Wireless Biomedical Sensing

Challenges and Opportunities

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Tampere, Finland

Content

- Institute of measurement and information technology (MIT), Sensor Technology group
- Wireless biomedical sensing
  - Requirements, technological challenges and possibilities, applications
- Short-range links
- Project examples (PROACT, TULE, WISEPLA)
- BIRCA Consortium
- ITALH – International cooperation project
- Conclusion

Measurement and Information Technology (MIT)

Research and teaching

- Research and educational activities of the institute are focused on the subjects of fundamental measurement science, sensor technology and measurement information technology
- Special emphasis is placed on developing practical and theoretical skills through experimental work and research projects

Staff

- 3 full-time professors: Jouko Halttunen (Head of the institute), Jukka Lekkala (Sensor Technology), and Risto Ritala (Measurement Information Technology)
- 2 teaching assistants, 1 laboratory engineer, 2 secretaries
- ~30 researchers and research assistants

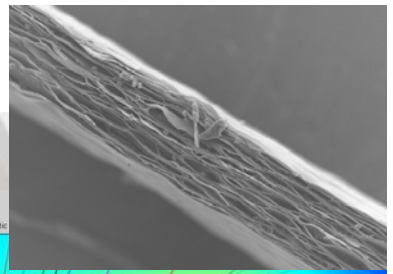
MIT in numbers

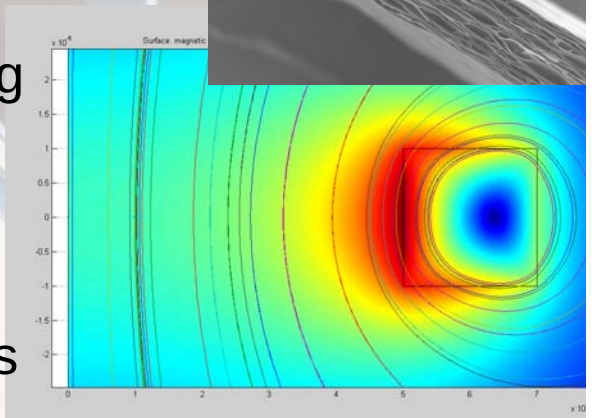
- Total budget 1.587 M€ (2005)
- 11 MSc theses (2005)

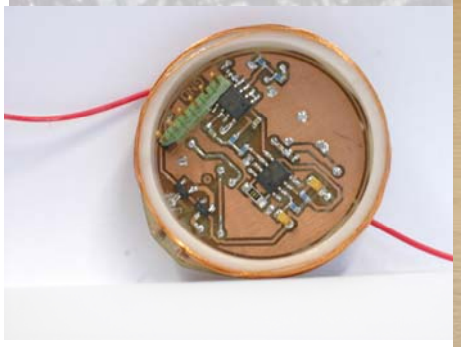
Sensor Technology

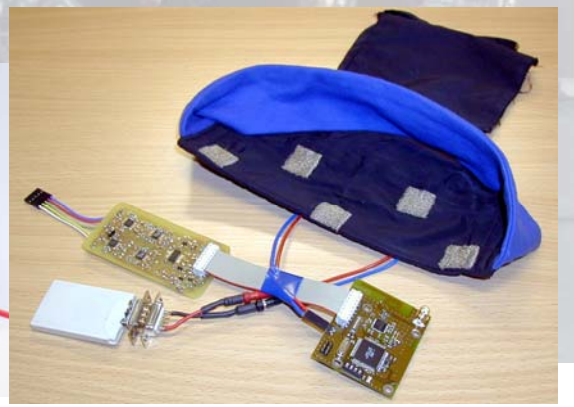
Teaching and research

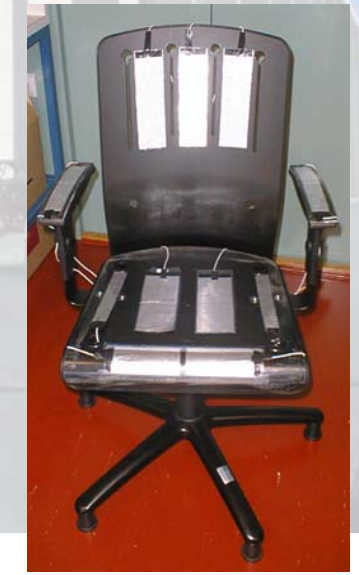
- Sensor physics and new sensing materials
- Modelling and simulation
- Focus in microsensors, biosensors and wireless sensors
- Applications of commercial sensors
- 6 researchers, 6 research assistants

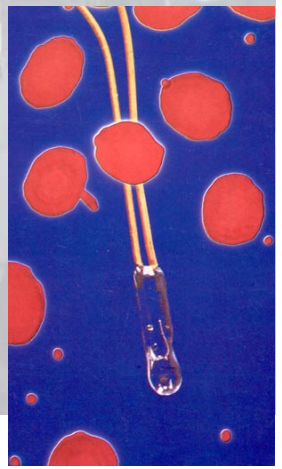












Measurement and Information Technology

Clean room facility

- The clean room has a 22 m^2 floor area and the class 7 (10000 particles per cubic foot), in a laminar flow cabinet the class is around 1000
- The room is equipped with **photolithography system** including a photoresist spinner, hot plate, mask aligner and exposure device (Karl Süss MJB-3, 2 μm resolution), wet etching station, a water purification system, and a microscope
- The laboratory is intended for **microsensor and biosensor prototyping**





New wireless biomedical sensing systems

- New technology, e.g. ambulatory or implantable wireless sensors, will dramatically change the way we understand healthcare today
- This development provides the enabling technology for real long term monitoring of physiological functions in sports, home health care as well as in hospital environment
- The healthcare system will become more mobile, demand driven, efficient, and person/patient friendly
- New wireless sensors and measurement systems have a huge market potential

Human Sensing

Diagnostics

- Bioelectrical and physiological measurements (ECG, arrythmia, other heart symptoms, EEG, EMG, blood pressure, ….)
- Biochemical assays (blood sugar, infarct markers, …)

Safety

- Monitoring of chronically ill patients (heart diseases, diabetes, epileptic events), alarms
- Monitoring at home and in nursing homes (elderly and demented people)

Sport, physical exercise, training

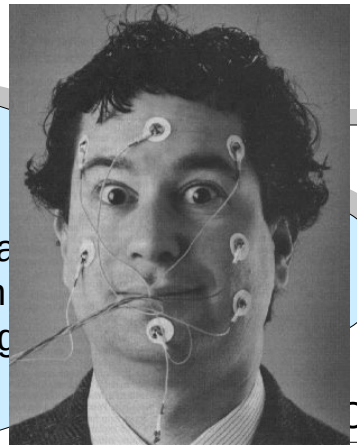
- Monitoring of physical condition and efficiency
- Control and feedback in training

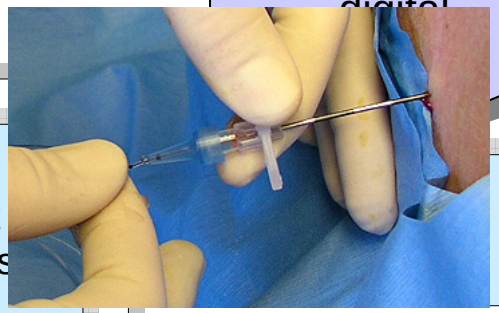
Ambient intelligence, smart devices, security

- Environment senses, recognizes and reacts (home, office, car)
- Smart user interfaces (telephone, PC, multimedia devices, digital-TV, games)

Physiological Measurements

Sensors…





Physical
or chemical para
condition
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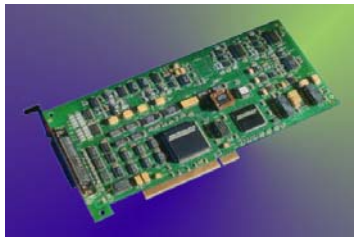
Capsule

Analog or
digital

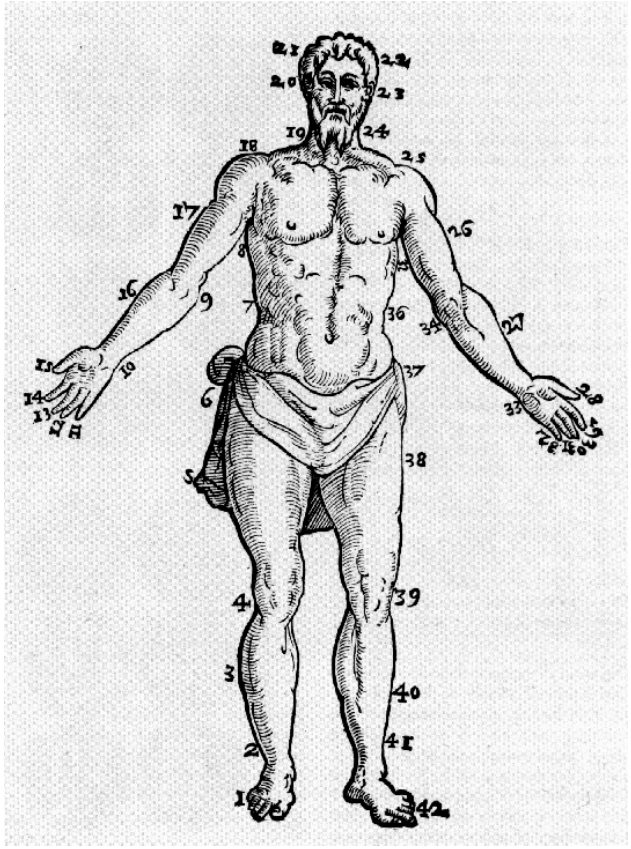
+ signal processing/data handling → measurement information



Biomedical Sensing – How?

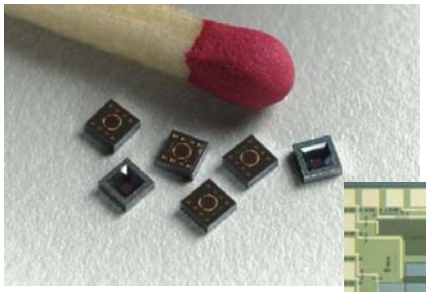
Requirements for new measurement devices:

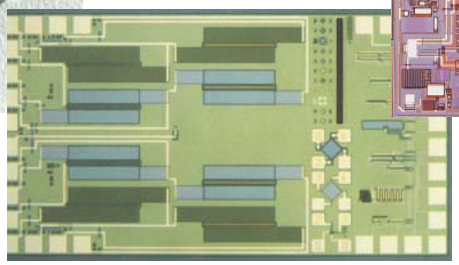
- Light weight and small size
- Flexible, soft, textile like material
- Biocompatible
- Easy to install and use
  → no wires, no connectors
- Possibly (partly) disposable
  → low priced
- Low power consumption
  → no or small batteries
  → energy harvesting
- Reliable and secure (data privacy)

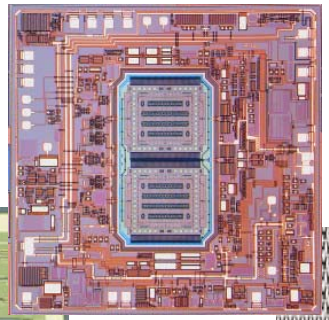


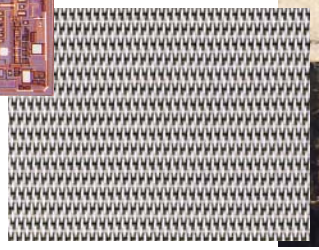
Light wireless measurement systems - What is needed?

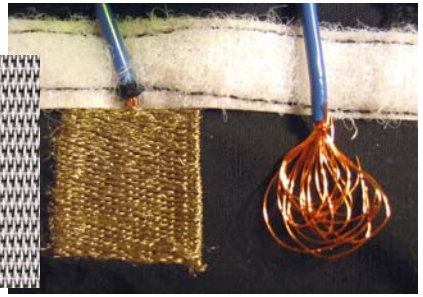
- Compact electrodes and sensors
  - New electrode materials
  - Silicon microsensors, nanosensors
  - *In vivo* biosensors and biochips
  - New sensing materials
  - New ideas for sensing



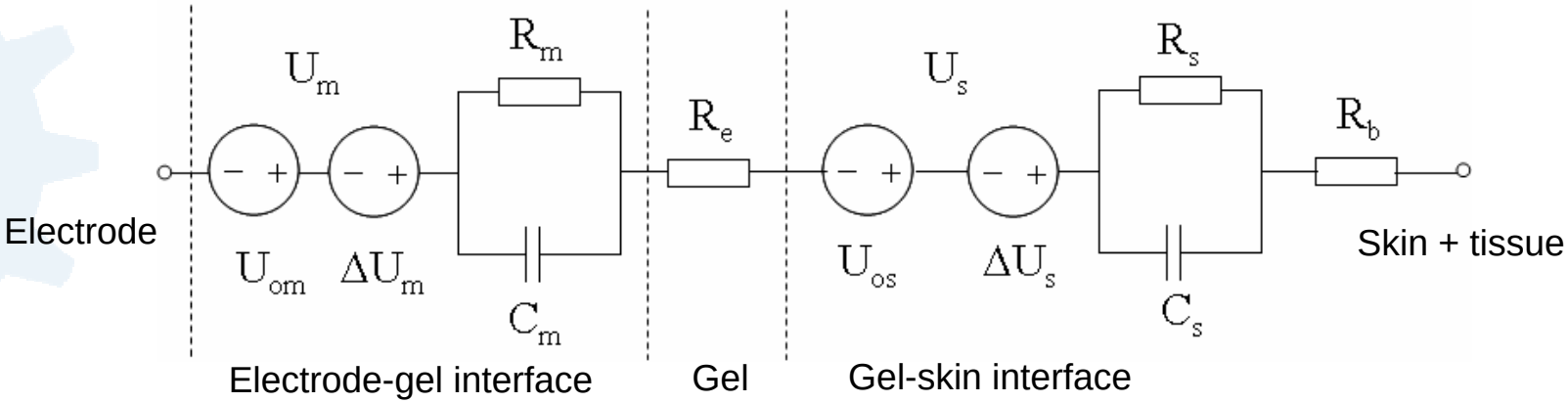








Electrode – skin interface

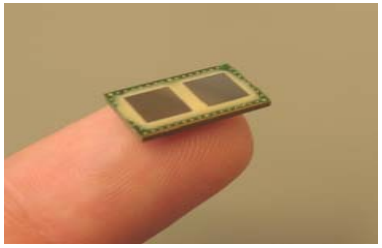


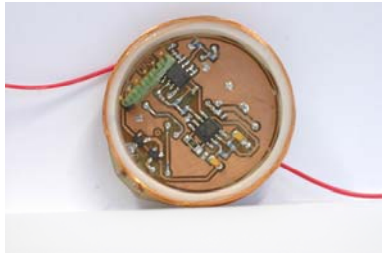
- Wearable monitoring – Challenge: How to reduce motion artefacts?
  - Flexible and elastic electrode materials
    - Textile and fabric electrodes
    - Flexible strips or plasters
  - Solid gels or adhesives
    - Hydrogels, conductive elastomers
    - Biocompatible bonding agents, “Compeed”-electrodes
  - Active electrodes (preamplifier integrated in the electrode)
  - Capacitive electrodes

→ Smart active MEMS-based electrodes?

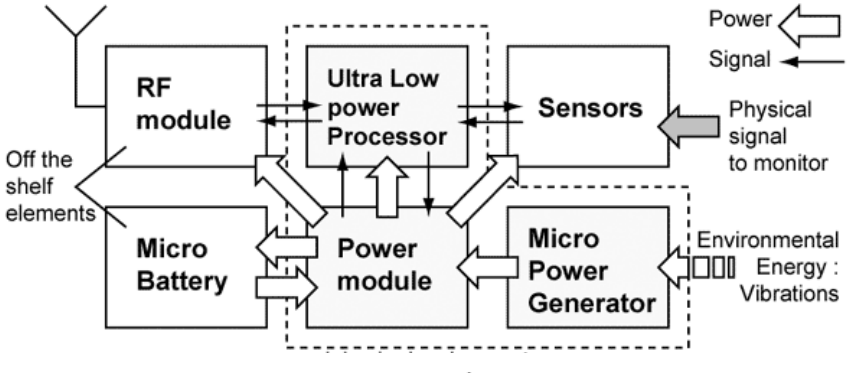
What is needed?

- Miniature electronics
  - High degree of integration and packaging
    - 3D System-in-Package
  - Low power consumption, μ-Batteries
  - Wireless powering methods
    - Inductive, capacitive, ultrasonic, light
  - Energy harvesting
    - Vibrations; piezoelectric and smart materials
    - Temperature gradient; thermopiles



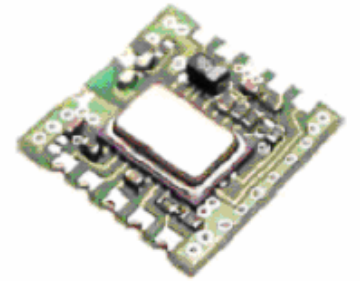


Source: MIT Energy Shoe

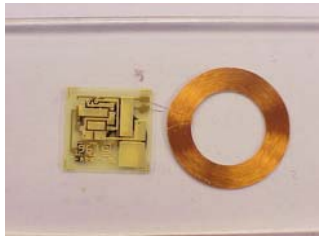


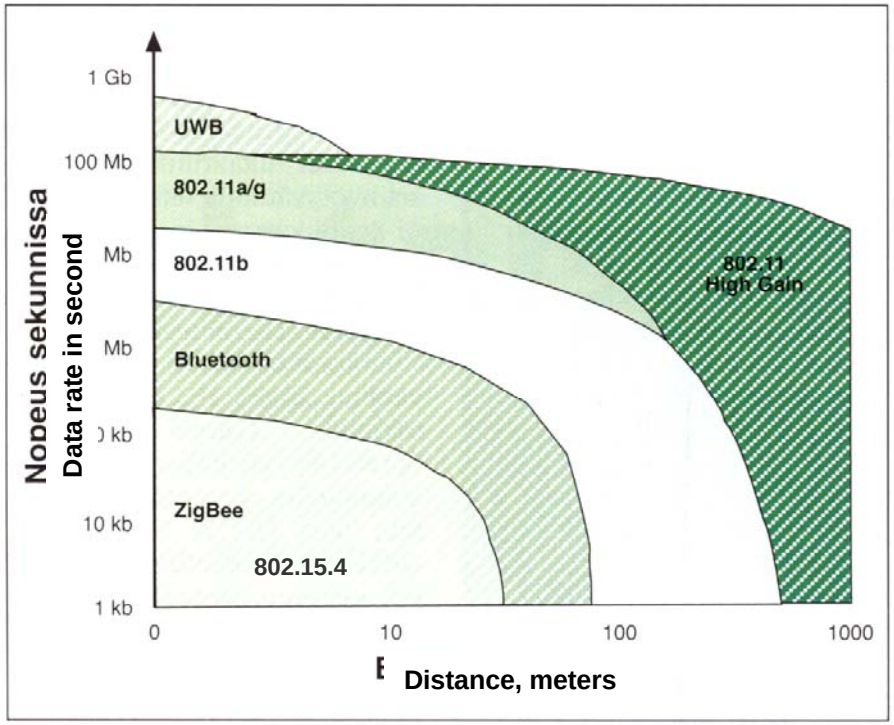
What is needed?

Wireless links



- Several short-range radios and protocols available:
  - Ultra Wide Band (UWB)
  - IEEE 802.11 WLANs
  - Bluetooth
  - ZigBee
  - ANT
  - TUTWS
- Inductive links
- IR-links





Prosessori 9/2004

Frequencies – "Limited Natural Resource"

European Radiocommunications Committee (ERC)

RECOMMENDATION 70-03
RELATING TO THE USE
OF SHORT RANGE DEVICES
(SRD)

www.ero.dk/documentation/docs/doc98/official/pdf/REC7003E.PDF
(Version of 17 November 2005)

Frequencies for different applications are listed in the Annexes

ISM = Industrial
Scientific
Medical (ITU)

Annex	Application
1	Non-specific Short Range Devices
2	Equipment for Detecting Avalanche Victims
3	Local Area Networks, RLANs and HIPERLANs
4	Railway applications
5	Road Transport & Traffic Telematics (RTTT)
6	Equipment for Detecting Movement and Equipment for Alert
7	Alarms
8	Model Control
9	Inductive Applications
10	Radio Microphones
11	RF Identification Systems
12	Wireless applications in Healthcare.
13	Wireless Audio Applications

Table 1: Applications

Annex 12 Wireless applications in Healthcare

Scope of Annex

This annex covers frequency bands and regulatory as well as informative parameters recommended for wireless applications in healthcare.

Regulatory parameters related to Annex 12

Frequency Band	Power	Duty cycle	Channel spacing	ECC/ERC Decision	Notes
a 402 - 405 MHz	25 µW e.r.p.	No Restriction	25 kHz	ERC/DEC/(01)17	The application is for ultra low power active medical implants (for convenient definitions see EC Directive 90/385/ECC) Individual transmitters may combine adjacent channels for increased bandwidth up to 300 kHz
b 9 - 315 kHz	30 dBµA/m at 10 m	< 10 %	No spacing		The application is for ultra low power active medical implant systems using inductive loop techniques for telemetry purposes
c 315 - 600 kHz	-5 dBµA/m at 10 m	< 10 %	No spacing		The application is intended for animal implantable devices
d 30 – 37.5 MHz	1 mW e.r.p.	< 10 %	No spacing		The application is for Ultra Low Power medical membrane implants for blood pressure measurements

Example

Heart rate monitor

- Electric ECG signal is measured by using a band around chest
- The heart rate is sent wirelessly (inductive link) to a receiver on wrist or belt

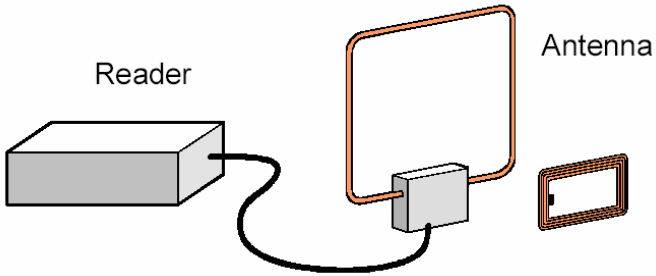
Polar Electro

SportBrain

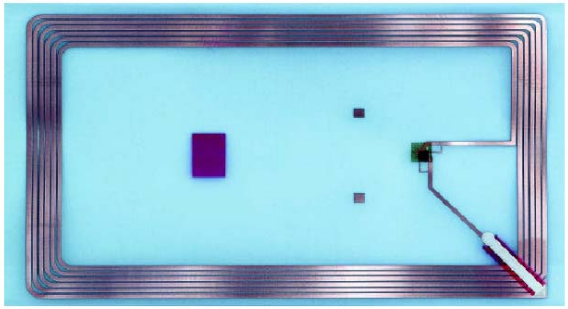
Suunto

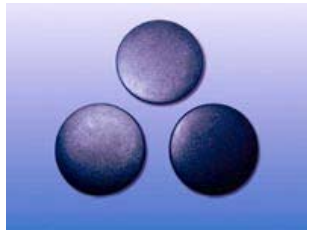
RFID Techniques

- Passive (no battery) Radio Frequency IDentification tag
- Reader sends a magnetic RF field for the transponder → the energy captured by its antenna activates the transponder
- Transponder returns its ID code by modulating the antenna circuit impedance



Tag-It HF-I Transponder


Inductive 13.56 MHz (Rafsec)

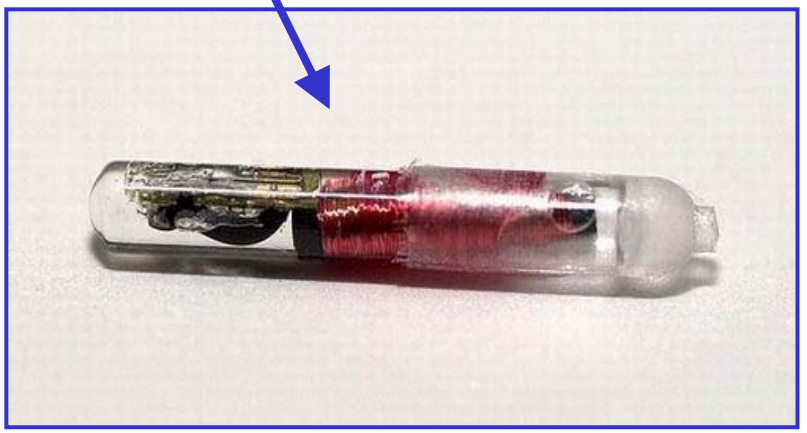


Inductive 134.2 kHz and 13.56 MHz (Texas Instruments)

Radio wave 868 MHz (Palomar)

VeriChip

The Food and Drug Administration (FDA) has approved an implantable microchip that can pass a patient's medical details to doctors, speeding care

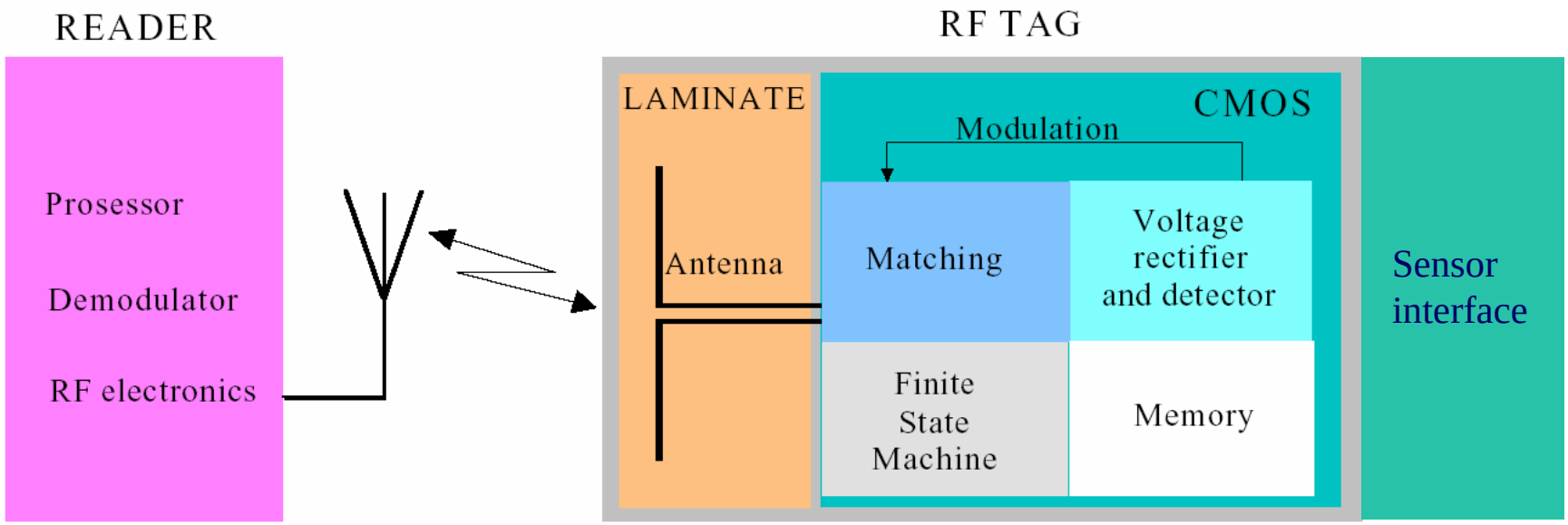
- VeriChips, radio frequency microchips the size of a grain of rice, have already been used to identify for example dogs and horses
- Chips have already been implanted in humans in Mexico and USA
- The chip's serial number pulls up the patients' blood type and other medical information.



www.verichipcorp.com

RFID Sensors?

Radio Wave Reading (radiating system)

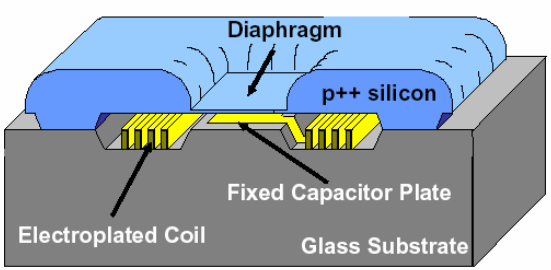


Source: Timo Varpula/VTT

Passive Wireless Sensors

A Wireless Batch Sealed Absolute Capacitive Pressure Sensor

Akar et al, EUROSENSORS XIV, The 14th European Conference on Solid-State Transducers August 27-30, 2000, Copenhagen, Denmark



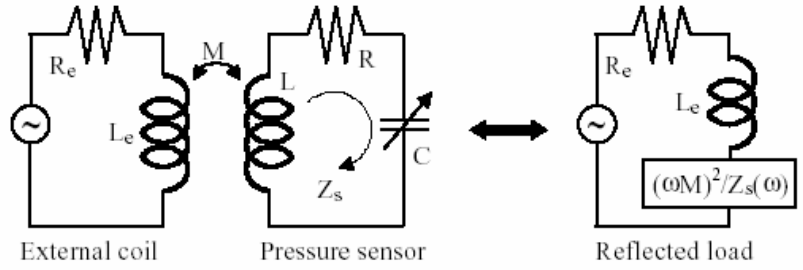
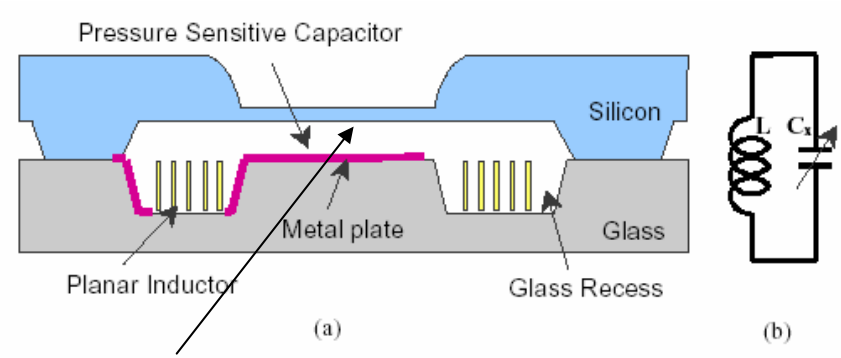


Fig. 3: Equivalent circuit model of the telemetric readout approach.



6 μm silicon membrane

24 turns of gold-electroplated coil, inductance 1.2 μH

2.6 mm x 1.6 mm

Wireless Electrode System

Project “Wireless Technology and Psychophysiological Computing”

- PROACT (Pro-active Information Technology) Research Program of **Academy of Finland**
- Funding: 531 000 €, 2003 - 2005
- Co-operation partners: MIT and RGI institutes of TUT, and two research groups from University of Tampere (UTA)

Electrodes + wires

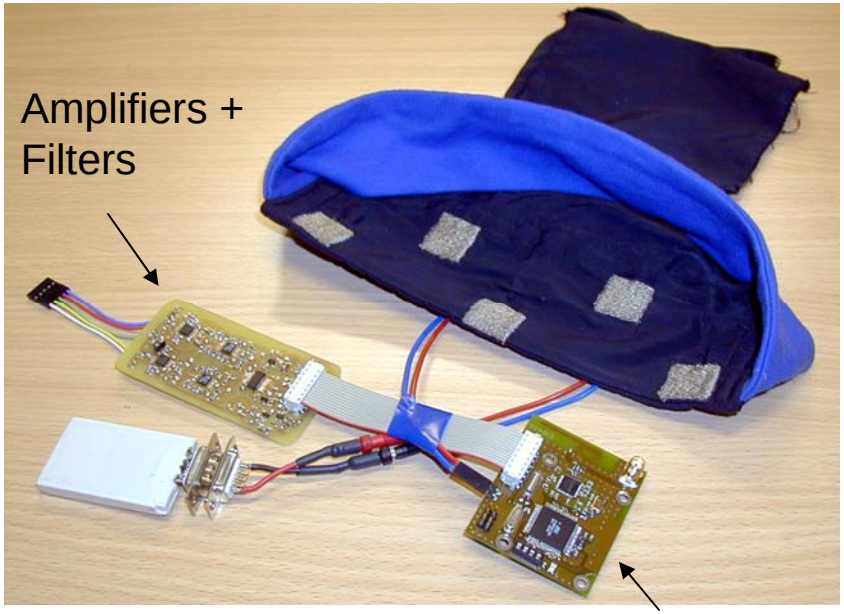
The aim of the project was to develop wireless sensor technology that can be used for monitoring of behaviors that are related to human physiological and psycho-physiological responses during computer-user interaction.

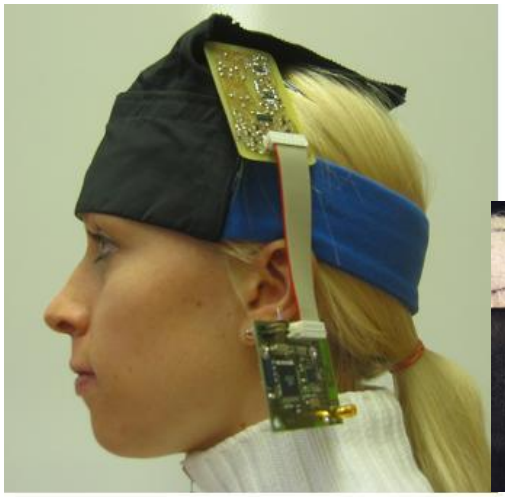
www.cs.uta.fi/hci/wtpc/

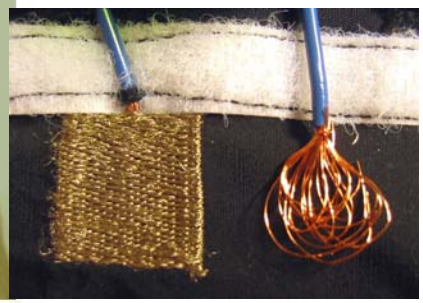
Wearable measurement device

Wireless measurement cap

- Fabric electrodes for measuring EMG originating facial muscles, eye movements (EOG, gaze direction, blink) and EEG (electroencephalogram)
- 2 acceleration sensors
- EMFi thin film pressure sensor for heart rate measurement
- 6 wireless channels based on now-noise amplifiers and 2.4 GHz commercial Chipcon radio
- 1 kHz sample frequency/channel, 16 bits data
- Mobile phone battery

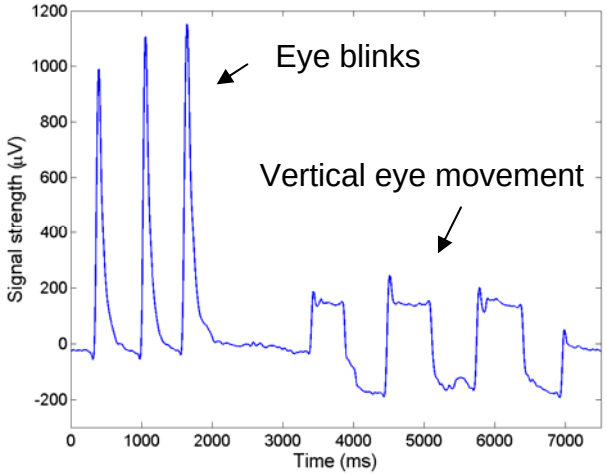


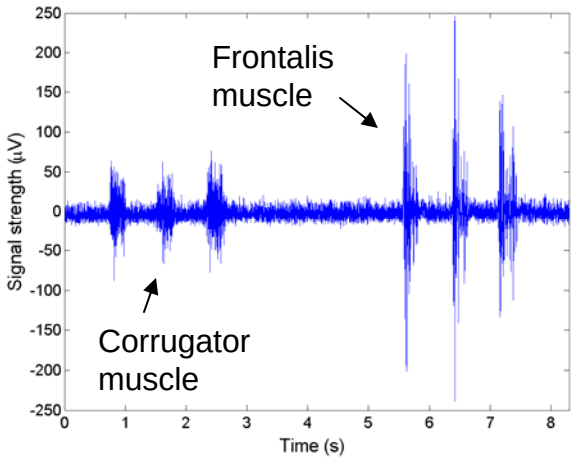




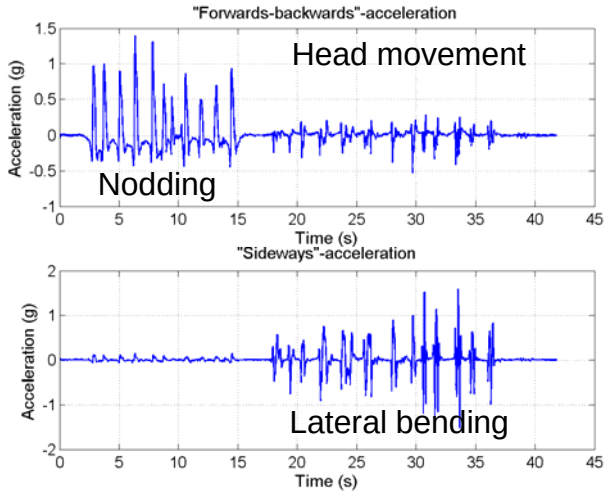
Examples of measured signals

- EMG (electromyogram) originating from facial muscles (behaviors related responses); corrugator and frontalis
- Accelerometers for sensing gesture of head (nodding and bending to the sides)
- Vertical and horizontal eye movements were recorded by measuring EOG (electro-oculogram). Also a signal from eye blinks are seen.

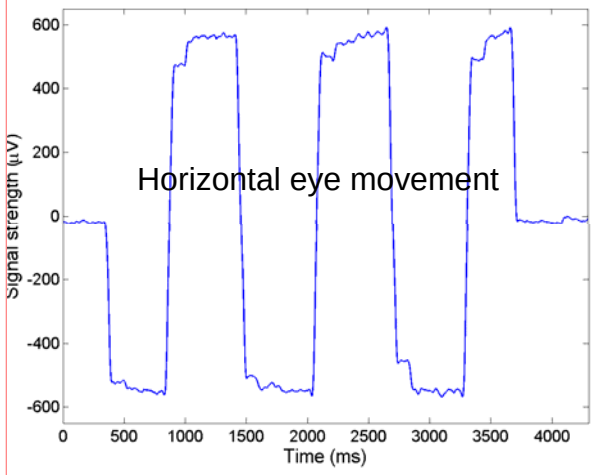




EMG signals



Acceleration signals



EOG signals

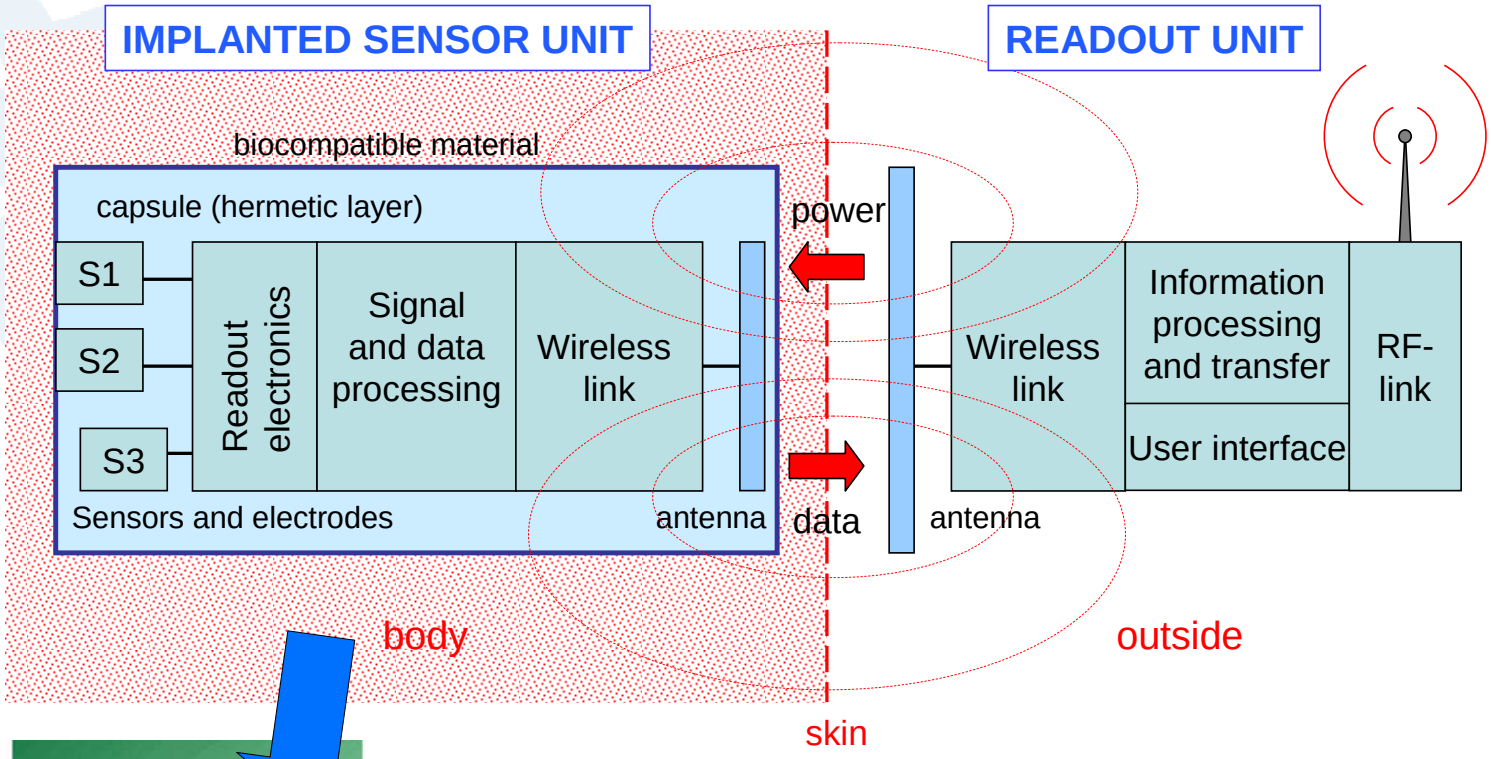
Wireless Implantable Sensors

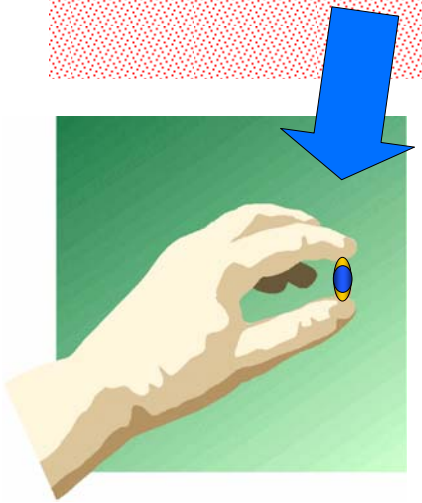
- Project ” Wireless physiological sensors for ambulatory and implantable applications”
- Future Electronics Research Program of **Academy of Finland**
- Funding: 780 000 €, 7/2003 – 12/2006
- Co-operation partners: MIT, RGI, ELE (Institute of Electronics) and BIOM (Institute of Biomaterials) from TUT

Wireless sensors will be developed and demonstrated in certain soft and hard tissue implant applications such as implantable electrodes for detection of ECG or bone implant monitoring.

www.ele.tut.fi/tule

Technology Concept





- Inductive wireless link (125 kHz, 13 MHz) data transfer and power delivery for the implant
- General implantable sensor platform + read-out electronics and signal and data processing
- Miniature size (inserted with a syringe?)

Wireless implantable sensor technology is the only way to realize reliable long term monitoring of physiological signals?

Applications 1(2)

Implantable ECG monitor

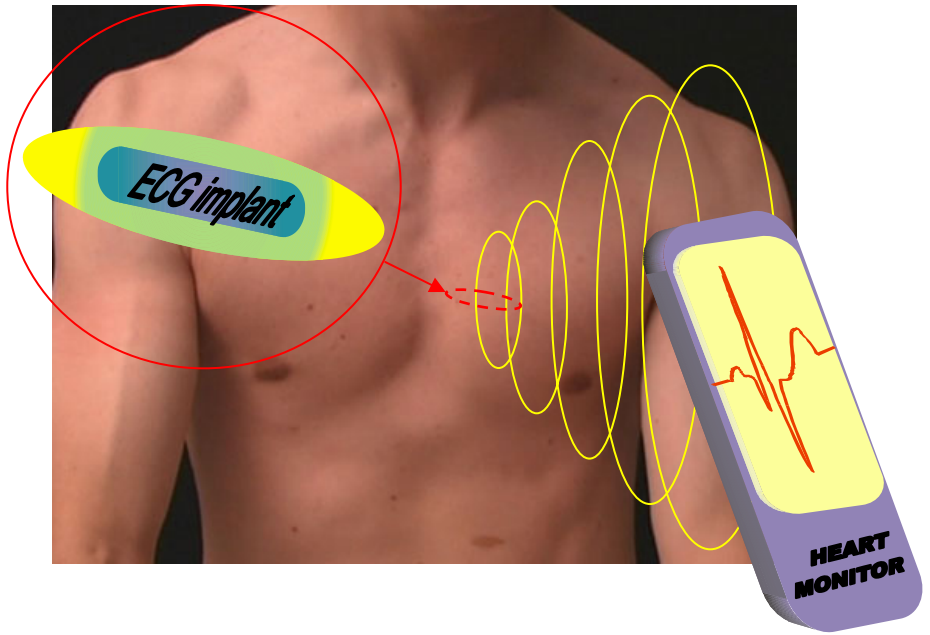
- where and how to make the measurement?
- to whom and why is the information sent?

Many possibilities:

- ECG signal, heart rate
- monitoring/alarm

Implant can also include:

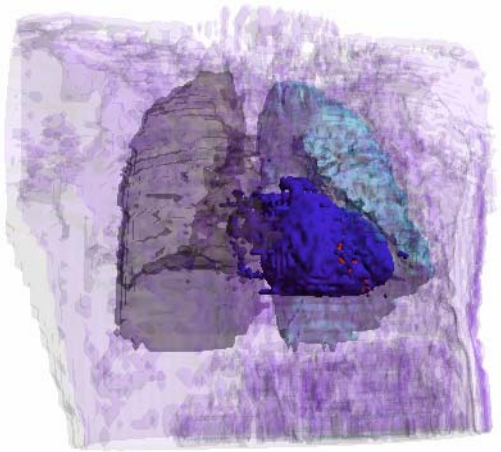
- temperature sensor
- microphone for heart or breathing sounds
- acceleration sensor



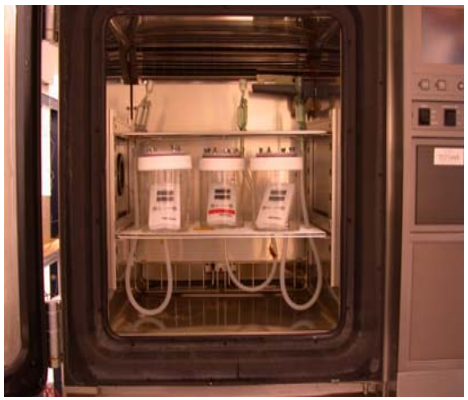
In vitro prototypes during 2005

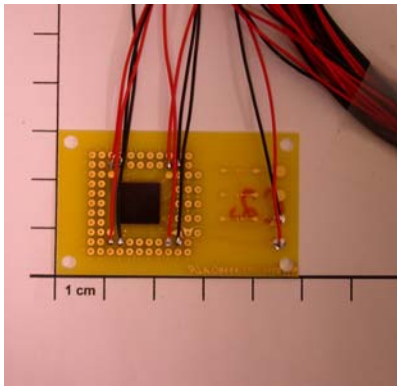
First animal *in vivo* tests with the implant prototype during June 2006

Several prototypes tested

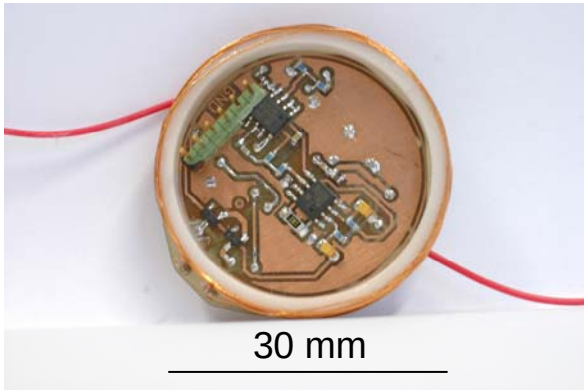


Modeling:
- location and size of the implant
- expected signal amplitude

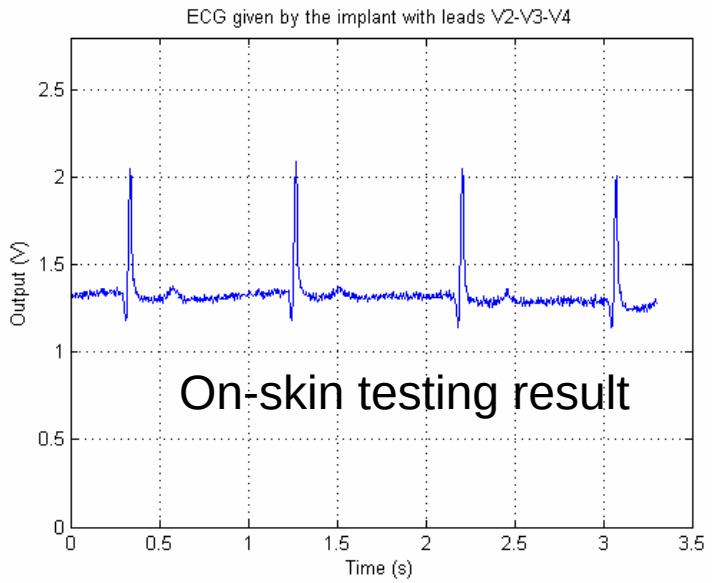




Testing of electrodes and biomaterial coatings (polymers, parylene, TiO_2, …)



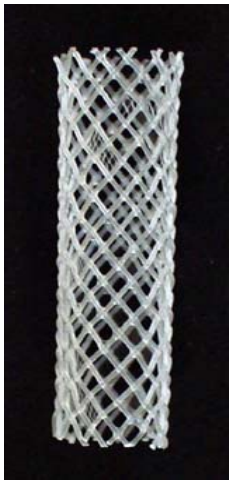
Prototype with a coil antenna



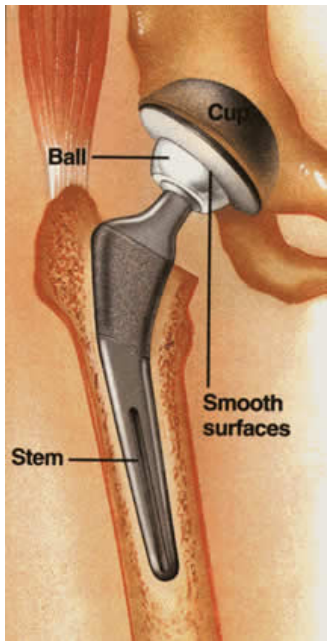
Applications 2(2)

2. Implants and artificial organs

- Closing implant of thorax (after open heart surgery)
  - Measurement of closing force
  - Micro movements
- Smart hip prosthesis
  - Functionality feedback
  - Monitoring of loosening and wearing
- Sensing stent (support implant)
  - Opening during installation
  - Condition monitoring

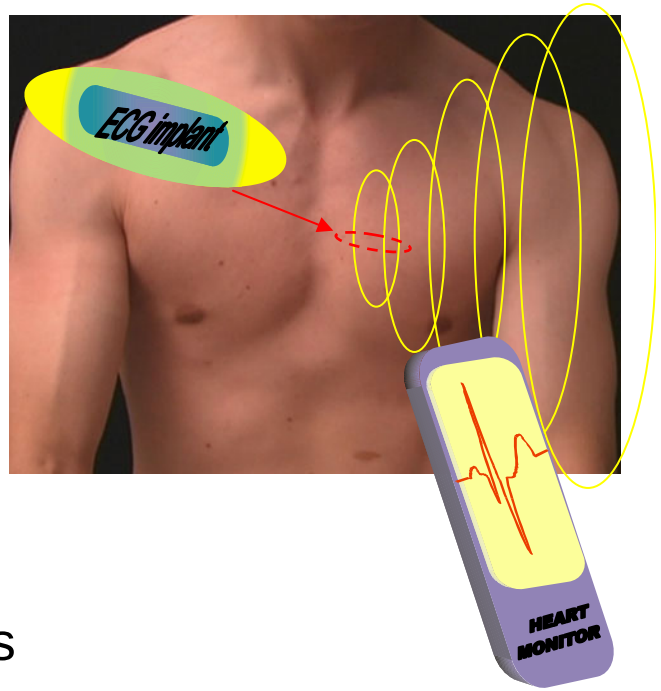


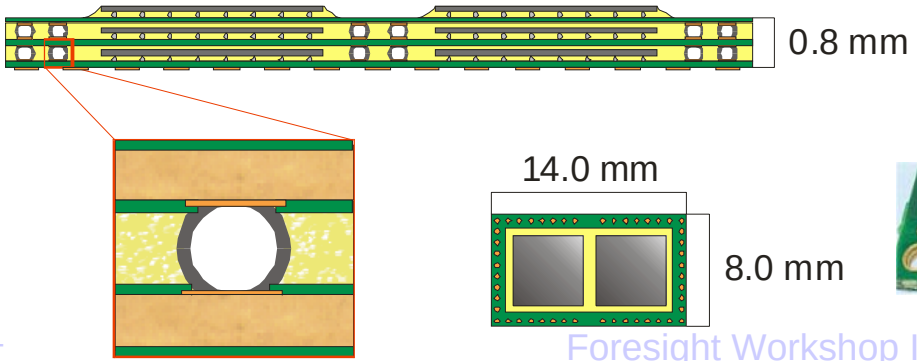
Stent

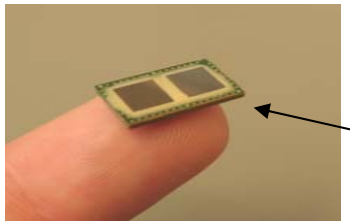


WISEPLA (2006 – 2008)

- Short-range wireless sensor platform for ambulatory and implantable applications (FinnWell - Future Healthcare Technology Program of Tekes).
- The project will develop and provide wireless sensor platform technology utilizing new sophisticated 3D packaging of electronics and biocompatible encapsulation technologies.
- ECG/heart rate, impedance, different sensors
- Co-operation: MIT, RGI, ELE, BIOM Institutes of TUT and 11 participating companies







Test chip made by ELE/TUT

Other Applications

Pressure and flow sensors

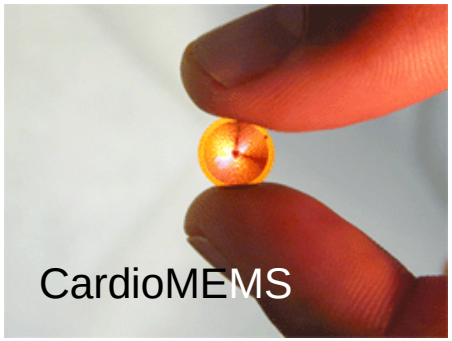
- Blood pressure
- Cardiac Output (CO)

Biosensors

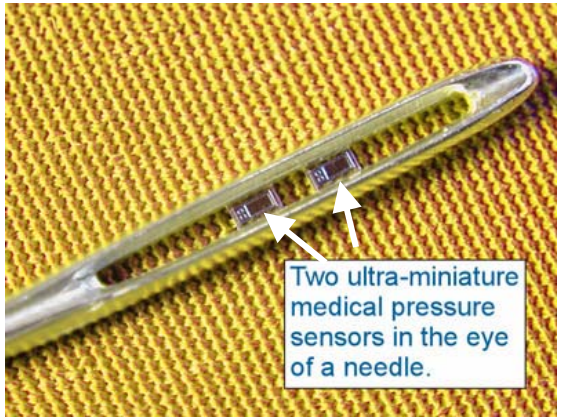
- Glucose
- Lactate
- Other analytes

Micro analyzers

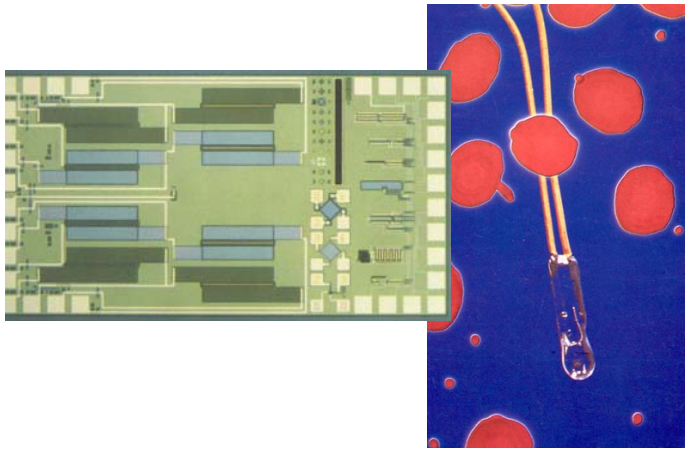
- BioMEMS
- Microfluidics

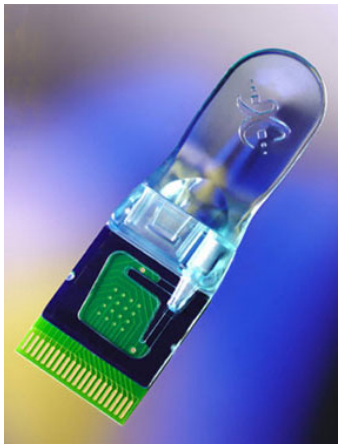


www.cardiomems.com

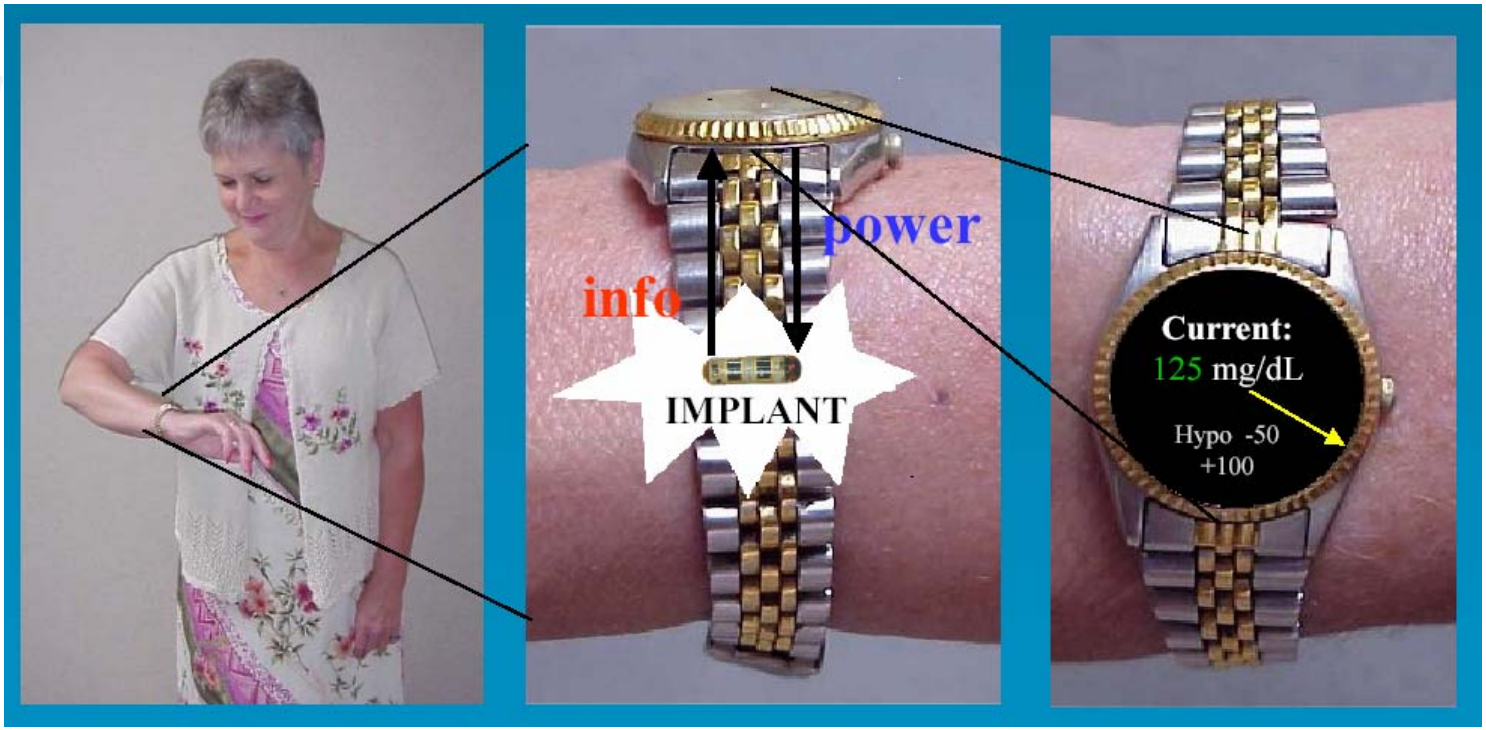


www.mems-issys.com





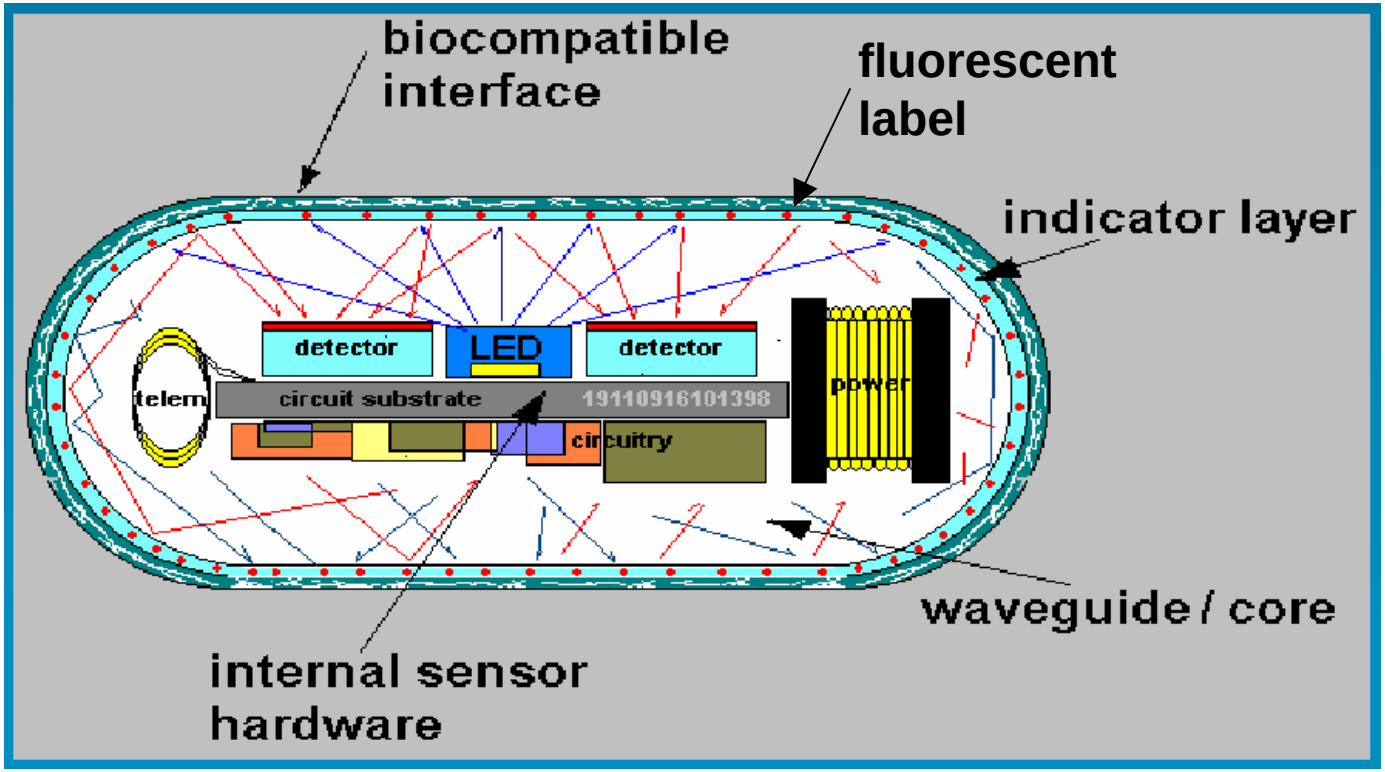
Integrated Glucose Monitoring System Concept



Sensors for Medicine and Science, Inc. (SMSI)

http://www.s4ms.com/products_glucose.htm

Integrated Glucose Monitoring System Concept

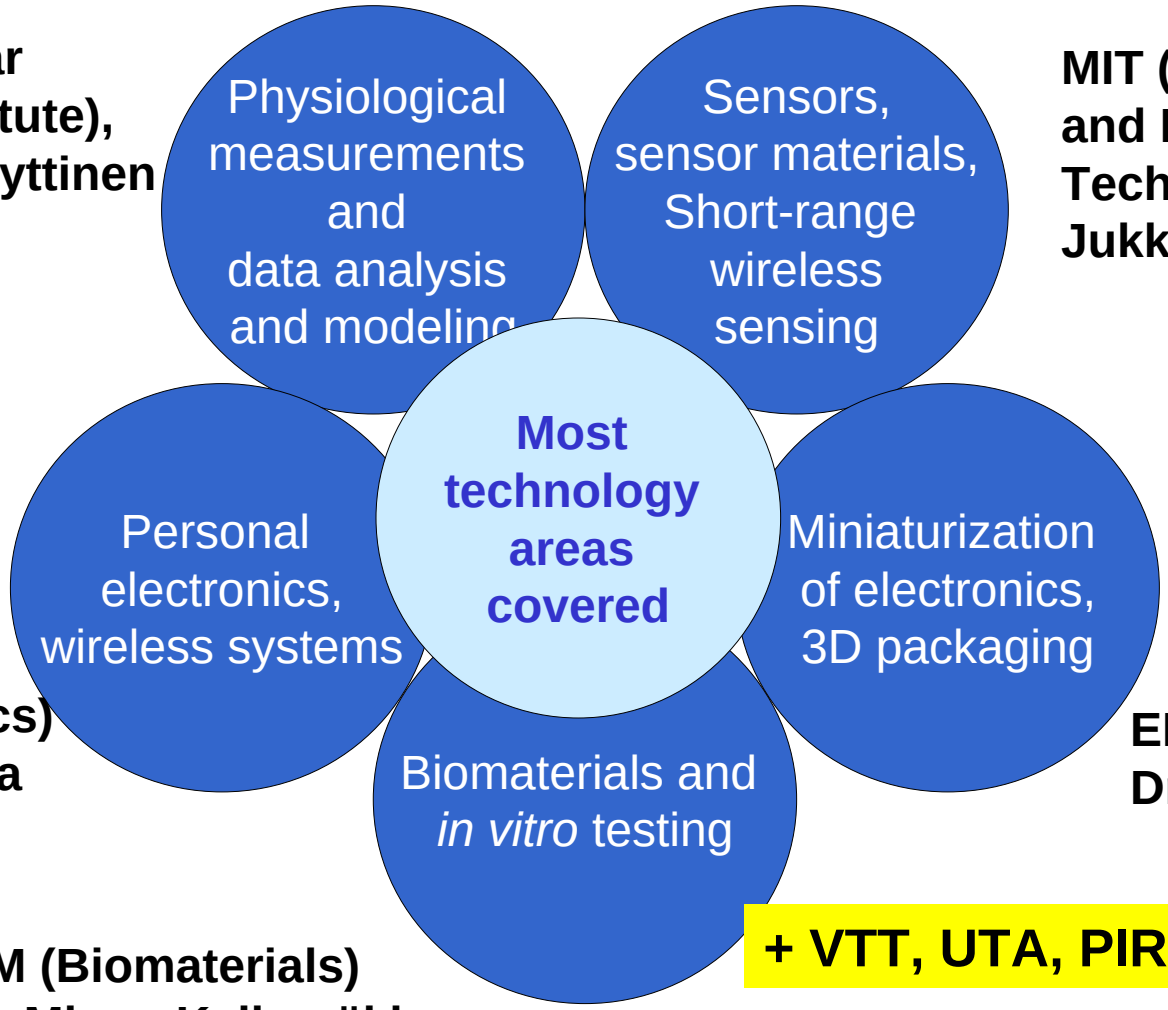


Fully Integrated “Grain” Design

BIRCA - Center and Alliance for Biosensing Research at TUT

RGI (Ragnar Granit Institute), Prof. Jari Hyttinen

MIT (Measurement and Information Technology), Prof. Jukka Lekkala



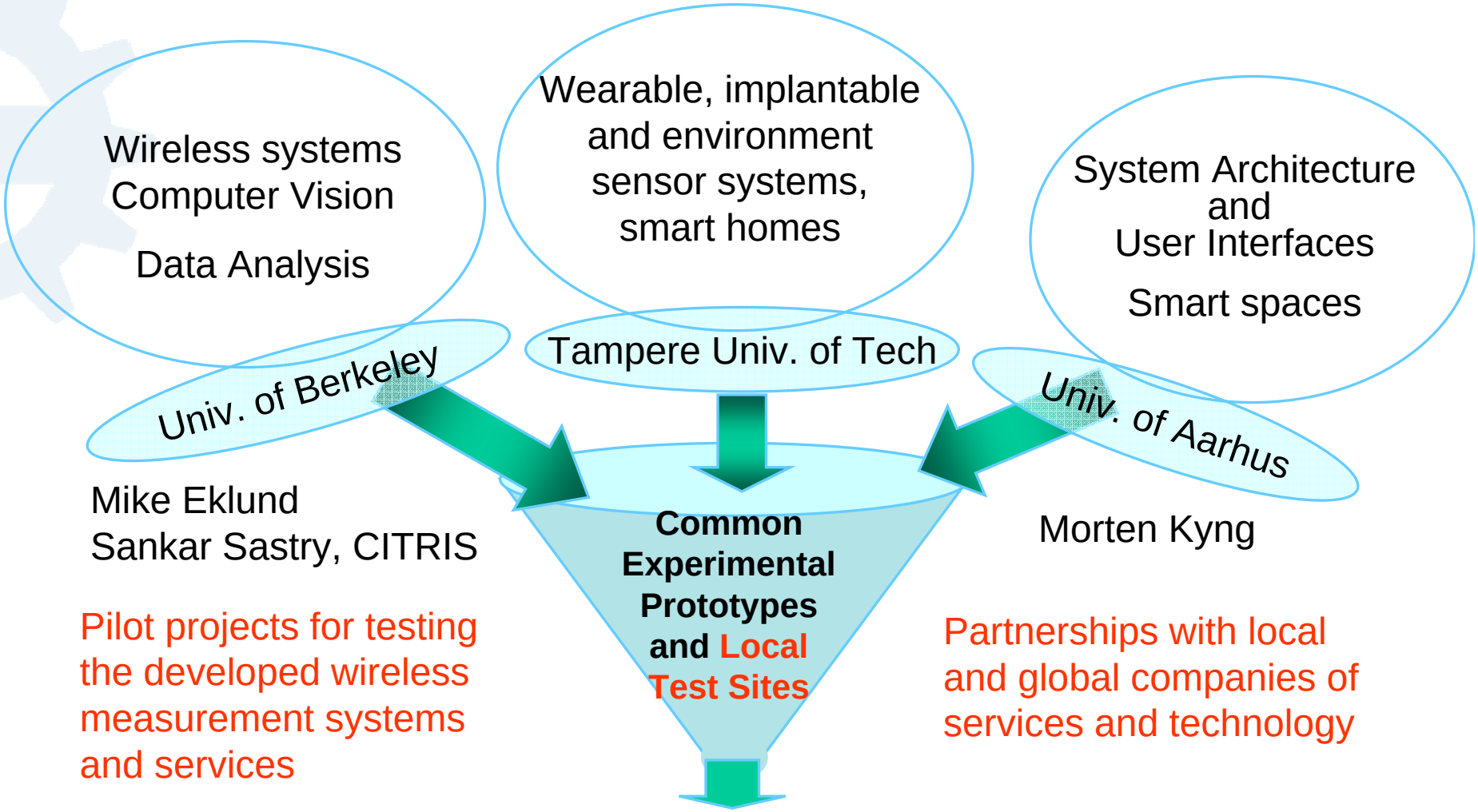
ELE (Electronics) Prof. Jukka Vanhala

ELE (Electronics), Dr. Pekka Heino

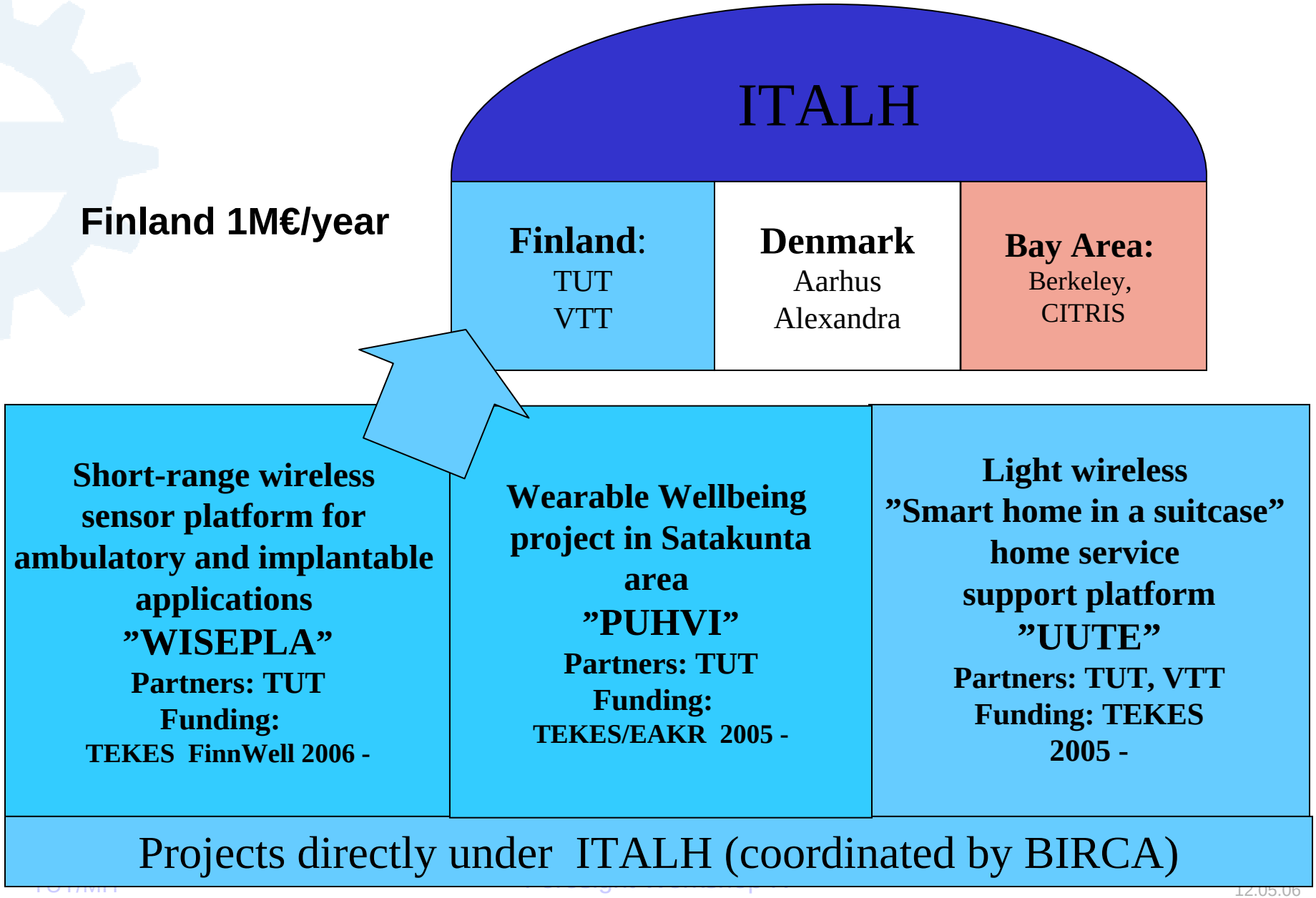
BIOM (Biomaterials) Prof. Minna Kellomäki

+ VTT, UTA, PIRAMK, TAMK

International Project Outline: INFORMATION TECHNOLOGY FOR ASSISTED LIVING AT HOME



ITALH Projects in Finland



Conclusion

- The present state-of-the-art technology enables development of completely new types of wireless devices for reliable long-term monitoring of physiological signals
- The projects of Academy of Finland have created the basis for research of implantable medical devices in Finland
- TUT, Tekes and several Finnish companies are participating in development of new advanced wearable wireless measurement systems
- Multidisiplinary expertise and research teams are needed
- Networking is important
- New innovative products for health care and other applications.

Thank you!