINQ™ system

Android Users Interface

Glucose

Lactate

Paracetamol

F. Stradolini, et al., IEEE Sensors Journal 16(2016) 3163-3170

The whole system with the Android™ interface that allows connectivity too

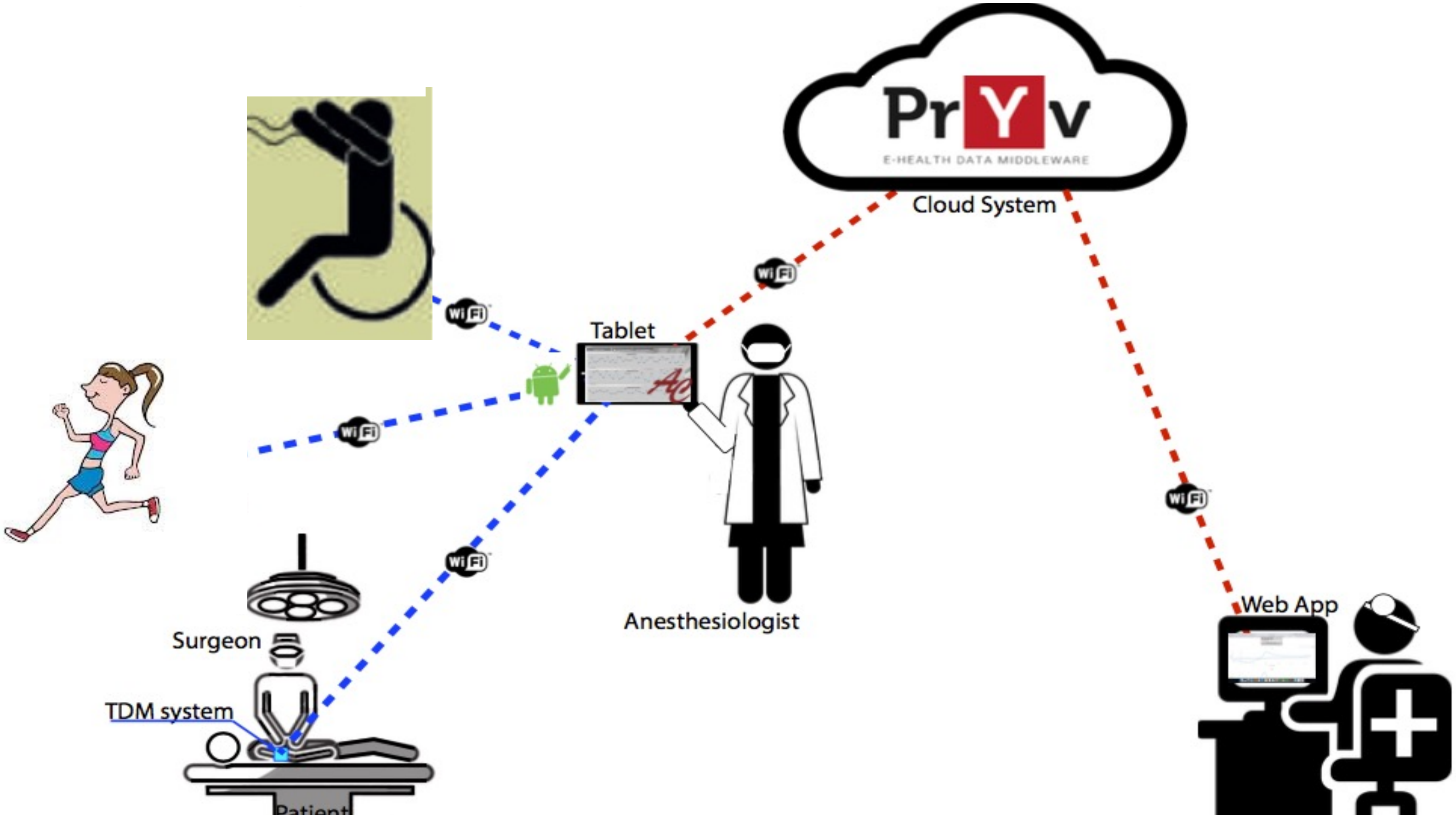
Connectivity with Smart-Watch

Live Demo @ BioCAS17

F. Stradolini, et al., MOBILHEALTH 2016

Connectivity till the smart-watch by the WiFi network has been successfully investigated as well

Connectivity by through the Cloud



N.Tamburrano, et al., IEEE ISCAS 2018, invited paper

Connectivity by through the cloud has been successfully investigated too

Portable, Implantable, ‘n’ Wearable!

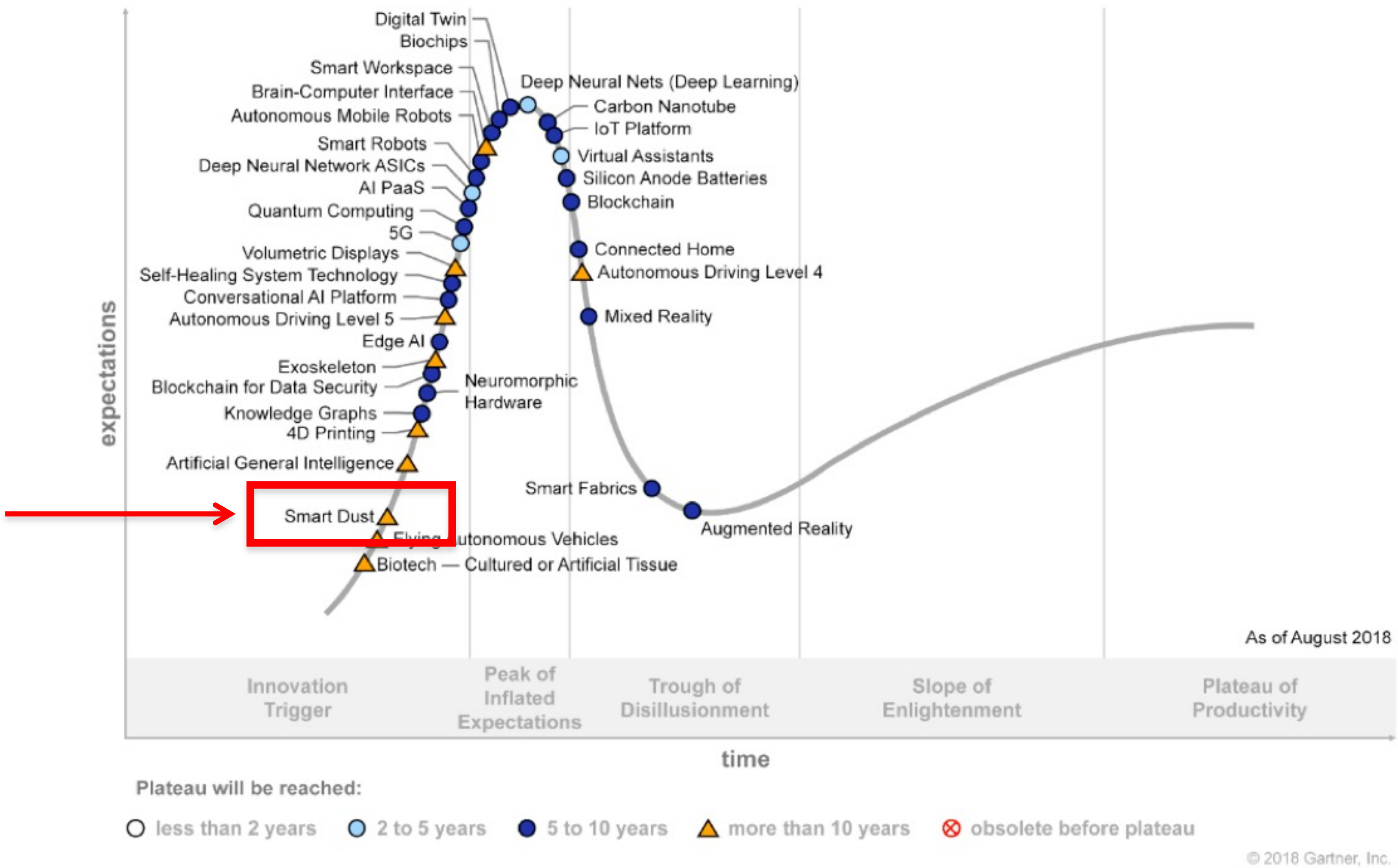
Monitoring scenarios

Beyond Implantable and Wearable Devices: Body Dust !

Body Dust: Drinkable Electronics

Monitoring scenarios

Hyper Curve with Smart Dust

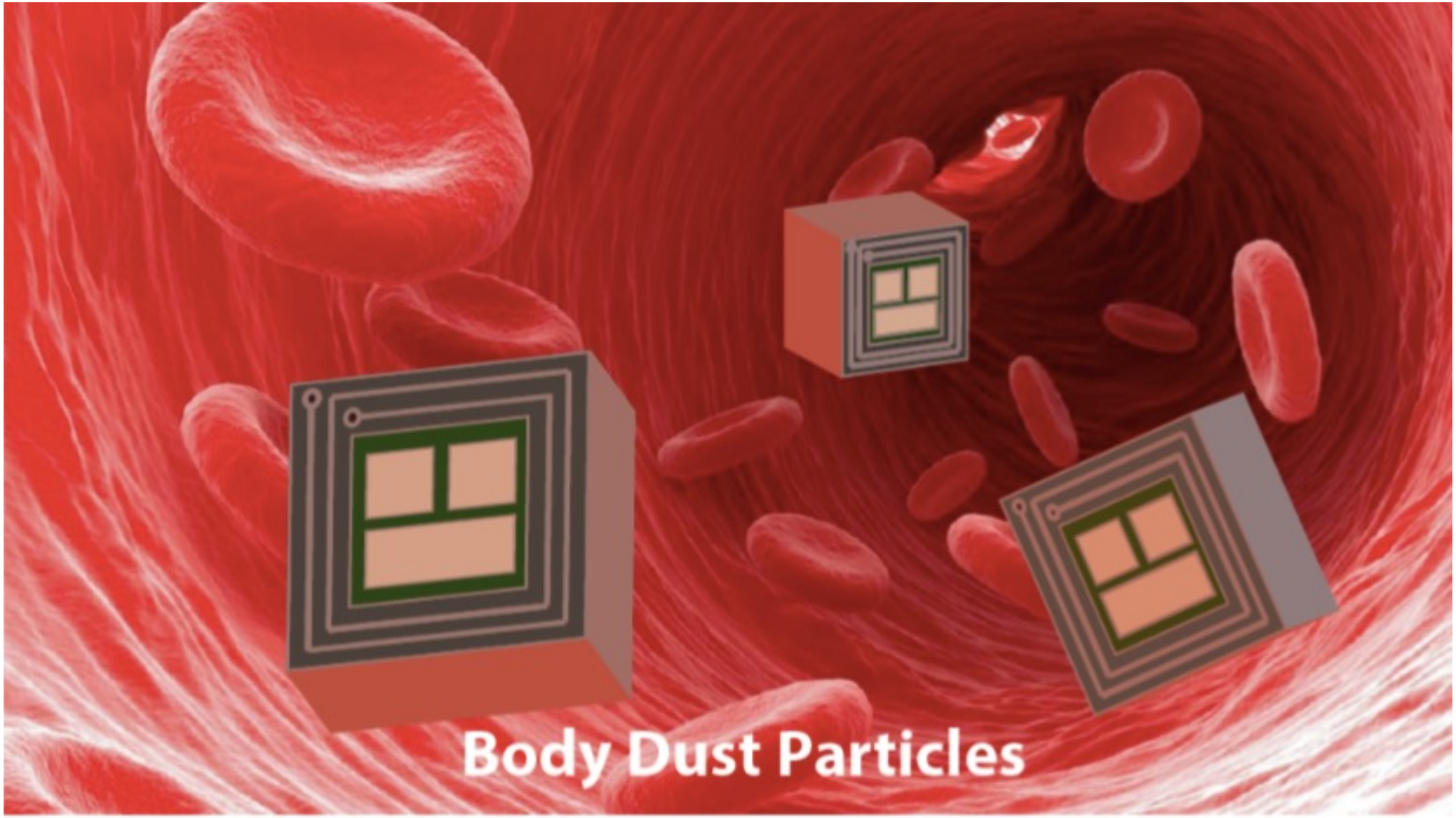


According to Gartner, "Smart dust" is set to take the technology industry by storm in the next decade [https://www.gartner.com]

The innovative concept of BODY DUST

Imagine to drink a water that contain an electronic Dust that spread in your body and then provide diagnostics

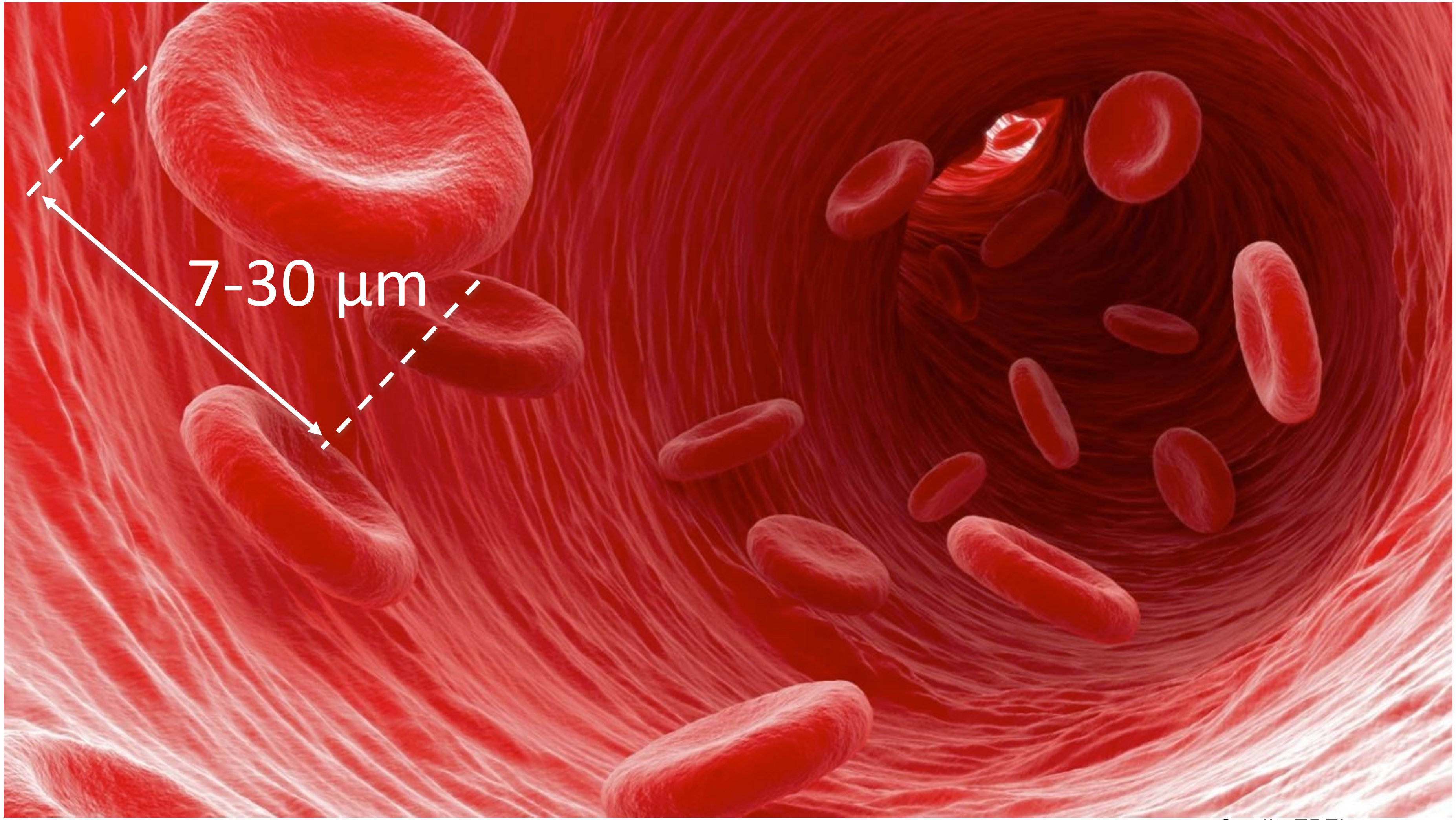
Body Dust



Credit: EPFL news pages

Tracking cancer-cell development with “drinkable” electronic sensors

Body Dust: Dramatically Small



Credit: EPFL news pages

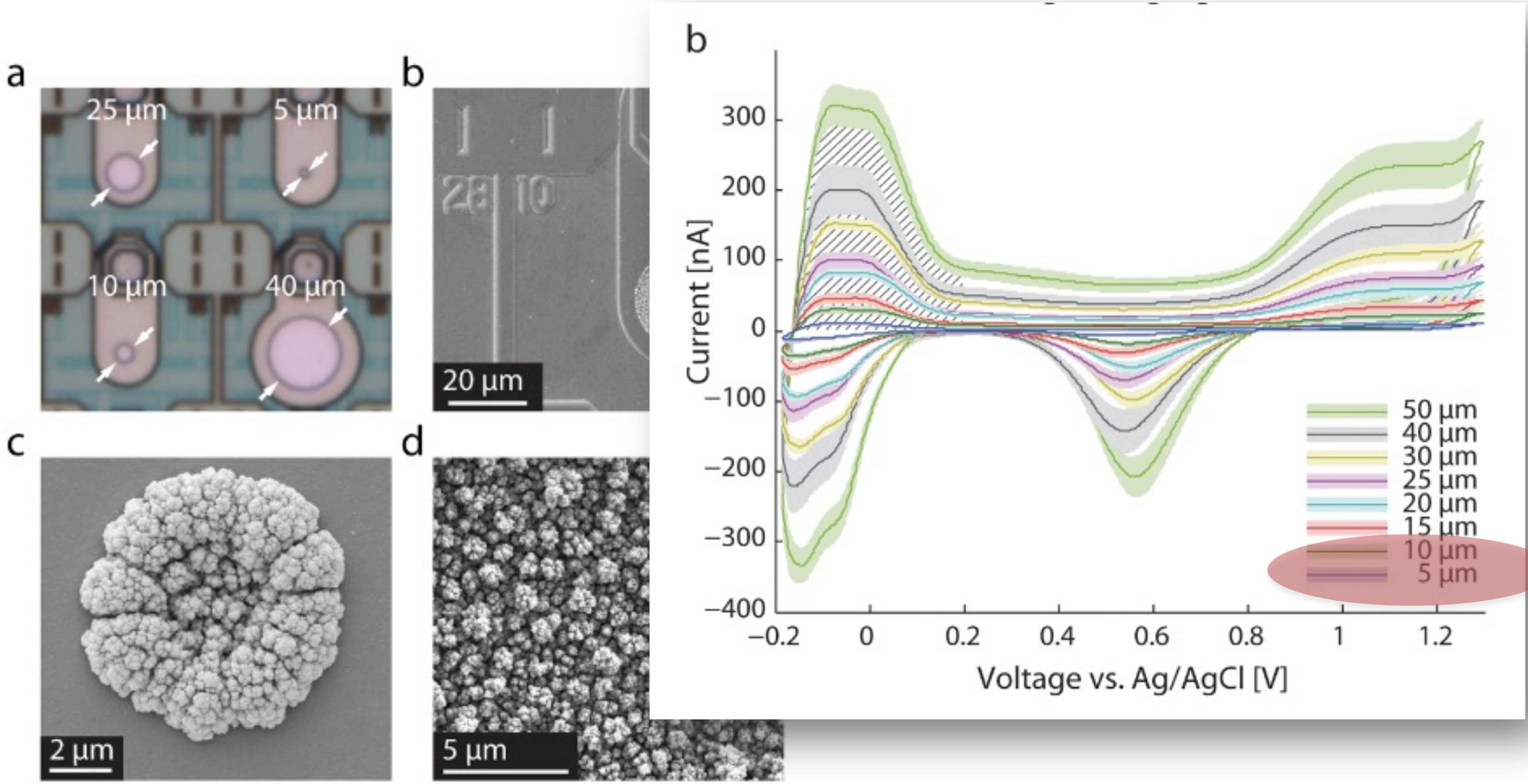
Drinkable electronics so small to be filtrated by liver and kidneys means sizes on the scale of a blood cell

Body Dust: Challenges to address!

Sandro Carrara / IEEE Sensors Journal, 2021

(i) Extremely small sensors;
(ii) Extremely small and thin CMOS;
(iii) Extremely small data-link;
(iv) Powering approaches with extremely small power-receivers;
(v) Demonstrating in-body applications by drinking

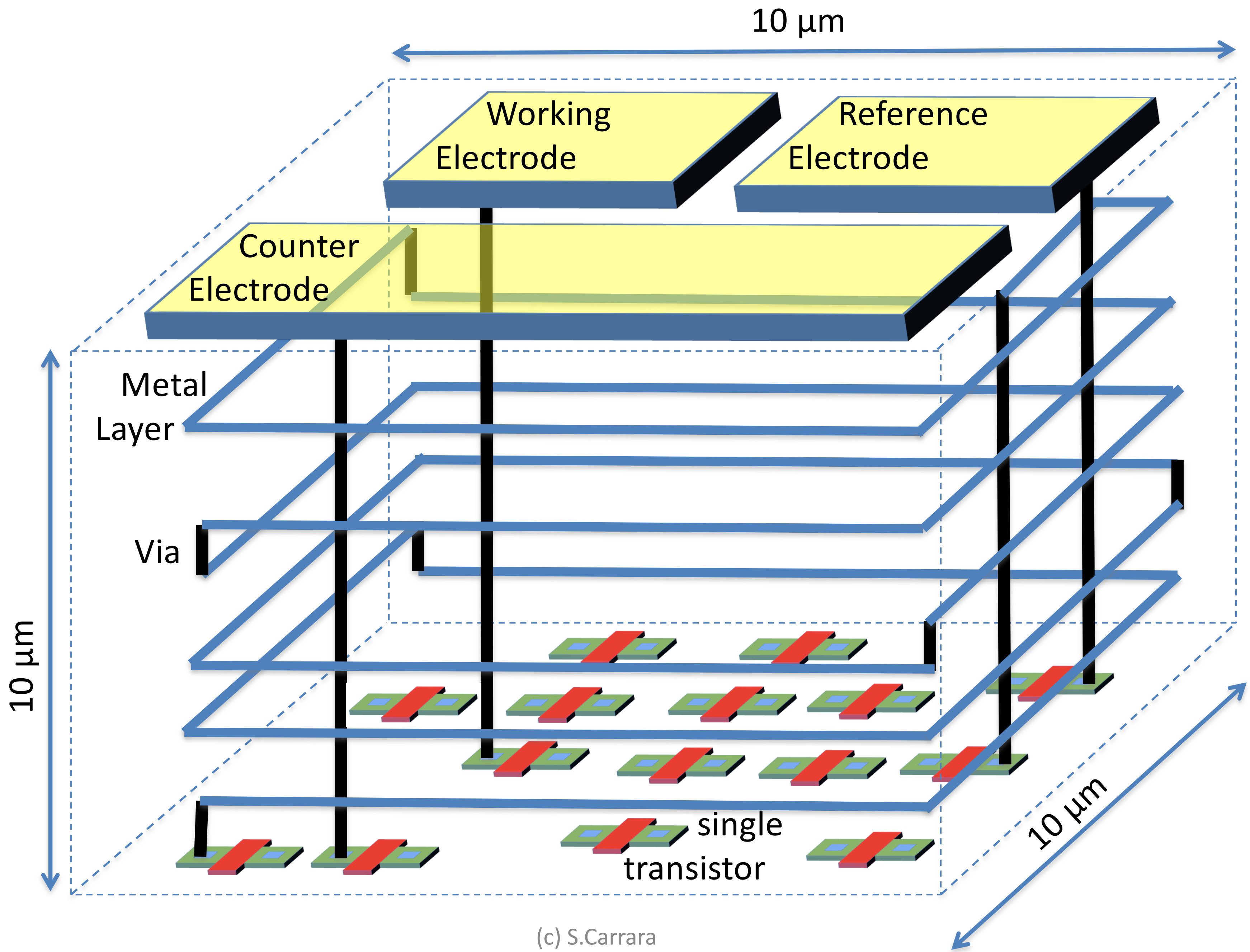
(i) Extremely small sensors;



Rothe, Joerg, et al. / Analytical chemistry 86.13 (2014): 6425-6432.

Imagine to drink a water that contain an electronic Dust that spread in your body and then provide diagnostics

(ii) Extremely small and thin CMOS;



(ii) Extremely small and thin CMOS; CMOS 0.18 µm within 10^2 µm^2 possible?

CMOS Body Dust - Towards Drinkable Diagnostics

Jan Snoeijs[1], Pantelis Georgiou[2] and Sandro Carrara[1]
[1] EPFL, Lausanne, Switzeland [2]Centre for Bio-Inspired Technology, Imperial College London, UK.
Email: sandro.carrara@epfl.ch

IEEE BioCAS 2017

Abstract—In this paper we introduce the concept of CMOS Body Dust. Body dust, as we envisage is to be, is a swarm of physical micro-sensing systems designed in CMOS as a cube with the size of red blood cells such that they will be drink
to deliver vital diagnos
the source of a diseas
therefore to discuss ar
CMOS architecture w
factor, to be in the sar
have a diameter of ar
total size of less than

Keywords—Diagnostics,

TABLE IV. TOTAL AREA AND POWER CONSUMPTION TRADE-OFF

	Area [µm^2] (best case)	Power [µW]	Power [µW] (best case)	Area [µm^2]
Potentiostat	8.7	0.141	0.124	12
I to f conv.	22	0.836	0.836	22
Rectifier	28.44	9.655	9.655	28.44
Voltage regulator	15.9	18.170	5.7	24
Band-gap ref.	15.2	[illegible]	0.039	15.2
Pulse generator	10	—		10
Total	100.24	2[illegible]741	[illegible]	111.64

Yes !

(ii) Extremely small and thin CMOS; CMOS 0.18 µm within 10^2 µm^2 possible?

Direct Digital Sensing Potentiostat targeting Body-Dust

IEEE BioCAS 2022

Roberto Rubino
DET

Sandro Carrara
Integrated Circu
ique F
nne, S
o.carr

Paolo Crovetti

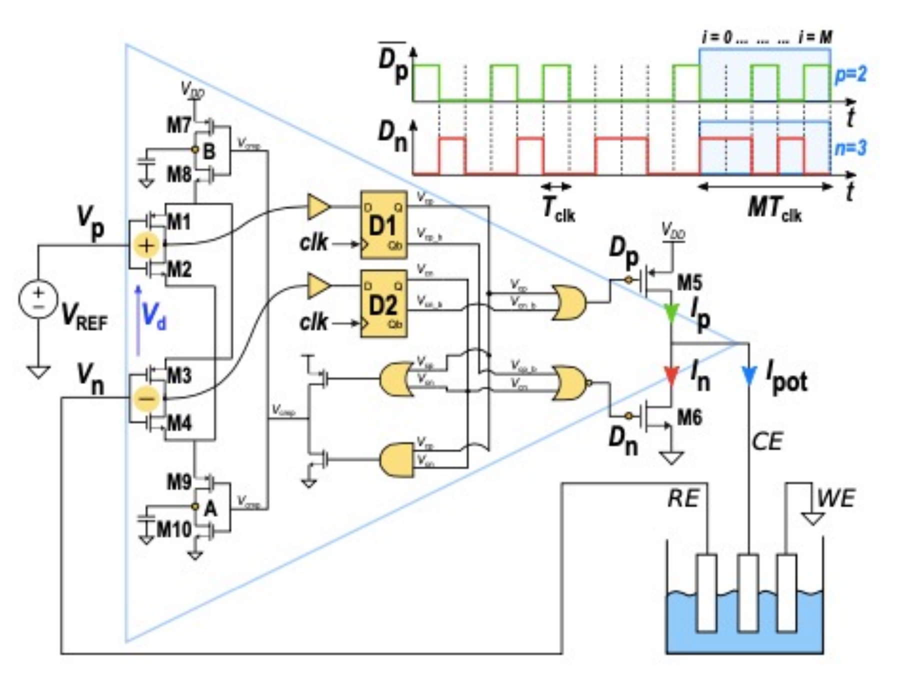


Fig. 3. Proposed digital-based potentiostat schematic and digital acquisition pulses.

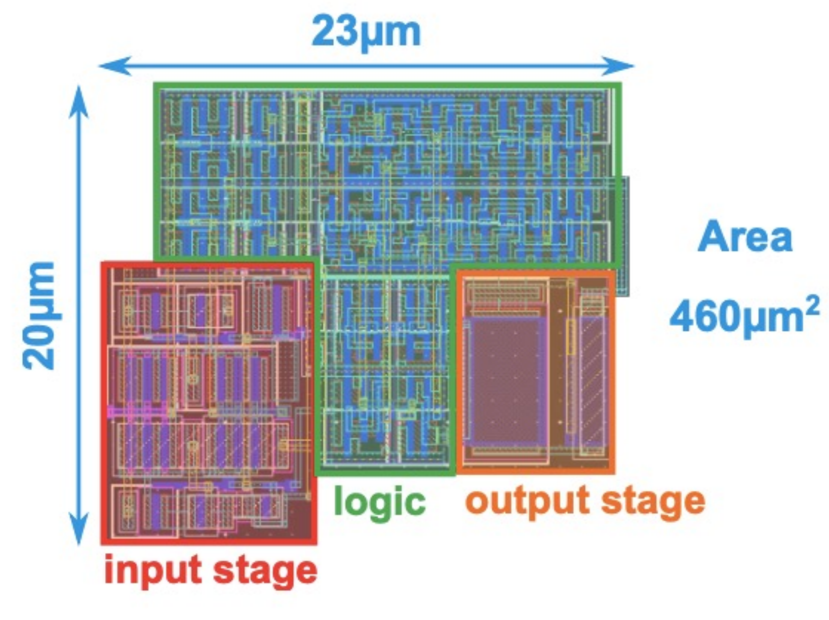


Fig. 4. Layout view of the DDSP.

(ii) Extremely small and thin CMOS; DATA 0.18 µm transmission within 10^2 µm^2?

Body Dust: Ultra-Low Power OOK Modulation Circuit for Wireless Data Transmission in Drinkable sub-100µm-sized Biochips

ArXiv, December 2019

...ssa*†, Danilo Demarchi*†, Sandro Carrara†
...ns, Politecnico di Torino, Turin, Italy
...dérale de Lausanne, Neuchâtel, Switzerland
...no di Tecnologia, Genova, Italy
....aiassa@polito.it

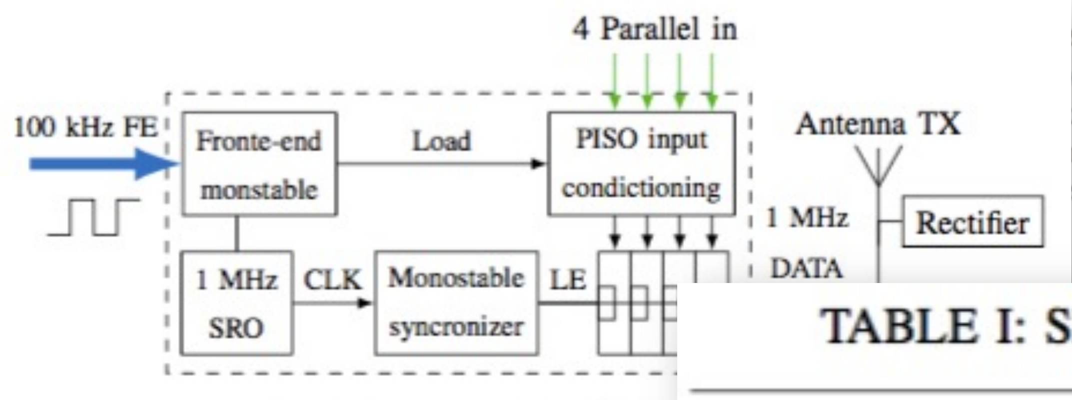


Fig. 1: System block dia...

...cell (diameter around 30 µm for white c... circulation of the cube in human tissue... came from the low-power consumption... energy provided by an external US... of the ... archi... architecture for a data transmission ... 0.18 µm CMOS process, with sub-10 µW... and a total chip area of 43x44 µm². T... the limits of the designed system and... improvements toward real applications i...

TABLE I: SRO performance comparison.

	[12]	[13]	This work
CMOS technology	130 nm	130 nm	180 nm
Voltage supply (V)	3.3	3.3	1.8
External component	Yes	No	No
[illegible]	22.5-360	1	1
Power (µW)	1515*	87	9.5
Area (mm²)	0.05	0.054	0.00116

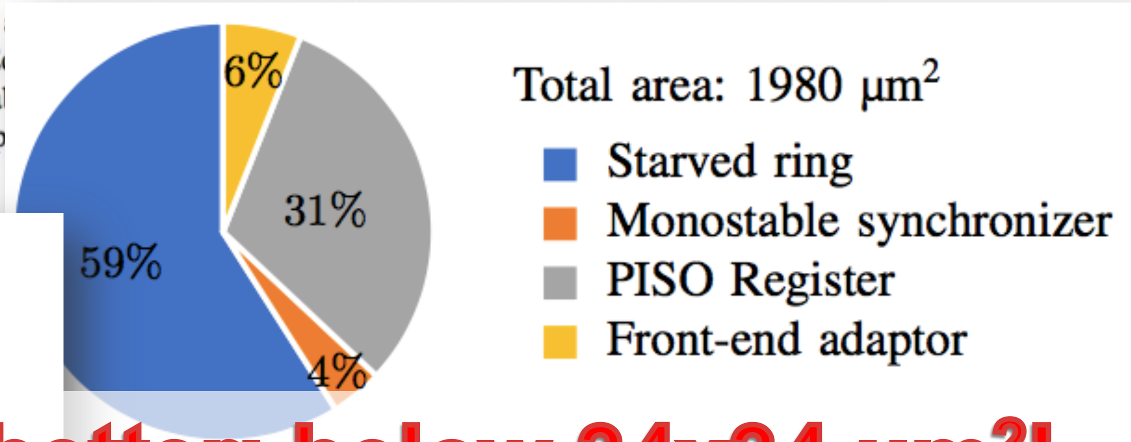
Almost: 34x34 µm²!

(ii) Extremely small and thin CMOS; DATA 0.18 µm transmission within 10^2 µm^2?

Body Dust: Ultra-Low Power OOK Modulation Circuit for Wireless Data Transmission in Drinkable sub-100µm-sized Biochips

ArXiv, December 2019

Gian Luca Barbruni*†, Paolo Motto Ros‡, Simone Aiassa*†, Danilo Demarchi*†, Sandro Carrara†
*Department of Electronics
†Integrated Circuits Laboratory, É
‡Electronic Design La
Corresp



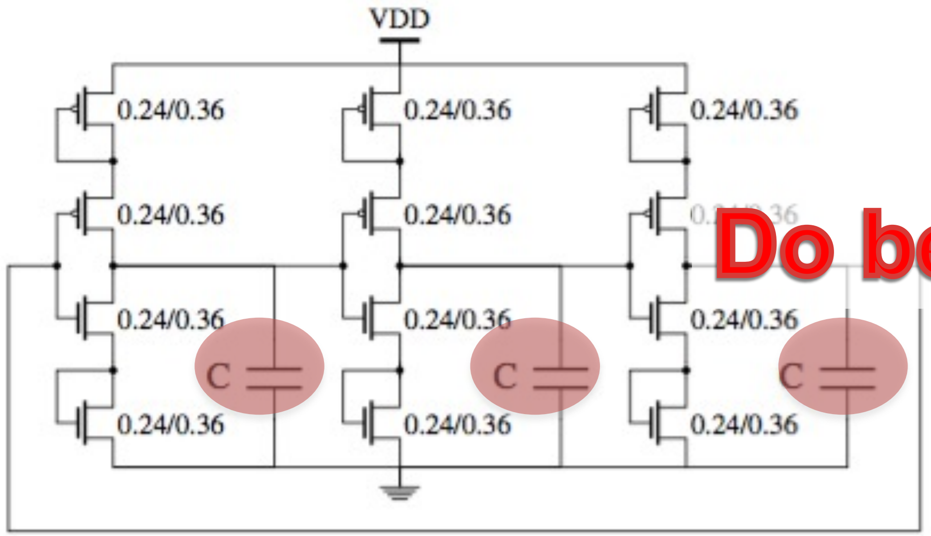


Fig. 2: Three stages starved Ring Oscillator (RO).

Do better: below 34x34 µm^2!

with the
he results
design an
y using a
nsumption
discusses
or further
iagnostics.

sensing approach [8], but in that case the architecture was quietly different: that proposed solution included three nodes (an external transceiver, a sub-dural one and the proper Neural Dust device) while in our design only two components are expected (the external base station that works both as power transmitter and data receiver and the body dust tags) and, secondly, in that architecture any communication circuit was

(ii) Extremely small and thin CMOS; DATA 28 nm transmission within 10^2 µm^2?

From 0.18 µm to 28nm Scaling CMOS Technologies for Data Links in Body Dust Applications

IEEE SENSORS 2021

Gian Luca Barbruni†*‡, Paolo Motto Ros, Danilo Demarchi* and Sandro Carrara†

†Integrated Circuits Laboratory, École Polytechnique Fédérale de Lausanne, Neuchâtel, Switzerland
*Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy
...olytechnique Fédérale de Lausanne, Genève, Switzerland
...r: gianluca.barbruni@epfl.ch

Done better:
total size smaller than 55 µm^2 in 28nm!

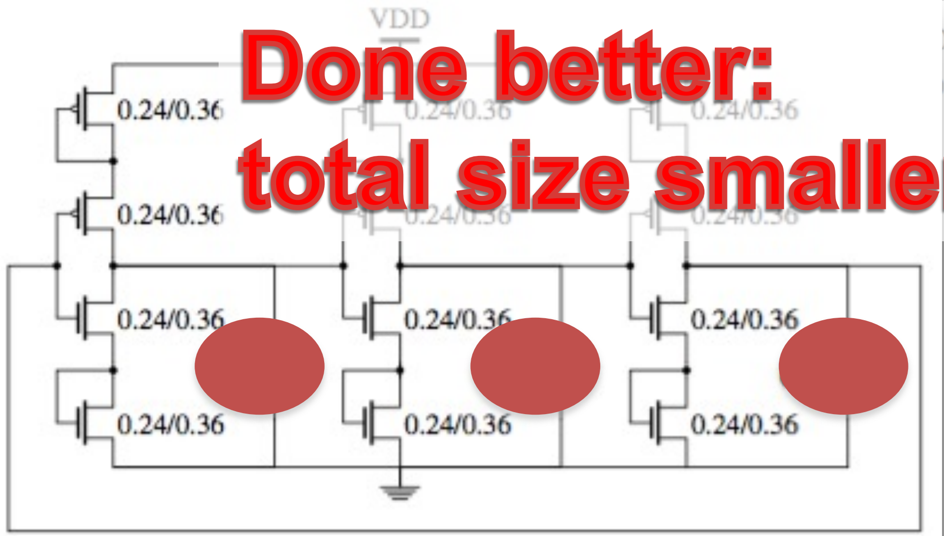
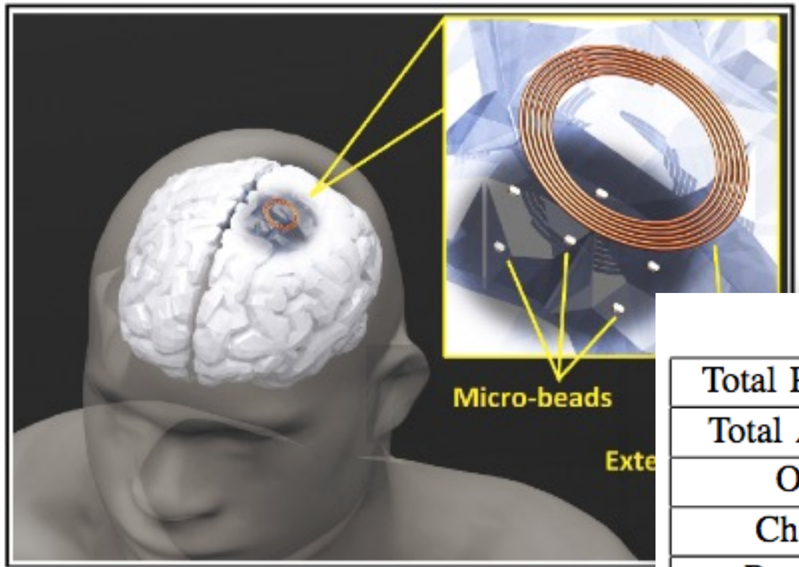
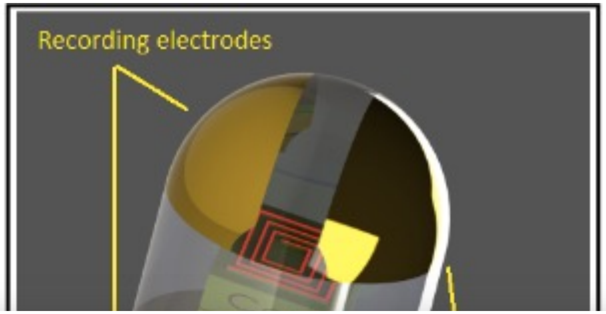


Fig. 2: Three stages starved Ring Oscillator (RO).

(iv) Powering approaches with extremely small power-receivers;

Khalifa, A., Zhang, et al. / 2016 IEEE ISCAS





	[6]	[1]	[7]	[2]	[3]	This Work
Total Power (mW)	0.468	0.0105	15	1.5	8	0.016
Total Area (mm^2)	4	0.125	2.25	12	24.4	0.039
Off-Chip	None	None	None	None	Cap	None
Chanels (#)	4	4	4	128	100	1
Process (nm)	180	65	500	130	600	180

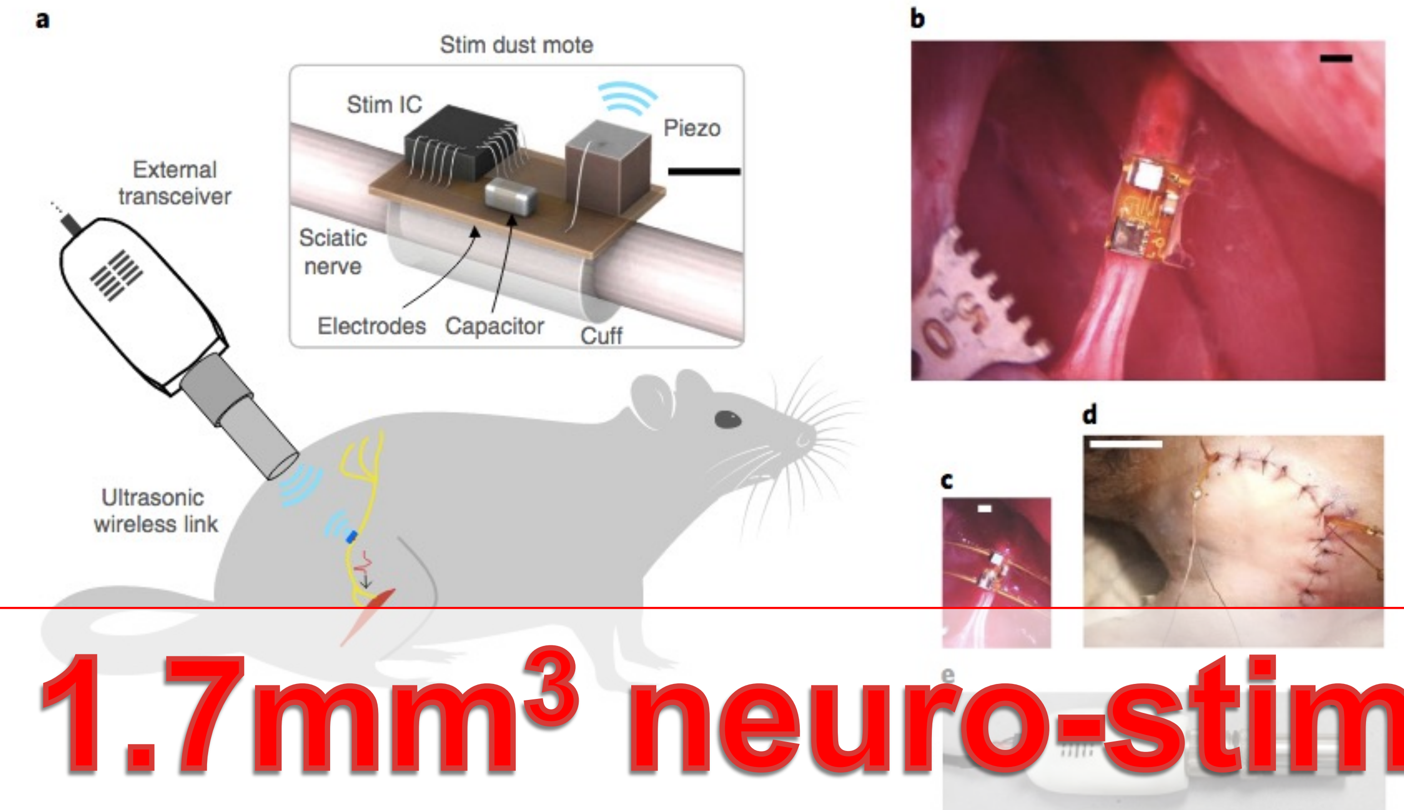
200µm x 200µm coil !

16 µW received to a 0.039 mm^2 area-coil

by inductive-link

(iv) Powering approaches with extremely small power-receivers;

D.K.Pietch, et al. / 2020 NATURE Biomedical Engineering



1.7mm^3 neuro-stimulator!

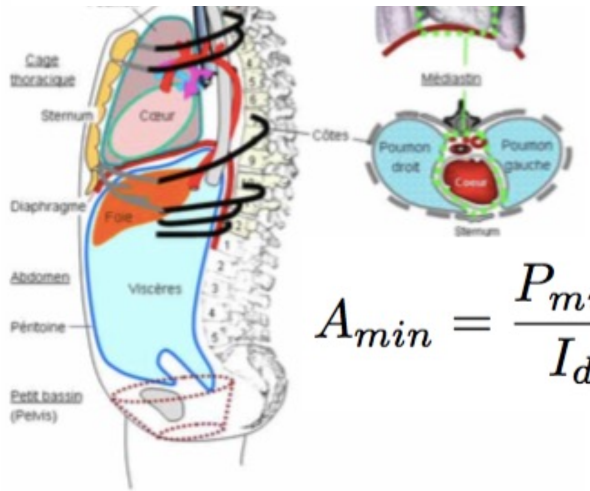
65 µW received to a 1.7 mm^3 volume-size transducer by ultra-sound

(iv) Powering approaches with extremely small power-receivers;

Three Scenarios

$$A_{min} = \frac{P_{min}}{I_d} = 1.98 \cdot 10^4 \mu m^2 \rightarrow \approx 140.81 \mu m$$

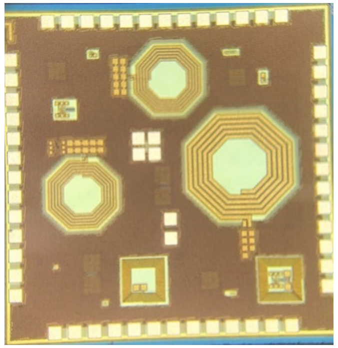
$$A_{min} = \frac{P_{min}}{I_d} = 4.22 \cdot 10^3 \mu m^2 \rightarrow \approx 65.6 \mu m$$



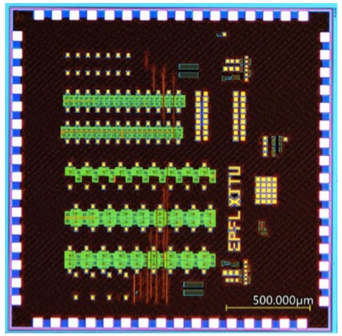
$$A_{min} = \frac{P_{min}}{I_d} = \frac{30 \cdot 10^{-6}}{1230 \frac{W}{m^2}} = 2.44 \cdot 10^4 \mu m^2 \rightarrow \approx 156 \mu m$$

Almost!

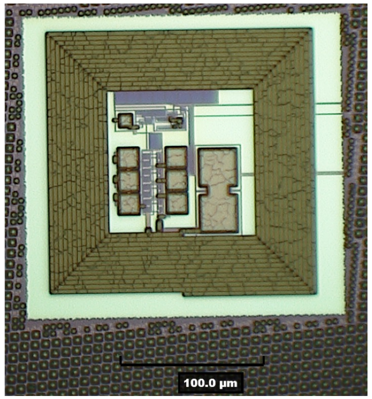
Some Recent Bio/CMOS interfaces



Chip # 5 TSMC 0.18
IEEE MOCAST, June 2022

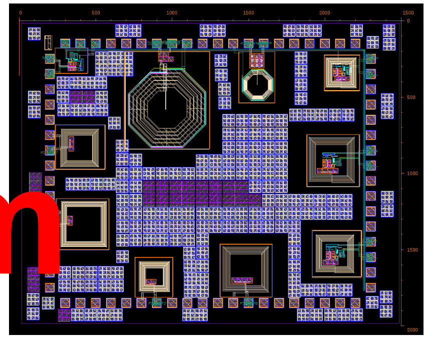


Chip # 6 TSMC 0.18
(arrived October 2022)



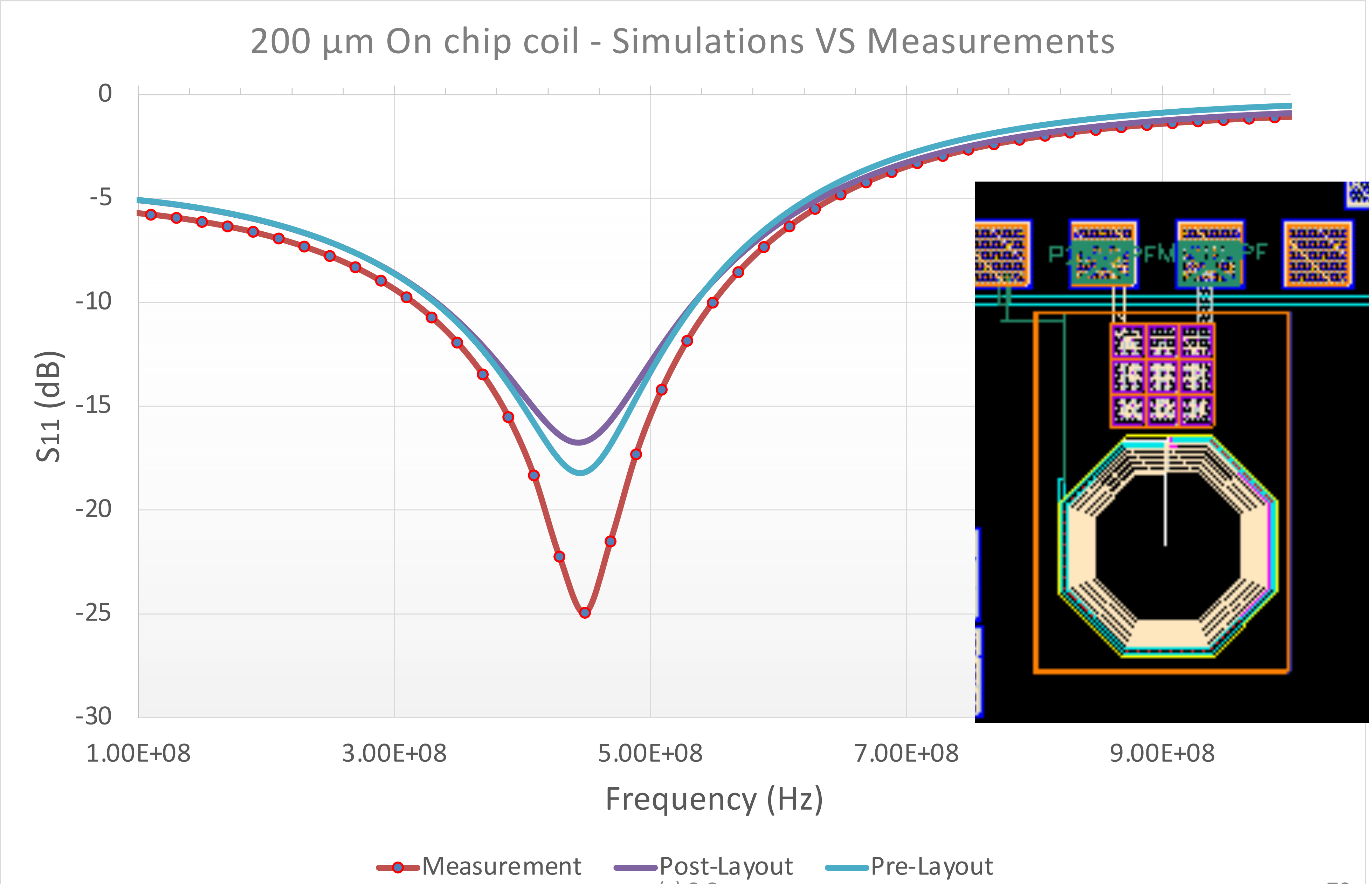
150 µm

Chip # 7 TSMC 0.18
(arrived October 2022)

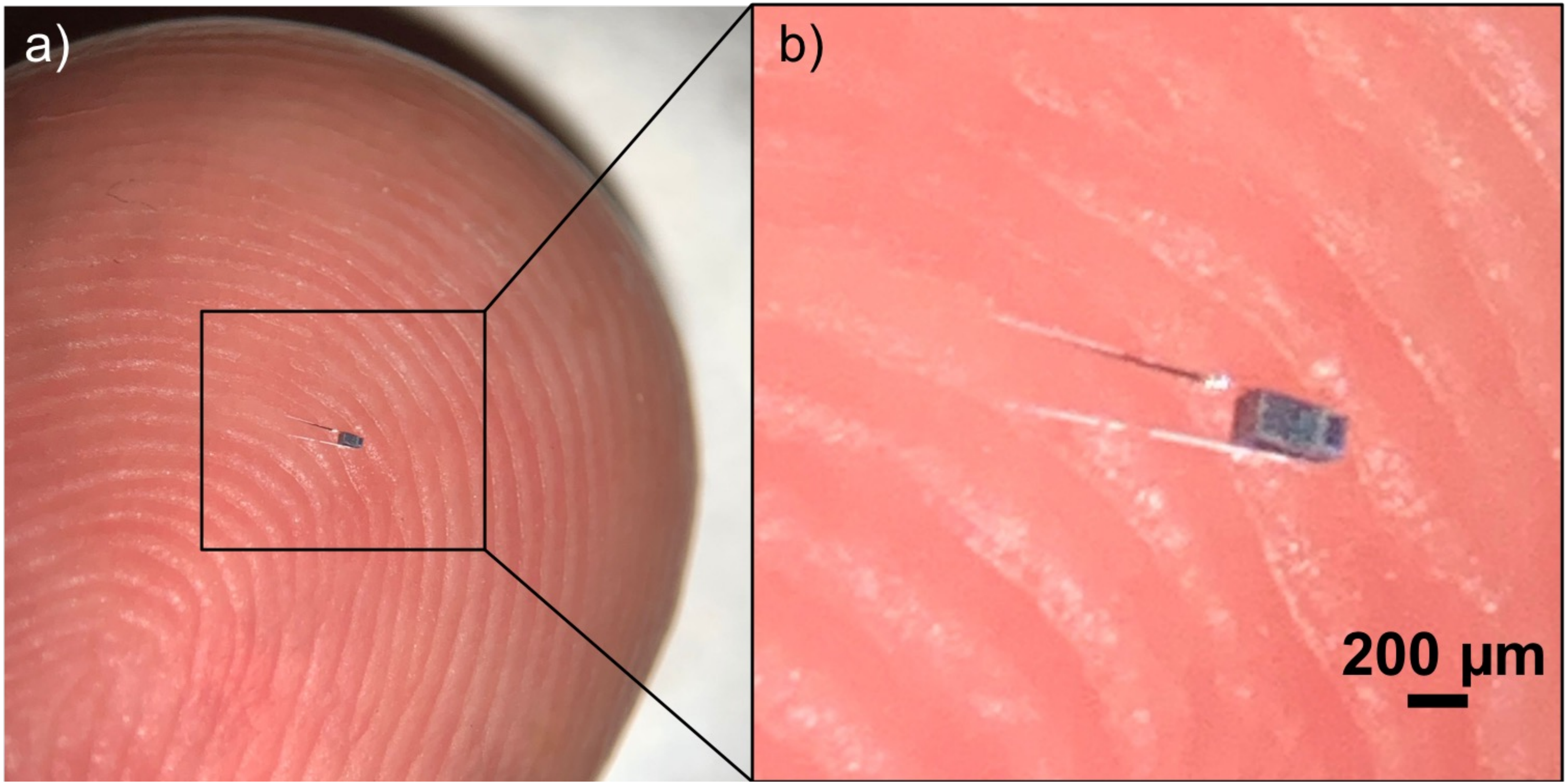


Chip # 8 TSMC 0.18
(Just arrived 2023)

Power Transfer to 150 um-coil



Smart Micron-sized Neural Dust



Barbruni Gian Luca, et al., PCT/IB2022/059944, 2022.

Body Dust: Challenges to address!

Sandro Carrara, al. et / IEEE Sensors Journal, 2021

(i) Extremely small sensors;
(ii) Extremely small and thin CMOS;
(iii) Extremely small data-link;
(iv) Powering approaches with extremely small power-receivers;
(v) Demonstrating in-body applications by drinking

Conclusions

- **CMOS ASICs design is still required for more reliable Bio/CMOS Interfaces and, especially, for electrochemical sensing for metabolism**
- **Special Biotech solutions are necessary to target the right selectivity in order to uniquely identify the right metabolic molecules**
- **Special Nanotech solutions are necessary to reach the right sensitivity and limit-of-detection in the ranges of concentrations on human tissues**
- **Automatic and continuous monitoring of the metabolism in humans is actually feasible from body tissues to our personal electronics, including portable, wearable, implantable, and may be one day also spreadable in the form of Diagnostic Dust!**

Summary

Course outline

Bio

1. Probes and Targets Building Blocks
2. Probes/Target interactions (DNA & Ab)
3. Probes/Target interactions (Ox & P450)
4. Probes Detection Principles (DNA or Ox)
5. Probes Detection Principles (P450)

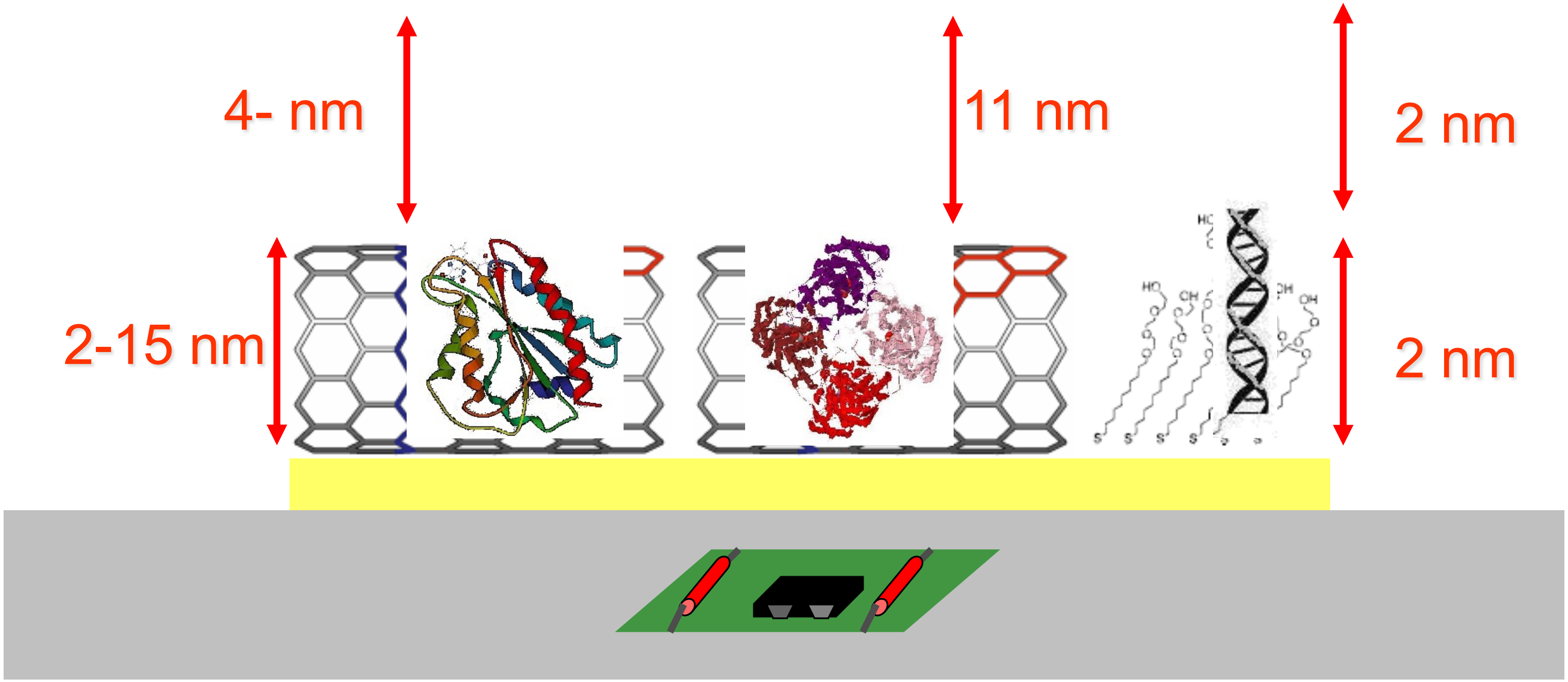
Nano

6. Probes immobilization
7. Checking Probes-layer quality (RR+SPR+SEM+AFM)
8. Nanotechnology to prevent Electron Transfer
9. Nanotechnology to enhance Electron Transfer
10. Nanotechnology for Memristive Biosensors

CMOS

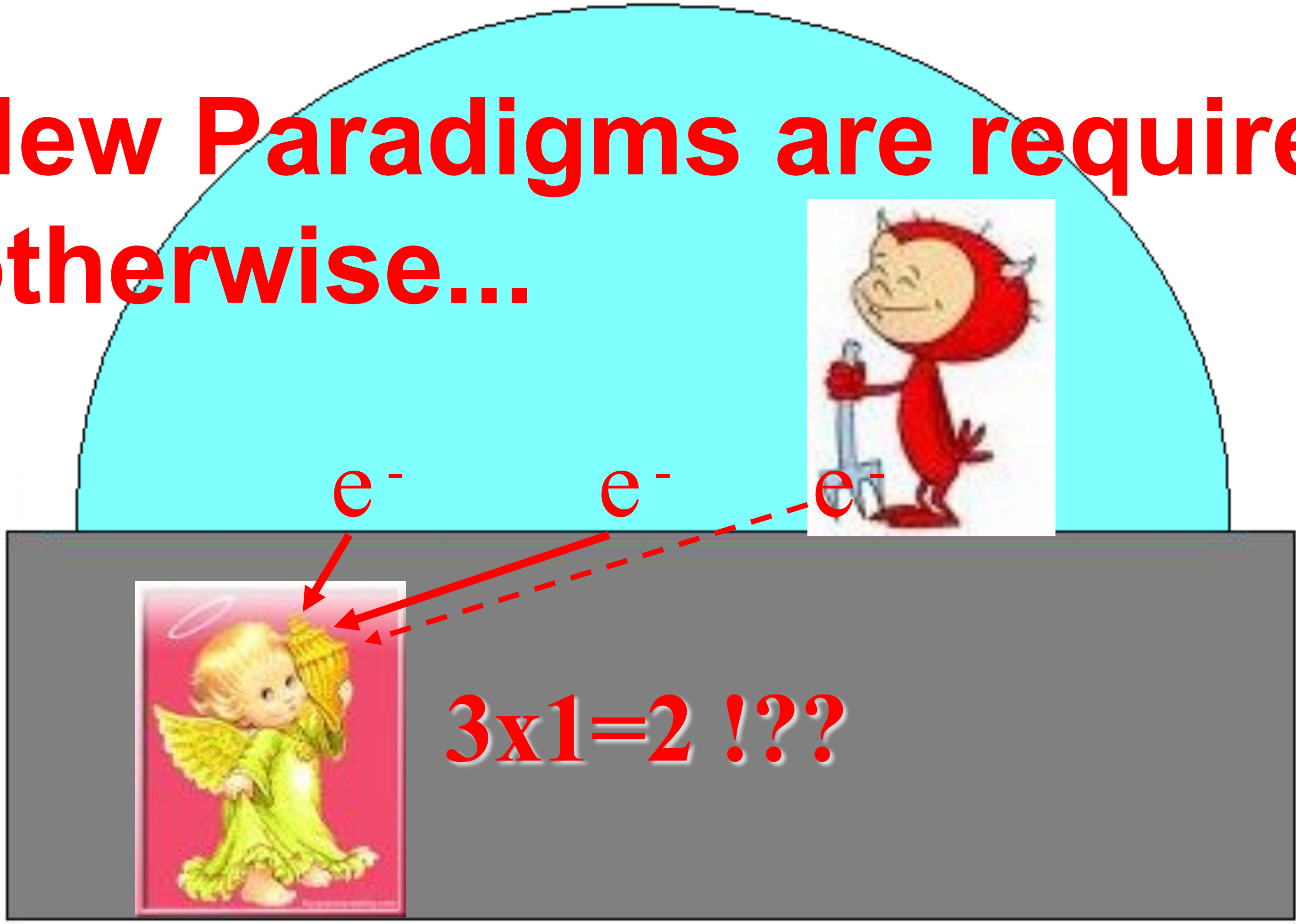
11. Circuits for metabolites detection in Fixed-Voltage
12. Circuits for metabolites detection in Scanning Voltage
13. Circuits for DNA Capacitance and Amperometric Detection
14. Circuits for metabolites detection with multi-panel systems
15. Summary on Bio/nano/CMOS interfaces co-design

Aim of the course



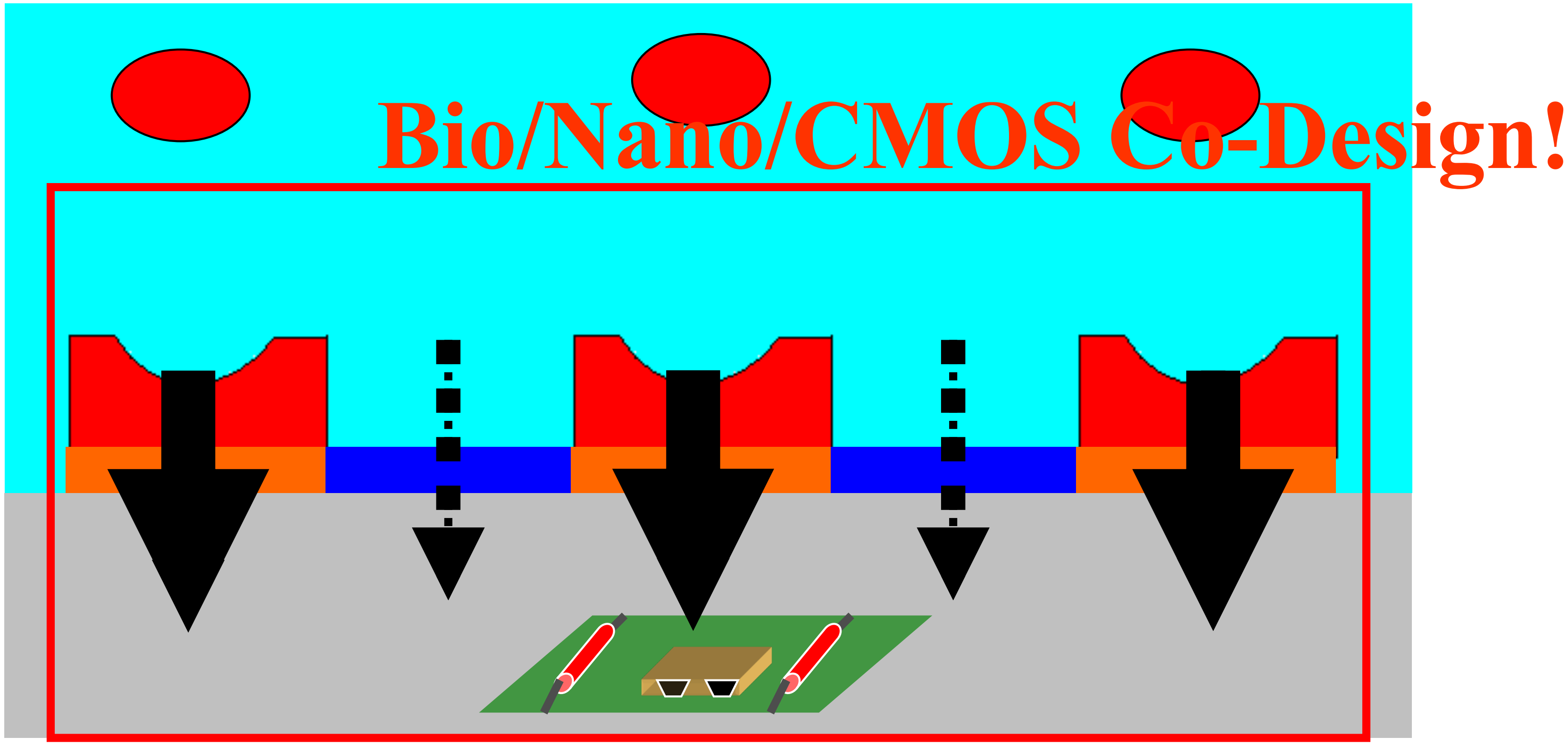
New paradigms for Nano-Bio-CMOS co-design are required to succeed in chip bio-sensing

New Paradigms are required otherwise...



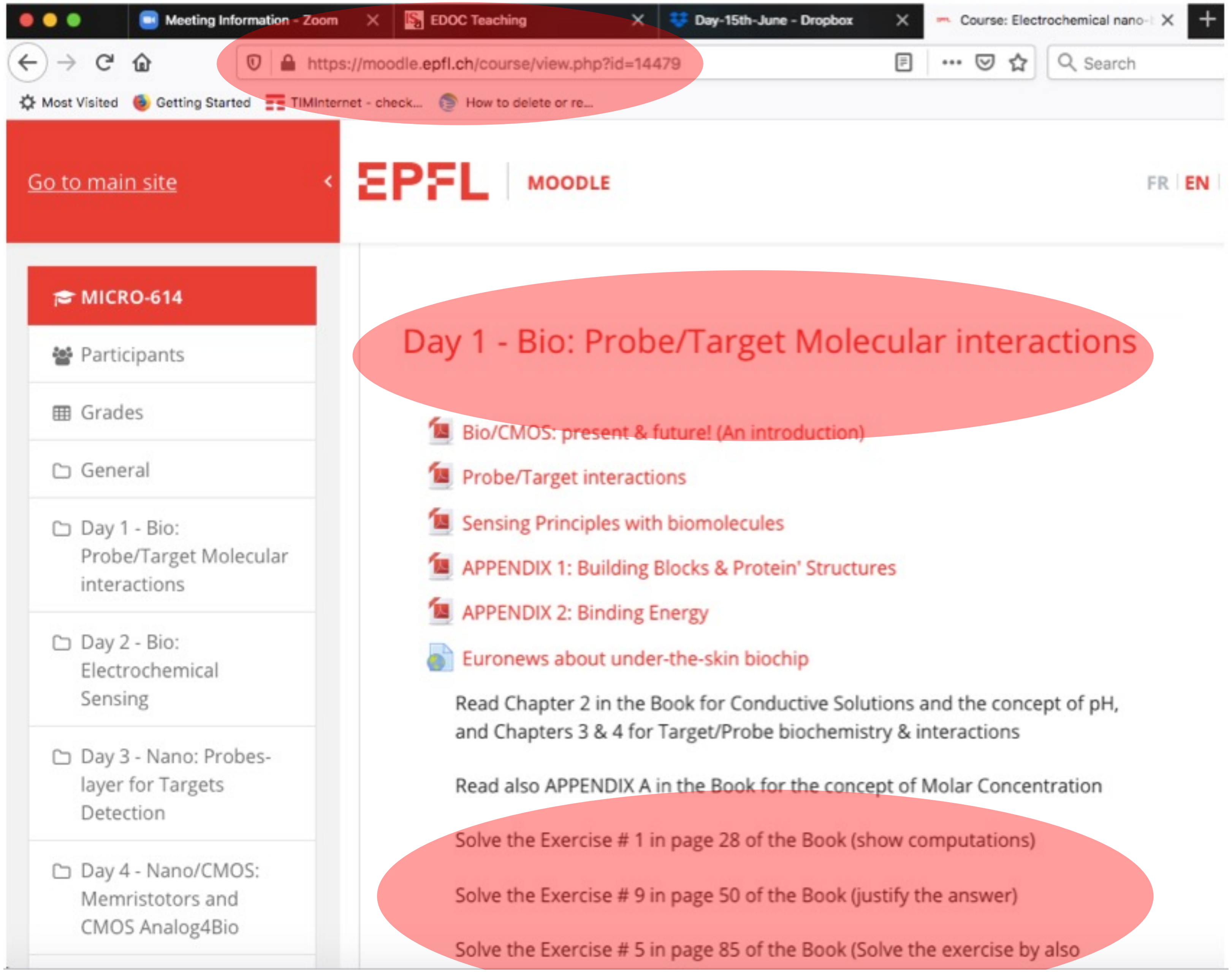
Excellent CMOS technology is not sufficient if molecules are not doing their own job at the Bio/CMOS interface!

CMOS/Sample interface



The interface between the CMOS circuit and the bio-sample needs to be deeply investigated and organized

Exercise' Solutions to get the Credit



Final Work to get the Credit

Final work for the grade

Highlighted

1. For the final Grade, the students have of write an IEEE-style essay-paper (two column, max 3 pages, plus one of bibliography), with which they have to demonstrate they understanding about the course content. Hard **deadline** to submit is in 4 weeks from now, namely the **end of July**. This essay-paper has to be submitted by email to sandro.carrarra@epfl.ch, together with all the solutions of the above-mentioned exercises proposed by the book.

2. This assay-paper needs to propose a solution to address the detection-need required student-by-student here below (please, search for your name). The proposed solution needs to address one of the electrical detection-techniques deeply-discussed during the course. Solutions with optical detections are not accepted.

3. This assay-paper is an ¨exercise of style¨ and, therefore, it might contain just hypothesis or assumptions. These need to be scientifically based on literature: e.g., if a certain sensitivity has been published for a similar target/probe biochemical-system, then the same sensitivity might be taken as assumption for the detection proposed by the student, with reference to the paper with similar system.

4. This assay-paper needs to report the typical concentration range of the target molecules for the proposed application. Then, the paper needs to contain and to explain the three layers that constitute the proposed Bio/CMOS interface: the bio, the nano, and the CMOS aspects need all to be explicitly mentioned and elaborated, each of them in a separated paper-sections. The bio part needs to be deeply explained in terms of the provided detection-technique and in terms of the proposed electrodes-functionalization. The nano part needs to be deeply explained in terms of the improved sensing performance. The CMOS part needs to be deeply explained in terms of the provided electronic frontend-functionality.

5. This assay-paper might be also written by student' couples: two students max per paper. In such a case, the assay-paper needs to address the two detection-needs proposed individually to each of the two students. Therefore, in such a case, the assay-paper needs to propose a multi-panel detection system. In such a case, the assay-paper will be co-authored by the two students. Therefore, the acknowledgement paragraph of the paper needs to report who-has-done-what in contributing to the paper.

Thank you to had chosen the EPFL PhD course on Electrochemical Nano-Bio-Sensing and Bio/CMOS interfaces

Coordinates

Sandro Carrara Ph.D
EPFL - Swiss Federal Institute of Technology in Lausanne – Switzerland

Web: https://www.epfl.ch/labs/bci/
Email: sandro.carrara@epfl.ch
Social: https://www.facebook.com/sandro.carrara.56