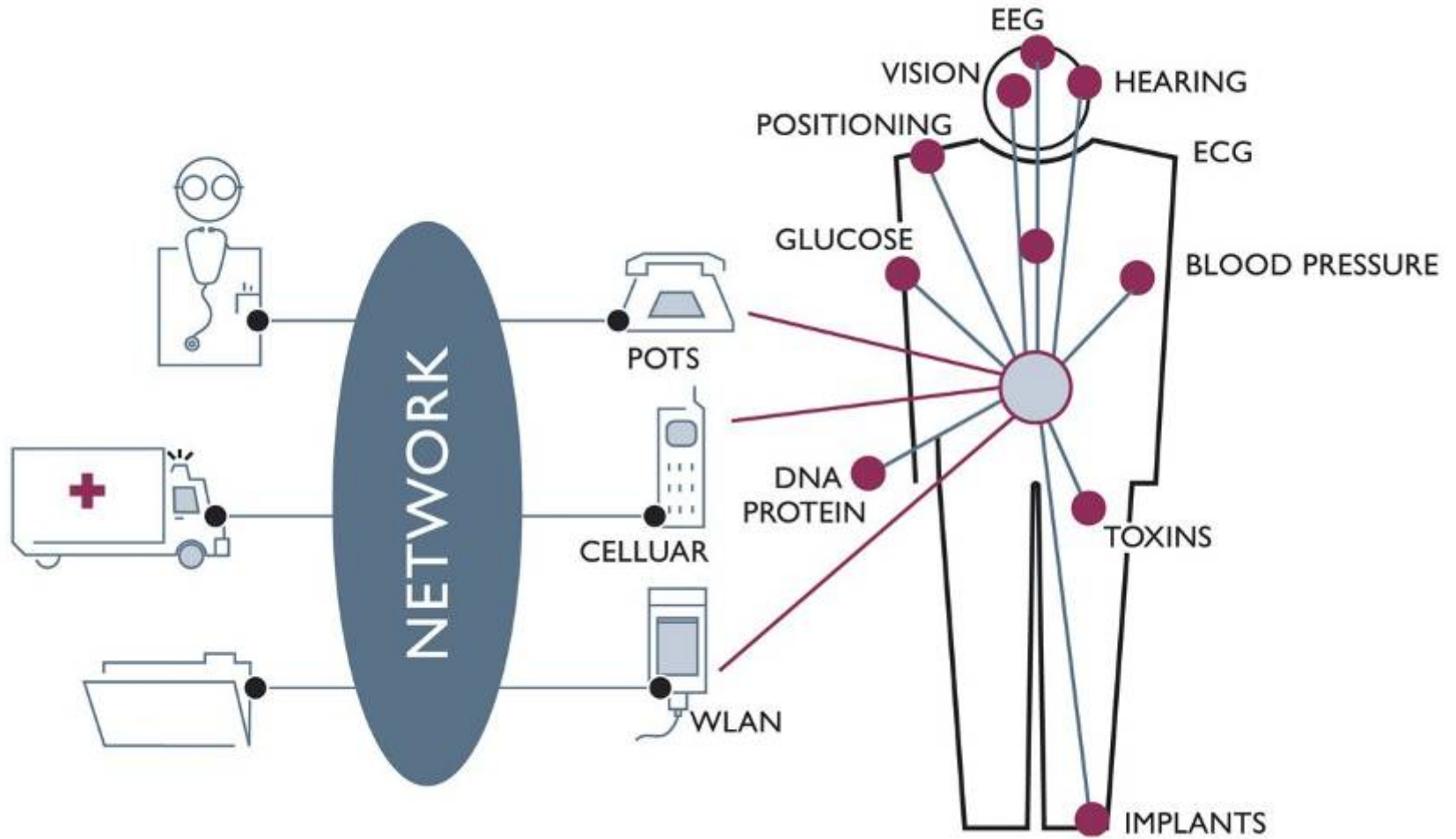


# Human+ +: Emerging Technology for Body Area Networks

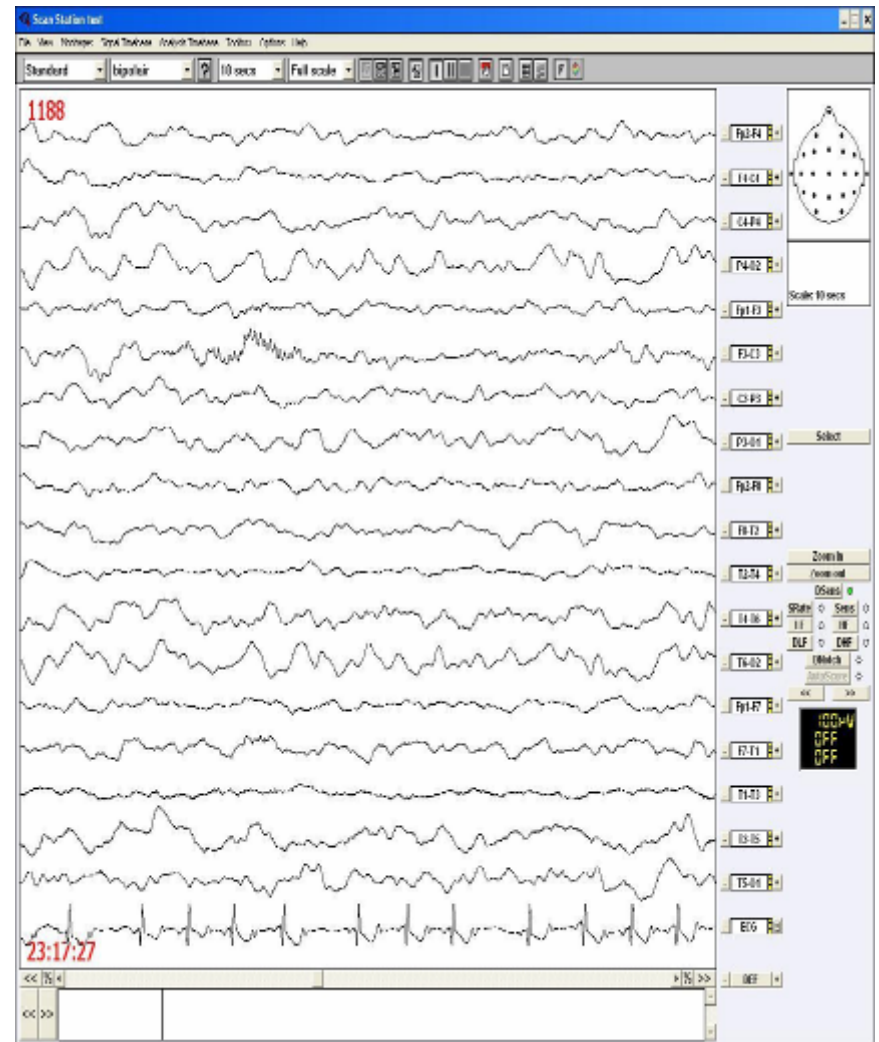
**CMOS Emerging Technologies Workshop  
Banff, Canada, July 21<sup>st</sup> 2006**

Bert.Gyselinckx@imec-nl.nl  
Program Director

# Human++ Vision



# 1<sup>st</sup> Generation 24 channel Wireless EEG System 2002



# Patient centric personalized healthcare ...

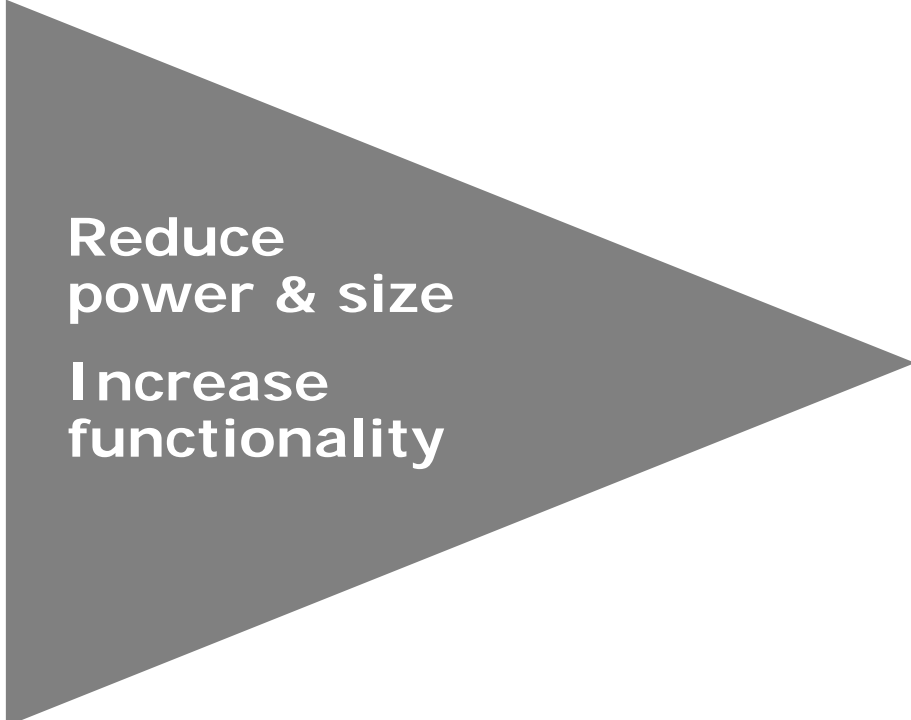


# Wireless autonomous microsystems as enabler for patient centric care

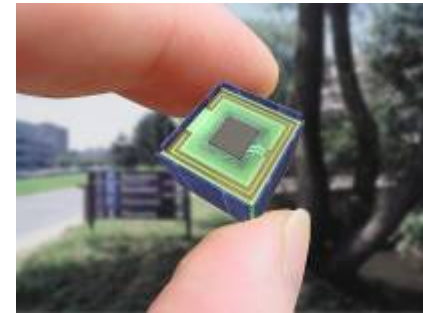
**2002**



**300 cm<sup>3</sup>**  
**140 mW**

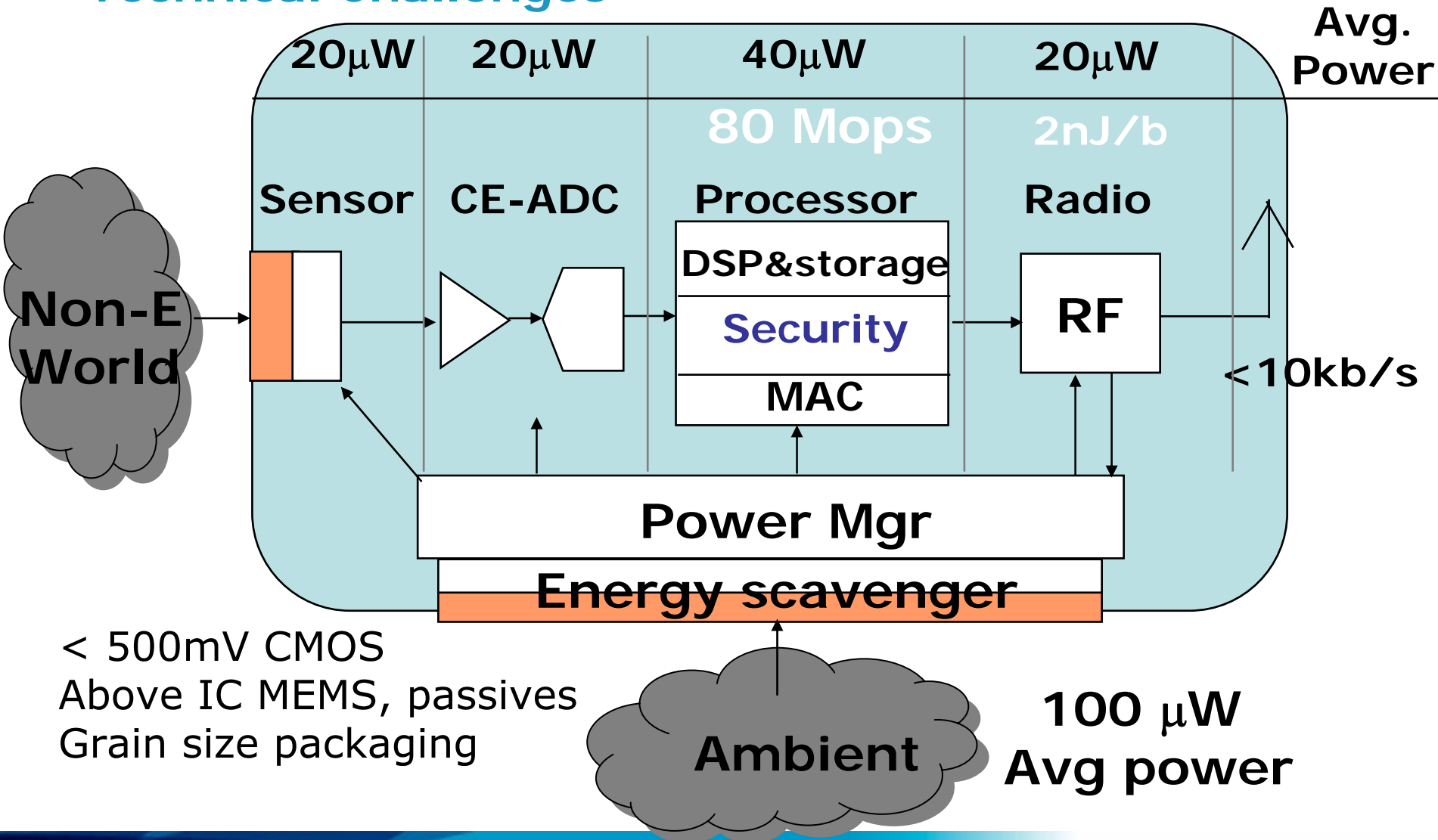


**2010**

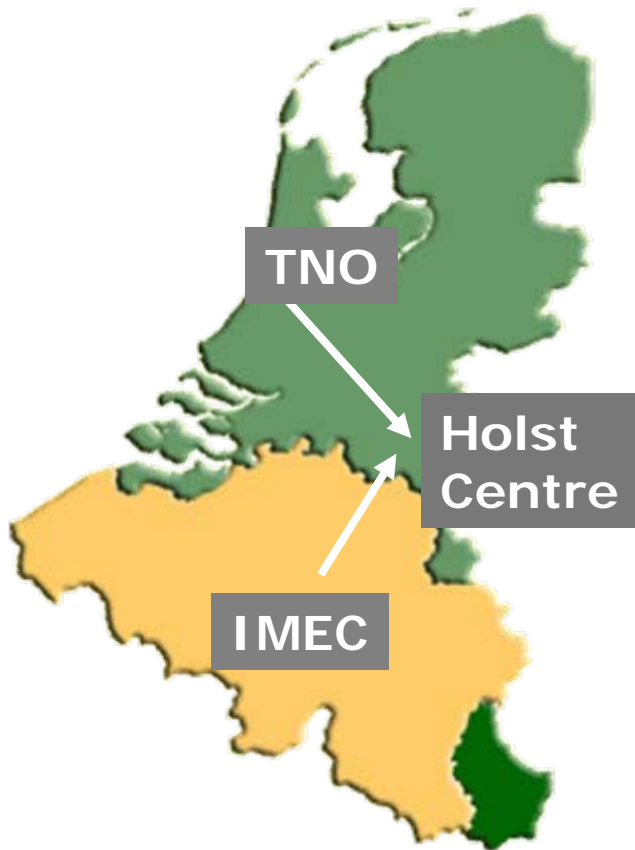


**1 cm<sup>3</sup>**  
**100 μW**

# Technical Challenges



## IMEC and TNO create the Holst Centre ...



- to create generic technologies for *wireless autonomous transducer solutions* and for *systems-in-foil*
- In program partnership with industry and universities
- Creating critical mass; 70 fte in 2006, 220 fte in 2010
- [www.holstcentre.com](http://www.holstcentre.com)

# Location at HTC



MiPlaza lab facilities



Located at HTC 48

# Wireless Autonomous Transducer Solutions Program

**Strategic programs:**  
windows on application areas, guiding choices in the technology programs

**Technology programs:**  
Development of key technologies

Ultra Low Power Wireless

Ultra Low Power Signal Processing

Micro Power

Sensors & Actuators

Integration technology

Medical  
&  
Lifestyle

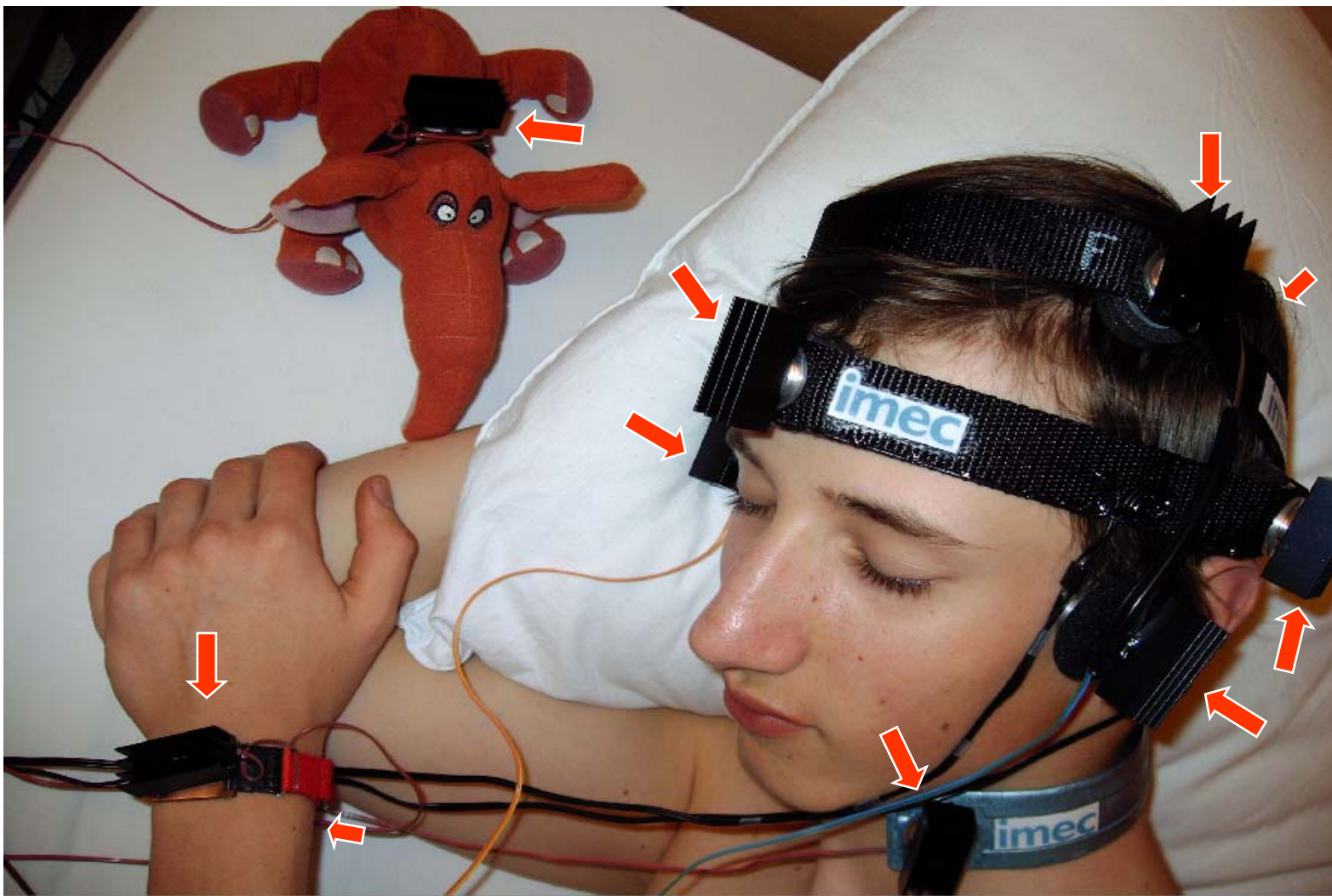
Process  
Automa-  
-tion

Agri-  
culture

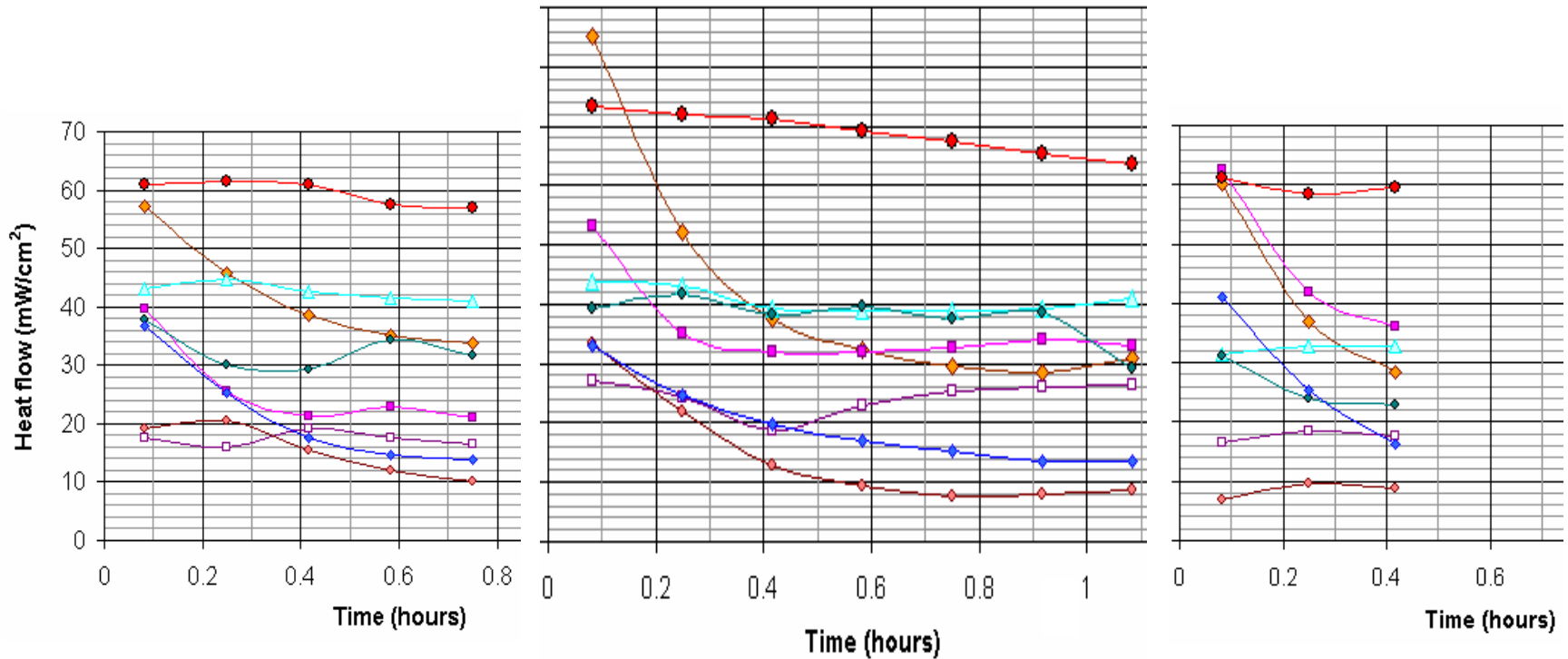
Mobile  
Gaming



## Body Temperature as Energy Source



# Measured Heat Flow



**Start sleep at 16:00**

**Start sleep at 18:00**

**After sleep at 07:00  
(resting in the bed)**

—◆— 2 earphones

—■— neck

—●— forehead

—▲— hair up

—□— hair to pillow

—◇— hair back

—◆— radial up

—◆— watch to linen

# Thermal Energy Scavenger produces > 100µW

Human thermal energy  
mW/cm<sup>2</sup>



```

Command Prompt
PowerLog (c) IMEC 2004 by Tom Torfs
Serial/USB datalogging utility for wireless sensor power modules
Starting capture from com? to powerlog.csv... press any key to abort.
Data #1: battery: 2.478 U, input: 1.124 U, charging: YES, temp.: 19.1 C
Data #2: battery: 2.475 U, input: 1.107 U, charging: YES, temp.: 18.6 C
Data #3: battery: 2.475 U, input: 1.041 U, charging: YES, temp.: 18.3 C
Data #4: battery: 2.478 U, input: 1.010 U, charging: YES, temp.: 18.3 C
Data #5(2): battery: 2.475 U, input: 0.968 U, charging: YES, temp.: 18.0 C
Data #6(9): battery: 2.475 U, input: 1.426 U, charging: YES, temp.: 17.7 C
Data #7(9): battery: 2.475 U, input: 1.168 U, charging: YES, temp.: 18.3 C
Data #8(15): battery: 2.475 U, input: 0.724 U, charging: NO, temp.: 20.8 C
Data #9: battery: 2.475 U, input: 0.726 U, charging: YES, temp.: 20.0 C
Data #10: battery: 2.475 U, input: 0.847 U, charging: YES, temp.: 20.0 C
Data #11(1): battery: 2.475 U, input: 0.818 U, charging: YES, temp.: 20.0 C
Data #12: battery: 2.475 U, input: 0.828 U, charging: YES, temp.: 20.0 C
Data #13: battery: 2.478 U, input: 0.833 U, charging: YES, temp.: 20.0 C
Data #14(2): battery: 2.475 U, input: 1.063 U, charging: YES, temp.: 19.1 C
Data #15(6): battery: 2.475 U, input: 0.887 U, charging: YES, temp.: 18.3 C
Data #16(2): battery: 2.475 U, input: 0.869 U, charging: YES, temp.: 18.3 C
Data #17(3): battery: 2.475 U, input: 0.721 U, charging: YES, temp.: 19.1 C
Data #18: battery: 2.475 U, input: 0.787 U, charging: YES, temp.: 19.4 C
Data #19: battery: 2.478 U, input: 0.814 U, charging: YES, temp.: 19.4 C
Data #20: battery: 2.475 U, input: 0.720 U, charging: YES, temp.: 19.1 C
Data #21(1): battery: 2.475 U, input: 0.758 U, charging: YES, temp.: 19.4 C
Data #22: battery: 2.475 U, input: 0.683 U, charging: NO, temp.: 19.7 C
    
```

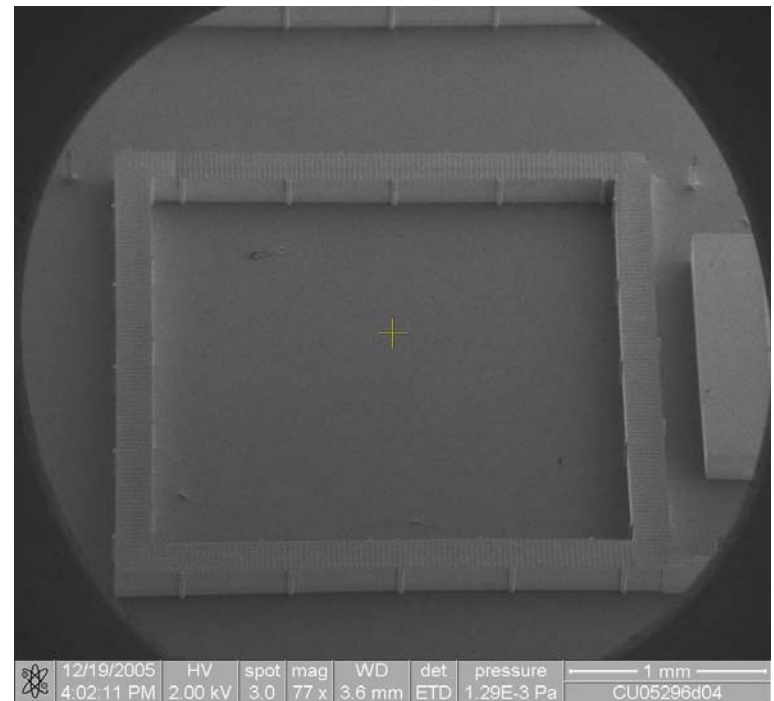
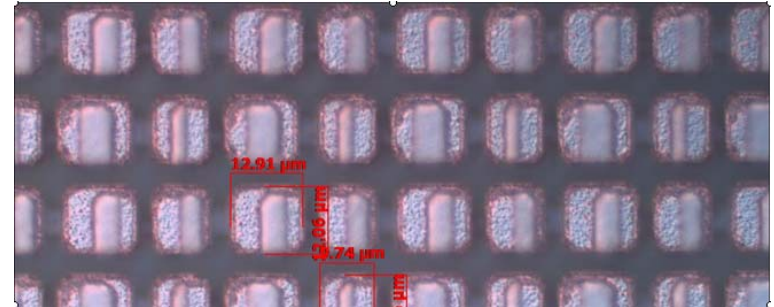
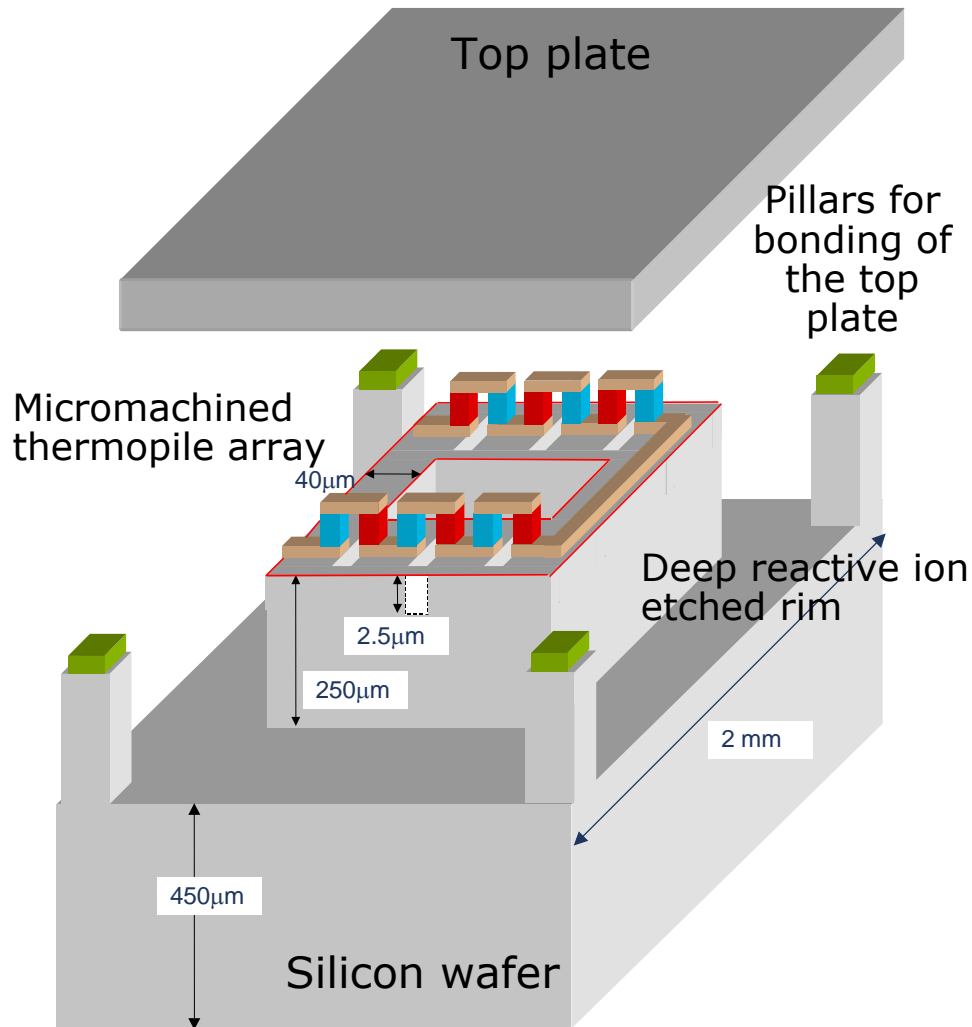


## Heat – Electricity - Light

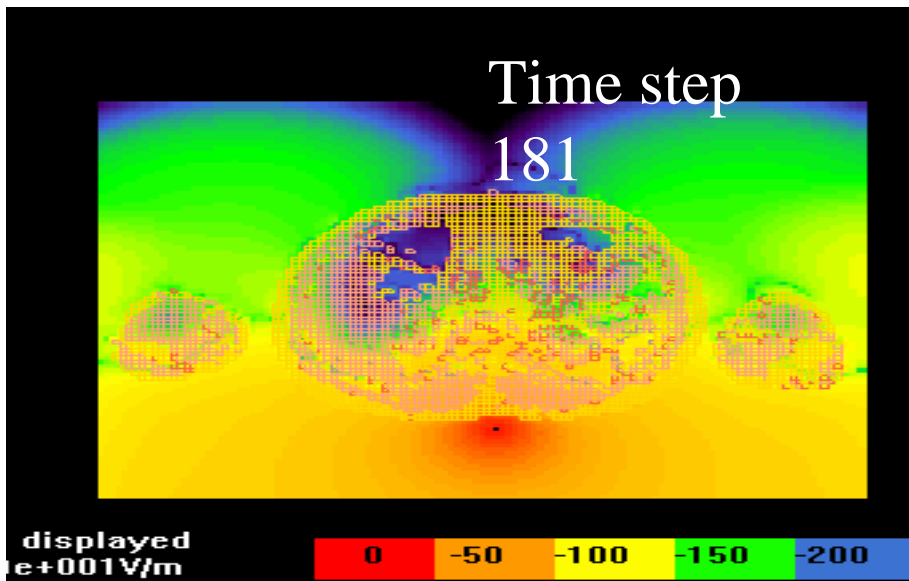
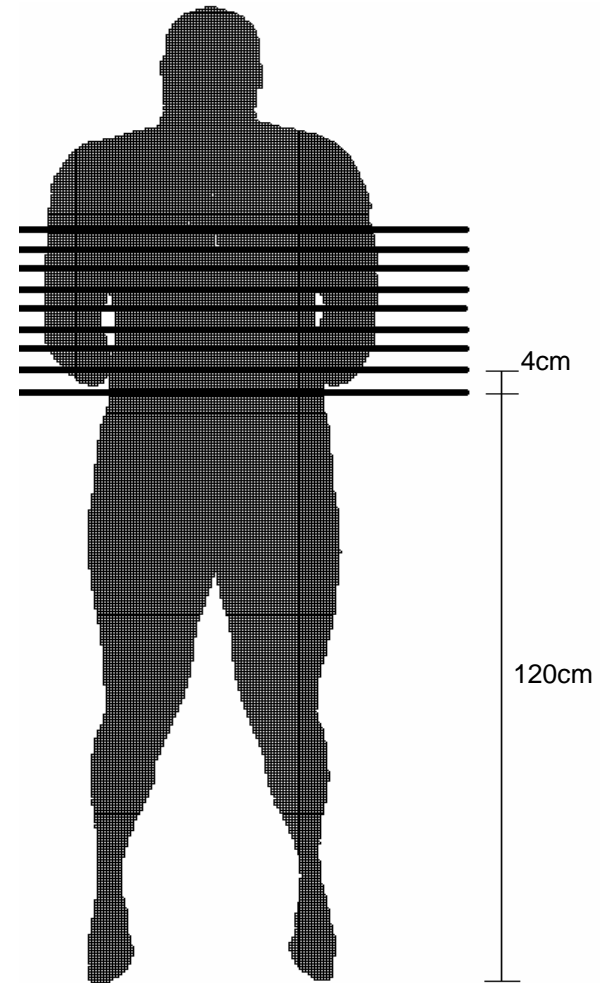
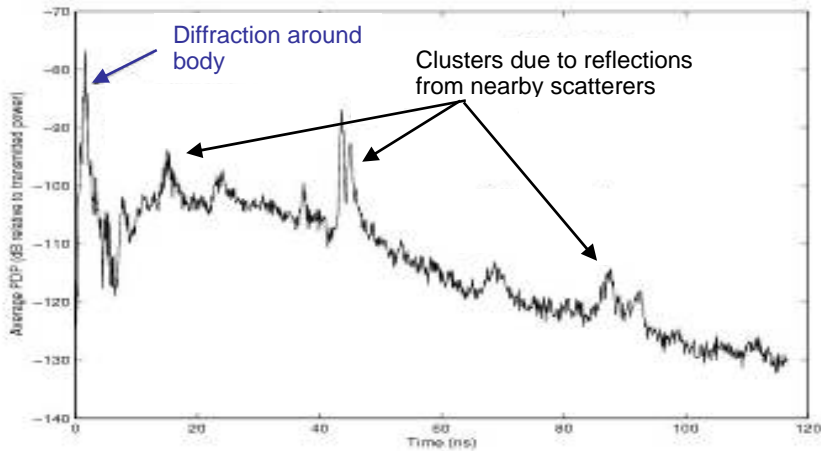


10 LEDs: 1.58 V @ 1.6 mA = 2.5 mW

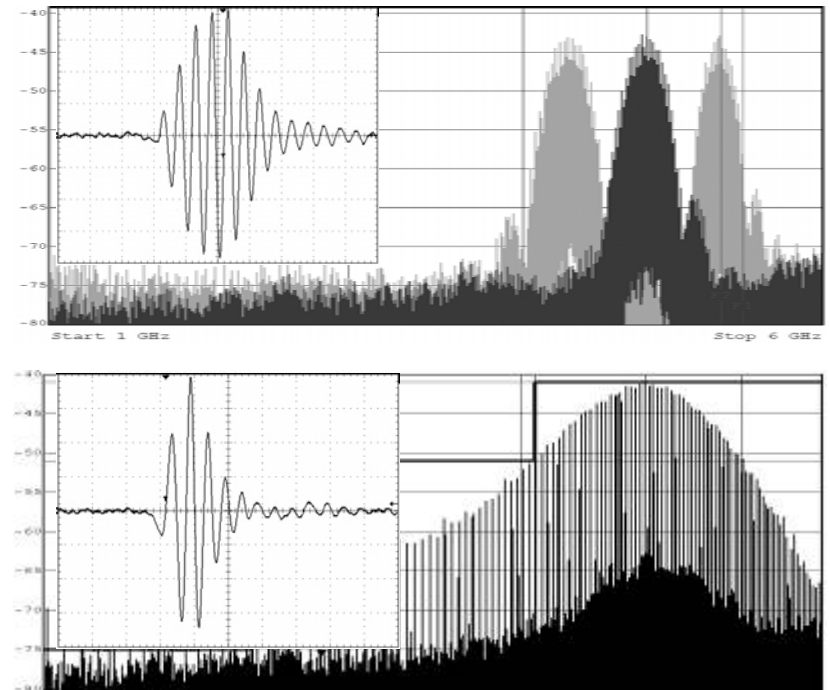
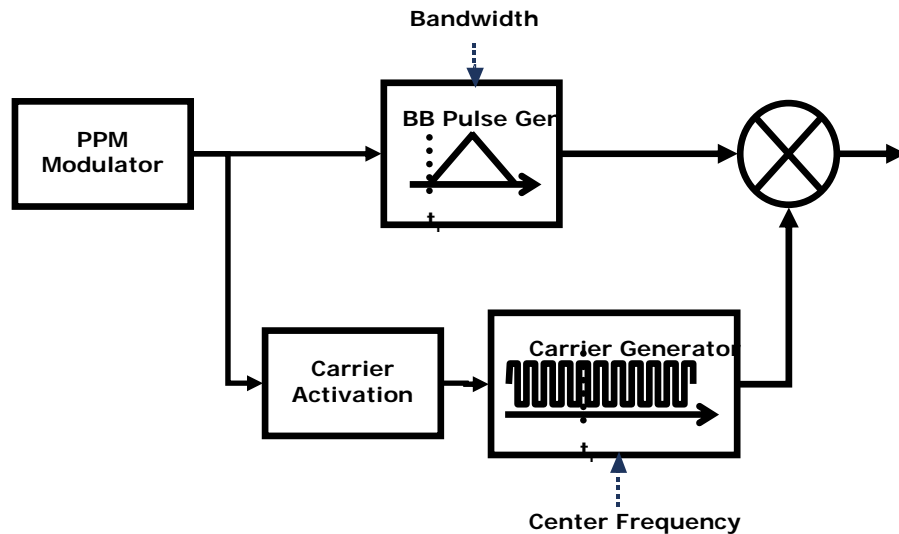
# Integrated polySiGe thermal energy scavengers



# Wireless Channel Modeling and Simulation



# First of a kind carrier based pulsed UWB works at 50pJ/pulse [ICU05]



180 nm CMOS

Carrier based IR

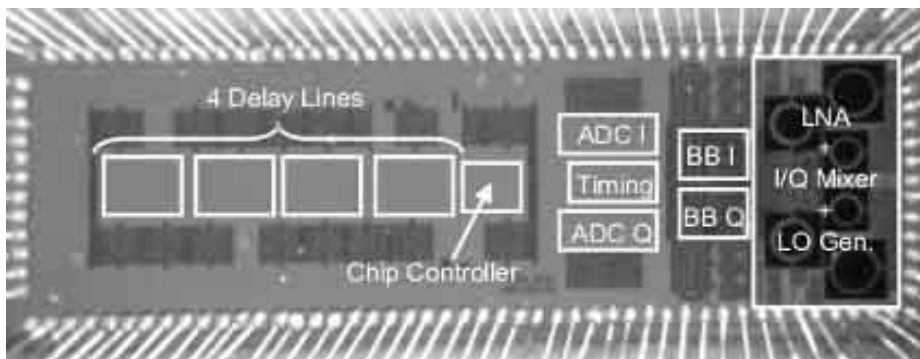
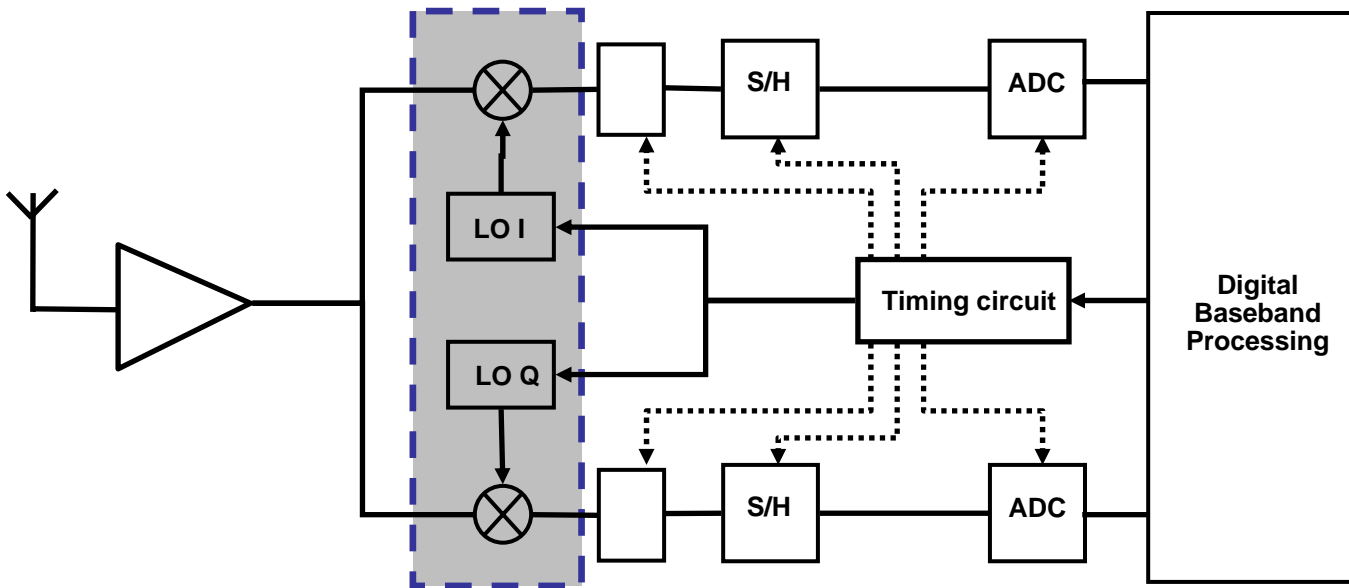
Pulse Position Modulation

Max. Pulse rate: 40 MHz

Energy per pulse: 50 pJ

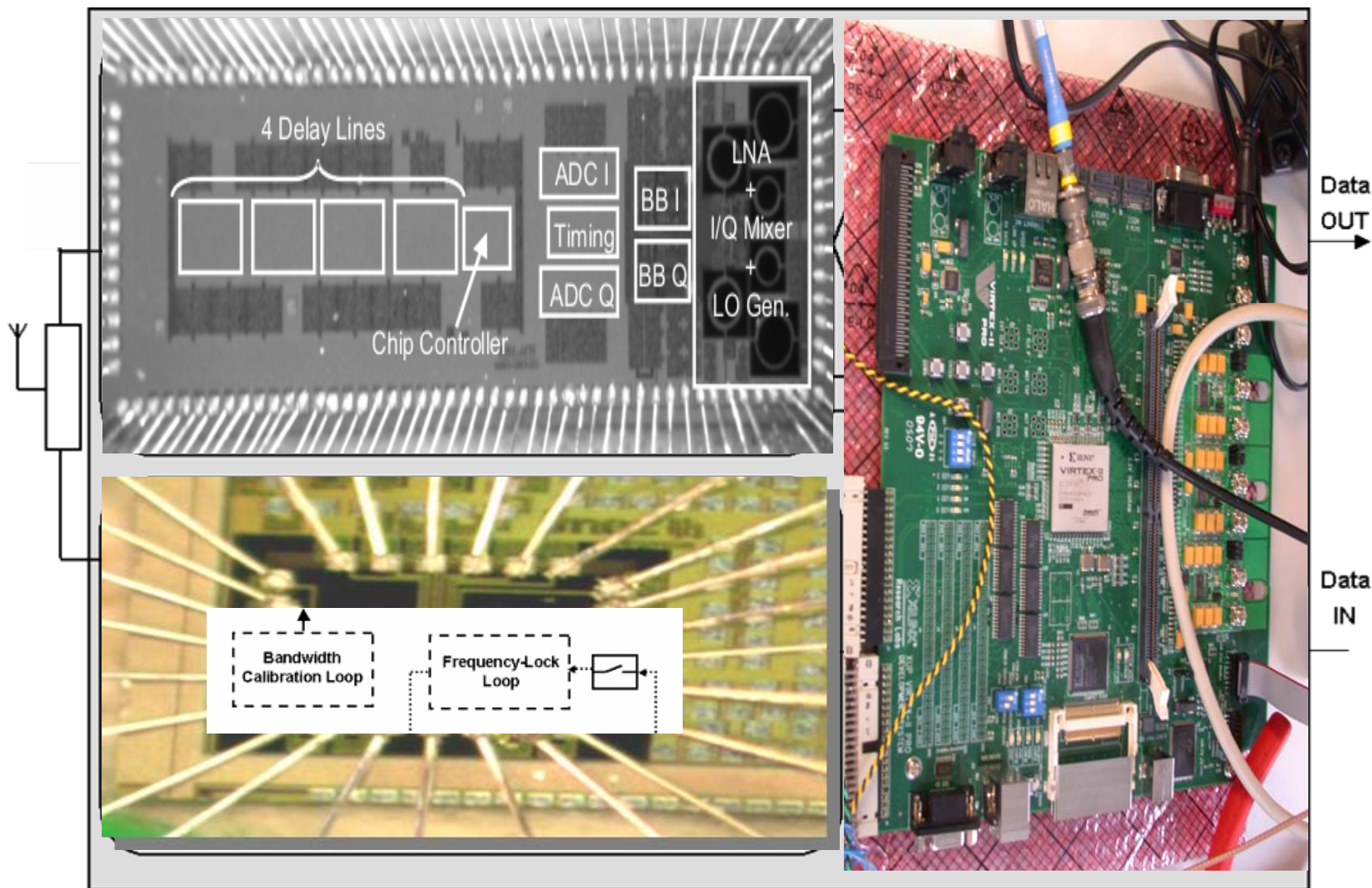
Power: 5  $\mu$ W @ 10 kbps (10 pulses per bit)

## First of a kind UWB receiver [ISSCC06]

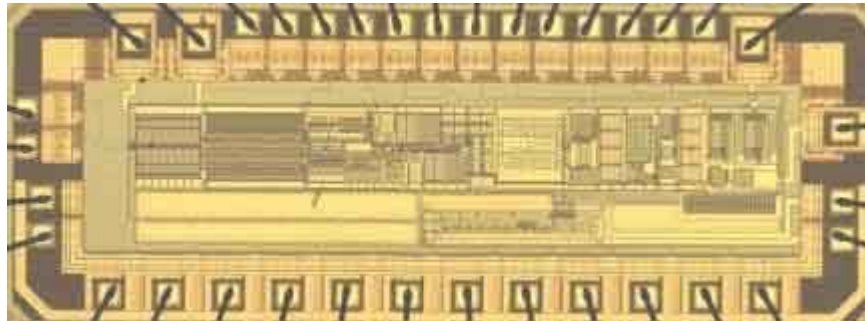
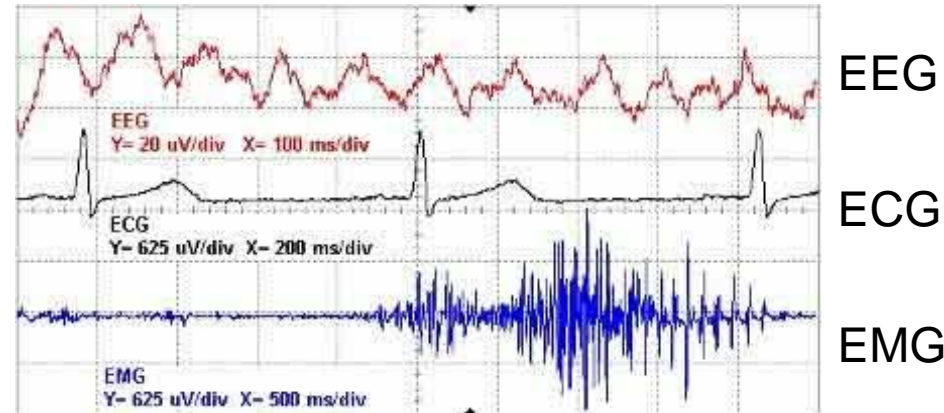
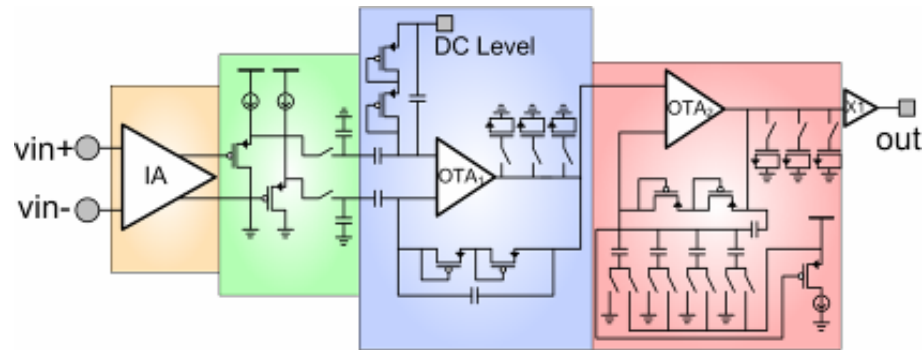


180 nm CMOS  
 3.1-5GHz (UWB Lower Band)  
 20MHz pulse rate  
 15mA @ 1.8V Supply

# UWB Transceiver Architecture

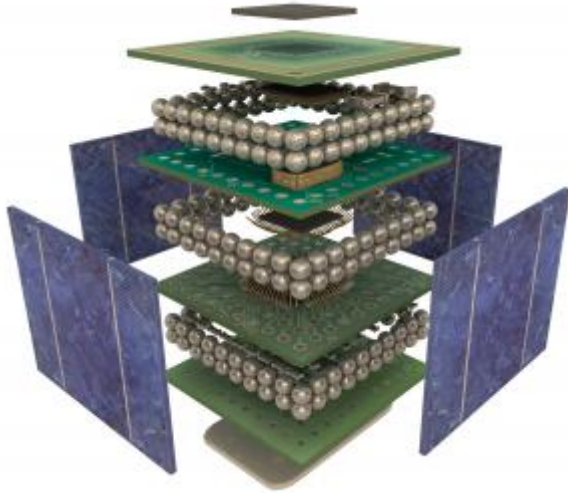


# EEG, ECG, EMG read out at ultra low power [ISSCC06]

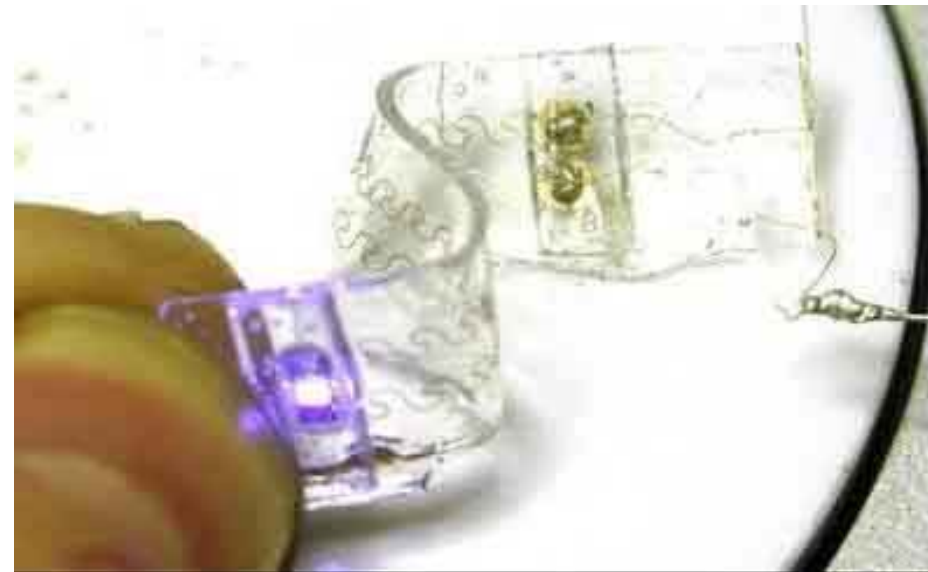
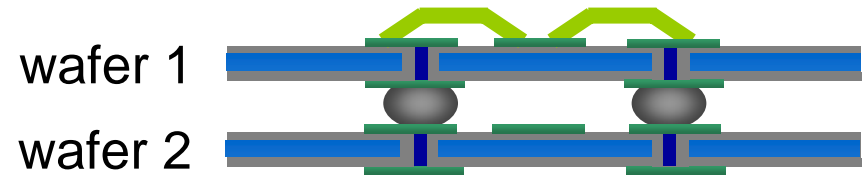


- Electronically Selectable Gain: 400 - 2600
- Adjustable Bandwidth
- Ultra Low Power Dissipation  $21 \mu\text{A}$  @ 3V
- Low Input Referred Noise =  $70 \text{ nV}/\sqrt{\text{Hz}}$
- High CMRR = 120 dB
- 110 dB CMRR at 50 mV electrode offset

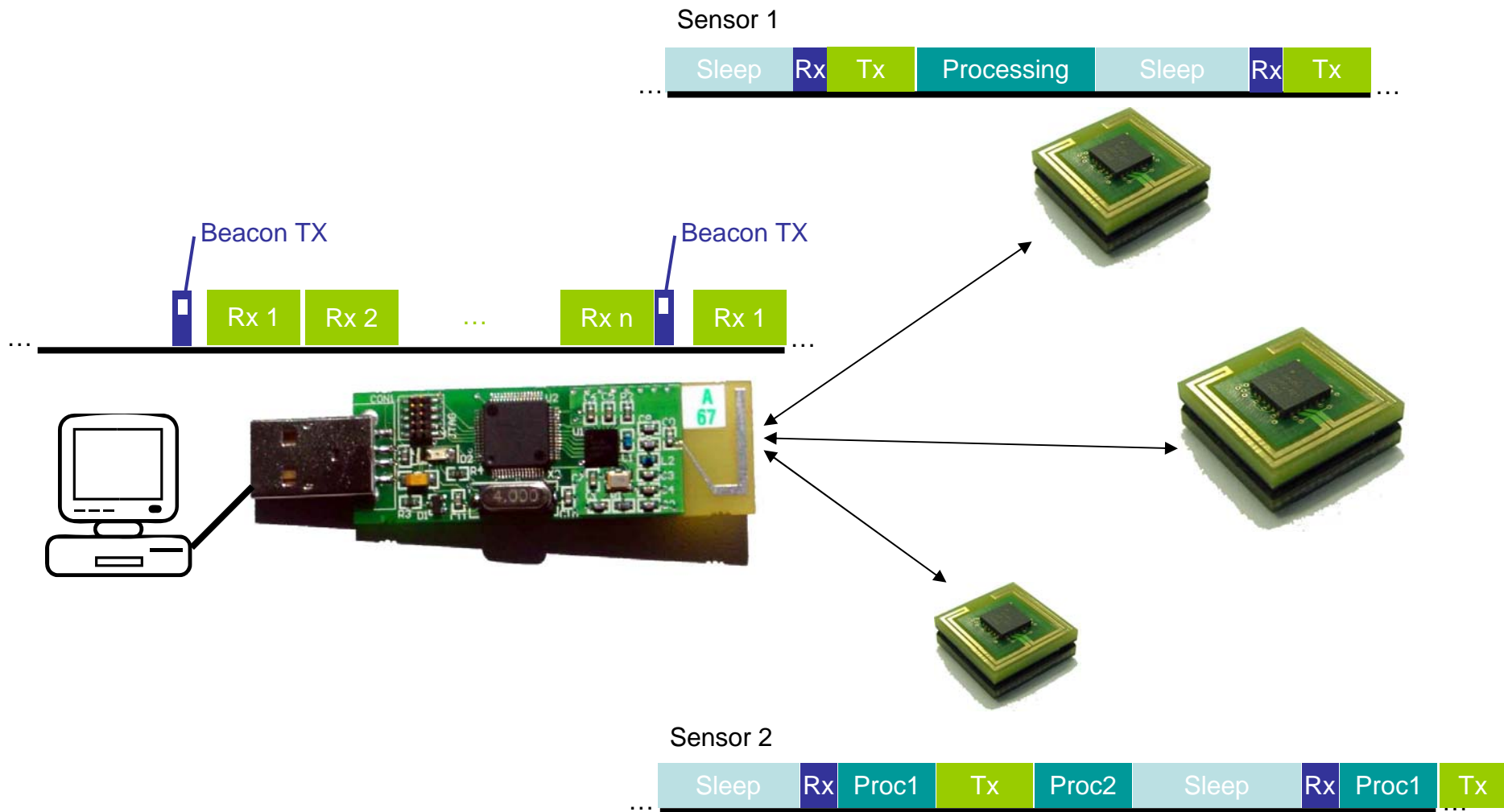
# Advanced Packaging and Interconnect



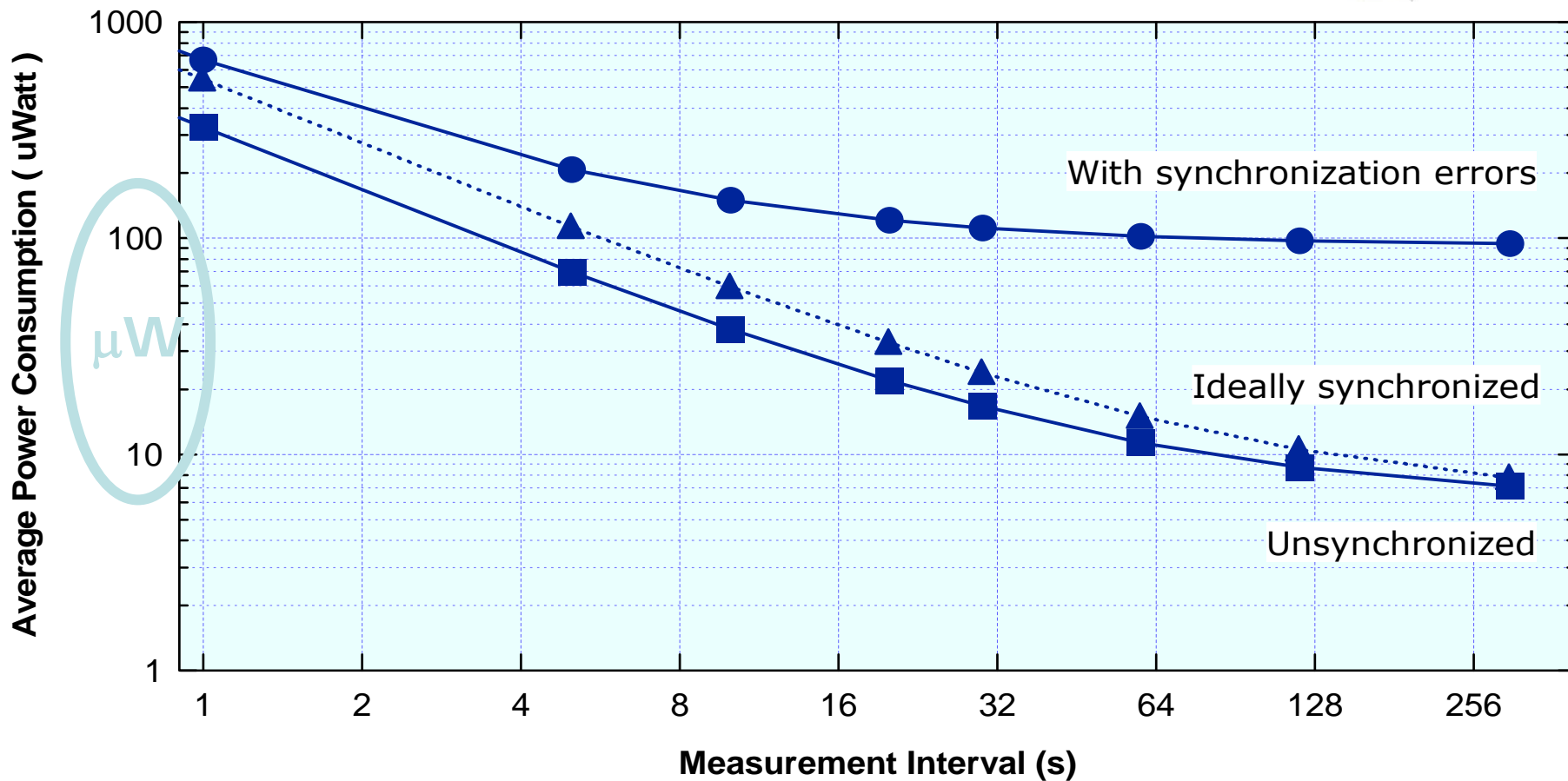
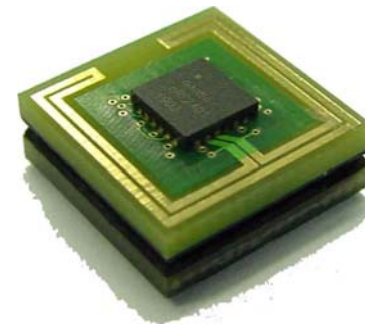
- **Advanced IC-centric techniques:**
  - through-wafer via's
  - wafer thinning
  - high-density solder interconnects



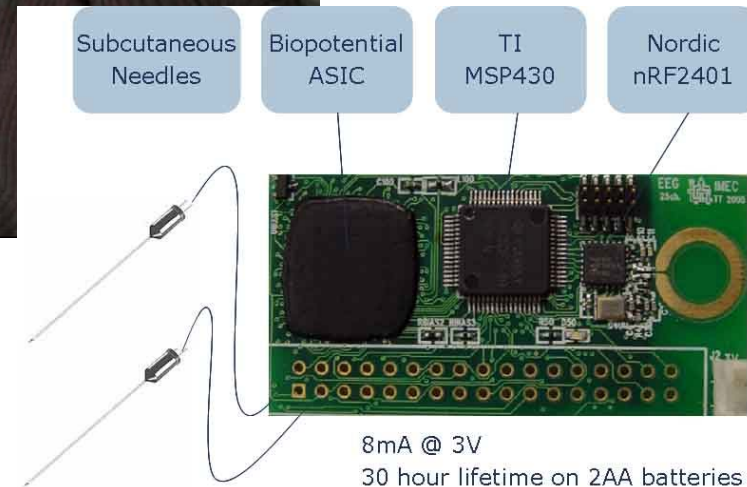
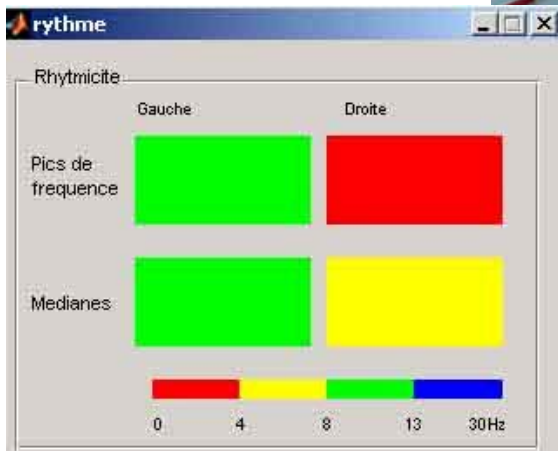
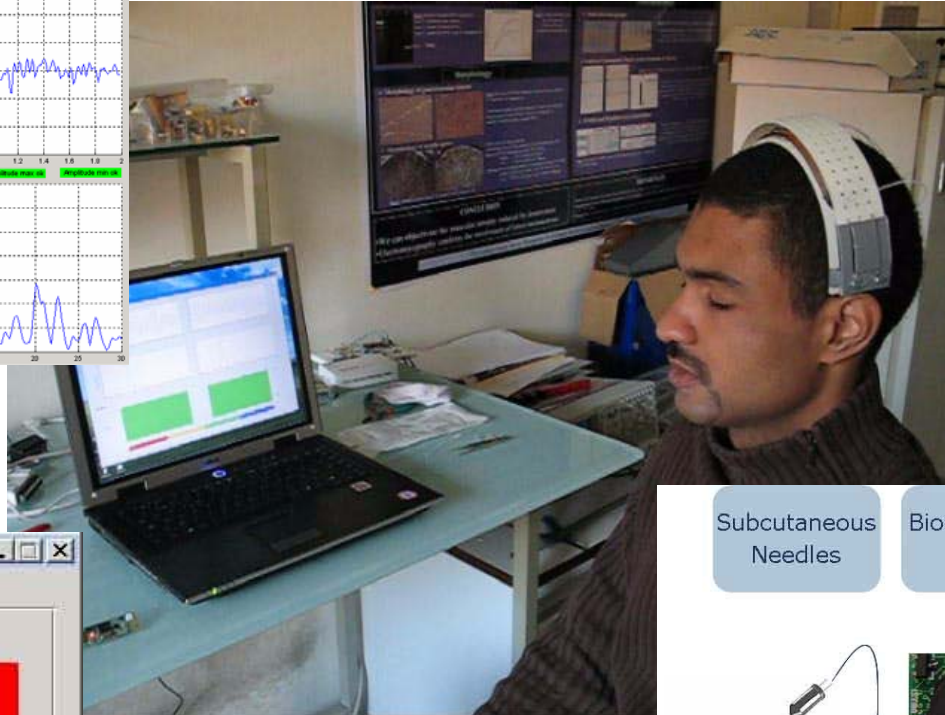
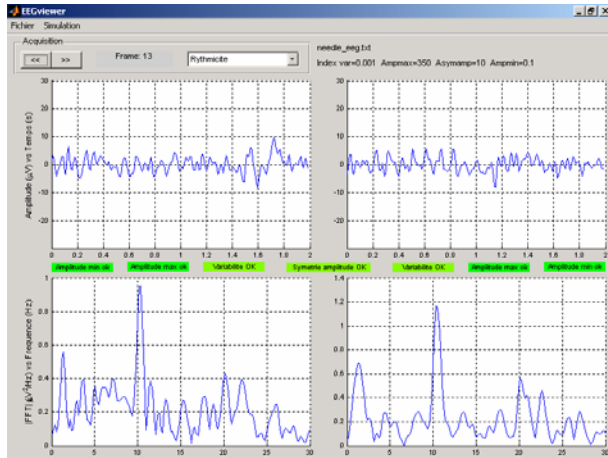
# Medium Access



# Power consumption of sensor node



# Case: Ambulatory Color EEG





Open Innovation by IMEC-NL and TNO



Feel secure

Save energy

Lower cost

Save time

Keep track

Stay tuned

Anticipate

Improve performance