Un progetto del Politecnico di Torino

BIENNALE TECNOLOGIA

Tecnologia è Umanità

PRINCÌPI
Costruire per le generazioni

Il progetto B-CRATOS e la connessione cervello-macchina per superare le disabilità

Letizia Bergamasco, Rossella Gaffoglio - Torino, 11 Novembre 2022

Fondazione LINKS

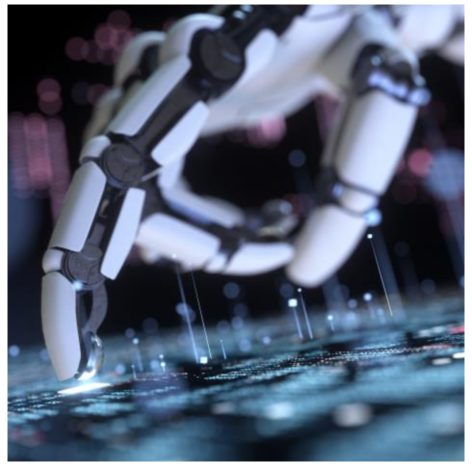
LINKS Foundation is an instrumental body of **Compagnia di San Paolo** and operates as an instrumental body of **Politecnico di Torino**

LINKS Foundation, a central node of the Turin research and innovation ecosystem, operates in a consolidated international network with the aim of **contributing to technological and socio-economic progress through cutting edge applied research projects.**

LINKS Foundation – 5 Research Domains

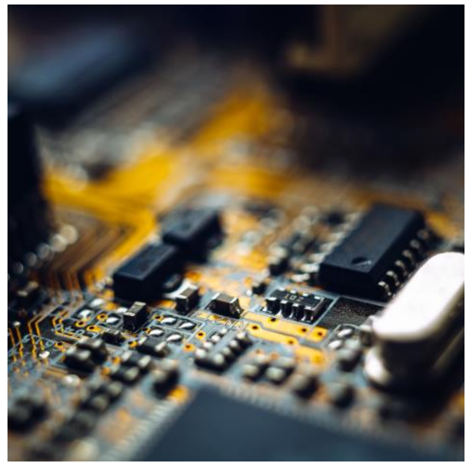
Connected Systems &
Cybersecurity
(CSC)

Artificial Intelligence,
Data & Space
(ADS)



Innovation in Culture,
Social& PA
(ICS)

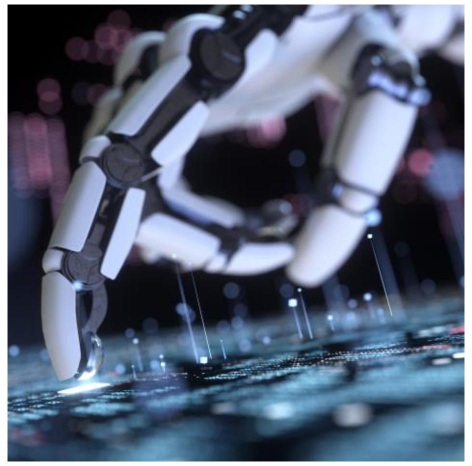
Advanced Computing, Photonics
& Electromagnetics
(CPE)



Future Cities &
Communities
(FCC)

LINKS Foundation – 5 Research Domains

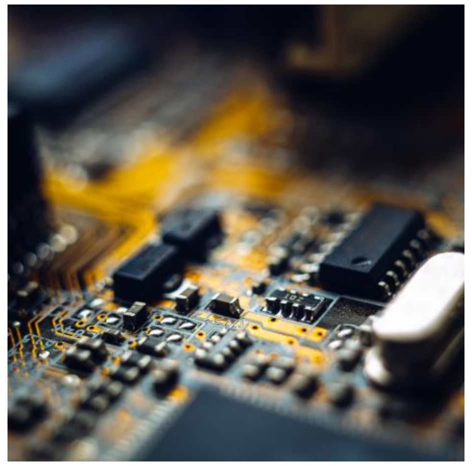
Connected Systems & Cybersecurity (CSC)

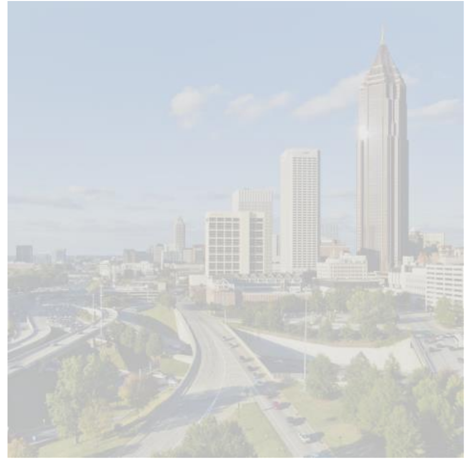


Artificial Intelligence, Data & Space (ADS)

Innovation in Culture, Social& PA (ICS)

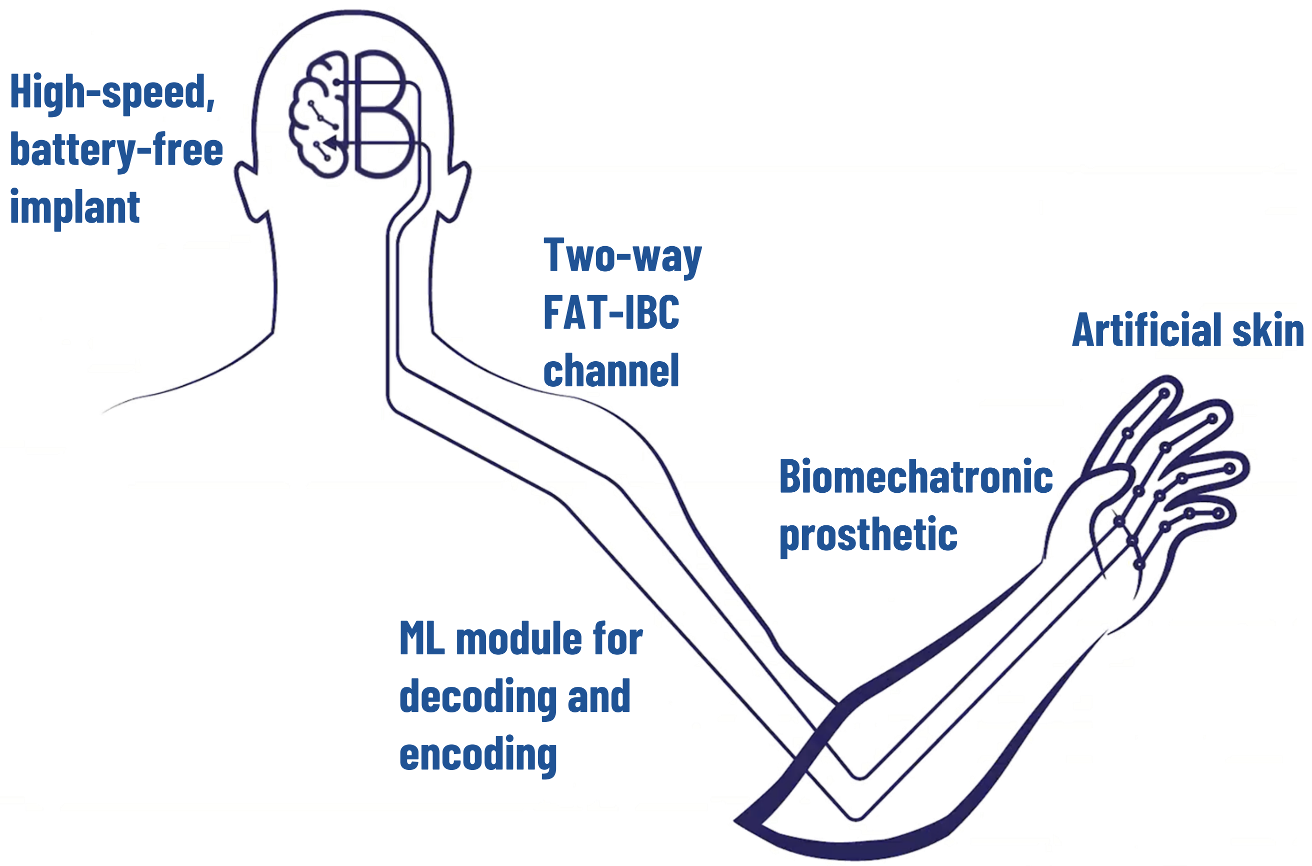
Advanced Computing, Photonics & Electromagnetics (CPE)





Future Cities & Communities (FCC)

B-CRATOS project



March 2021 – February 2025

FET-OPEN 4.7M EU funding

Partners from 5 countries

Coordinated by University of Uppsala

Societal challenge:

"Amputees tend to discard their prosthetic extremities as they are not integrated to the person's cognition"
(Prof. John Donoghue, Brown University)

"B-CRATOS overcomes technological barriers of wireless brain ↔ machine ↔ body communication, and represents the beginning of a paradigm shift in how signals can be sent to restore function and empower individuals"

(Robin Augustine, B-CRATOS coordinator)

This project has received funding from the European Horizon 2020 R&I program under grant agreement N°965044.

B-CRATOS project

Consortium

- **7 Excellent partners** (1 SME, 3 research institutes and 3 Universities)
- Scored 4.95/5 and ranked 10 among 58 funded projects
- **Most funded project** (4.59 M Euros for 4 years) in FET Open 2020
- FET Open success rate (2020) around 6.6%

Participant Legal Name	Country
UPPSALA UNIVERSITET	SE
INSTITUT SINANO ASSOCIATION	FR
SCUOLA SUPERIORE DI STUDI UNIVERSITARI E DI PERFEZIONAMENTO S ANNA	IT
Blackrock Microsystems Europe GmbH	Germany
FONDAZIONE LINKS - LEADING INNOVATION & KNOWLEDGE FOR SOCIETY	IT
DEUTSCHES PRIMATENZENTRUM GMBH	DE
NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU	NO

Next-Generation BCI Needs and B-CRATOS Potential

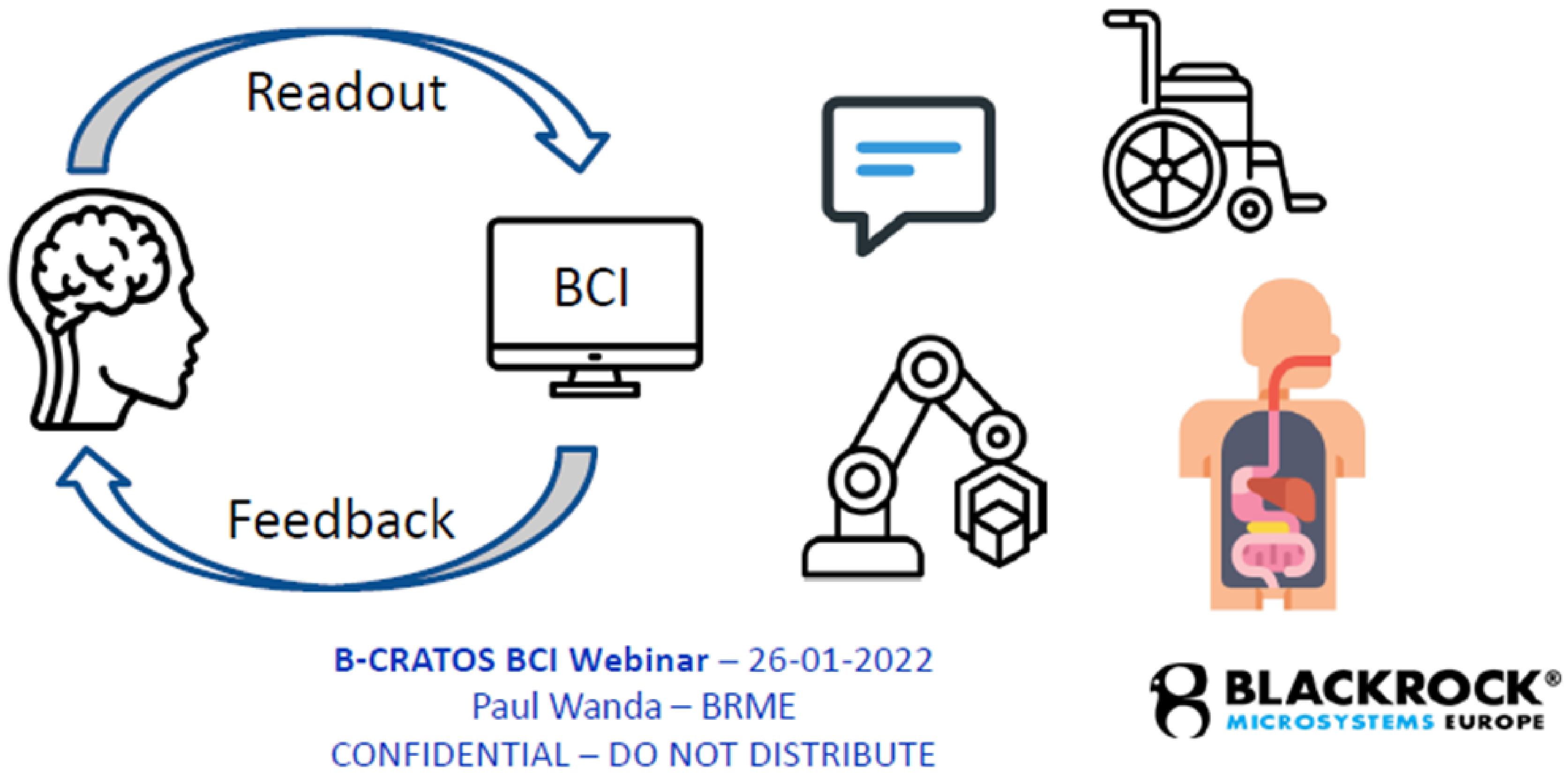
Paul Wanda, PhD
Engineer & Project Manager
Blackrock Microsystems Europe GmbH
January 26, 2022

This project has received funding from the European Horizon 2020 R&I program under grant agreement N° 965044.

What is a BCI?

- BCI (Brain-Computer Interface): broadly, a device that enables communication and control without movement (BNCI Roadmap, Horizon 2020)
  - Readout of brain activity -> actions/control signals

- "Closing the loop": providing feedback to the brain
  - Tissue stimulation (electrical current, magnetic field, chemical, etc.)

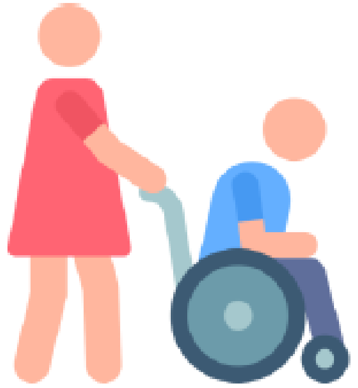


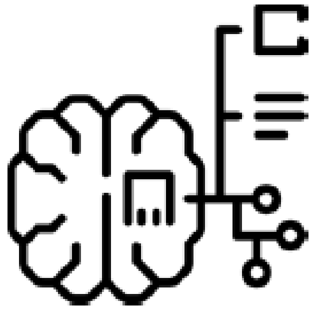
Why focus on neural devices?

- Current medication, surgery, therapy, assistive technologies -> gap in treating neurological ailments

- BCI devices can be another powerful tool to address such conditions:

- 250-500K yearly suffer a spinal cord injury (WHO, 2013)
  - 2B people will need 1 or more assistive products by 2030 (WHO, 2022)
- 10M people with Parkinson's disease (Parkinson's Foundation)
- 50M people live with epilepsy (WHO, 2019)
- 55M people live with dementia (10M new cases each year) (WHO, 2021)
- 280M with depression (IHME/WHO estimate, 2021)





What would we like BCI do?

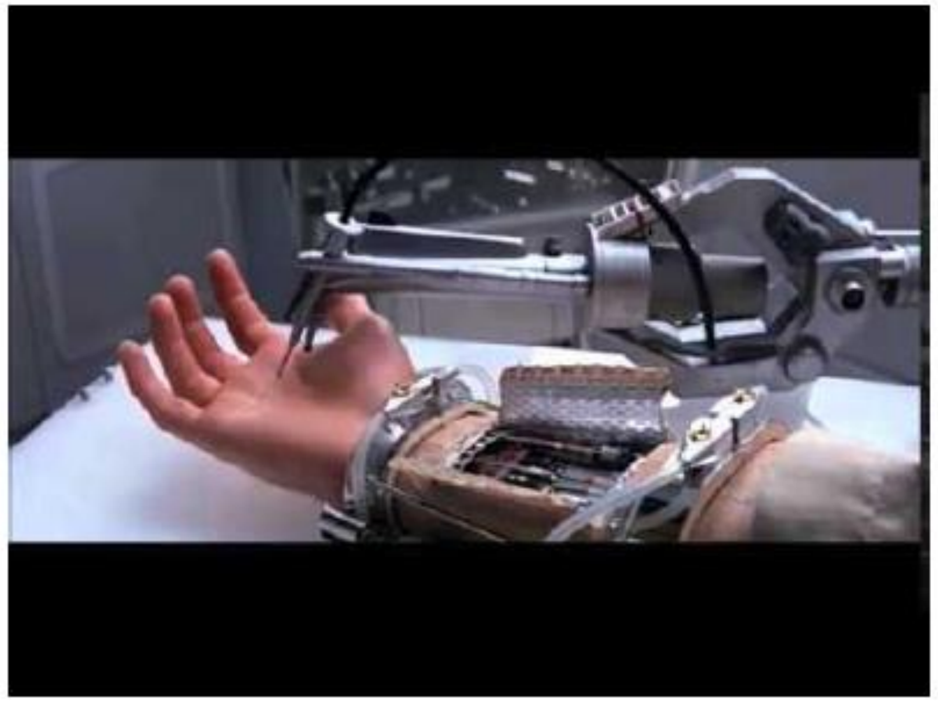


Photo: UPMC/University of Pittsburgh

Image: common.wikimedia.org

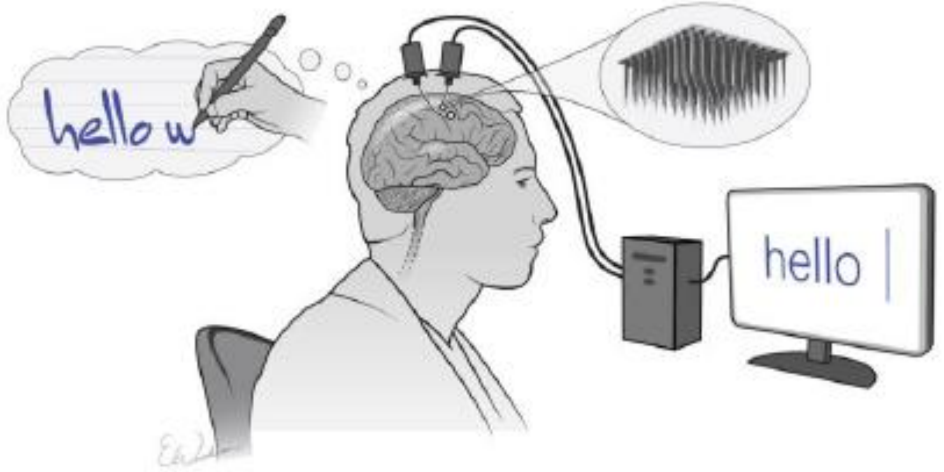


Image: Stanford WU Tsai Neurosciences Institute: https://neuroscience.stanford.edu/research/funded-research/design-and-development-high-performance-intra-cortical-speech-bci

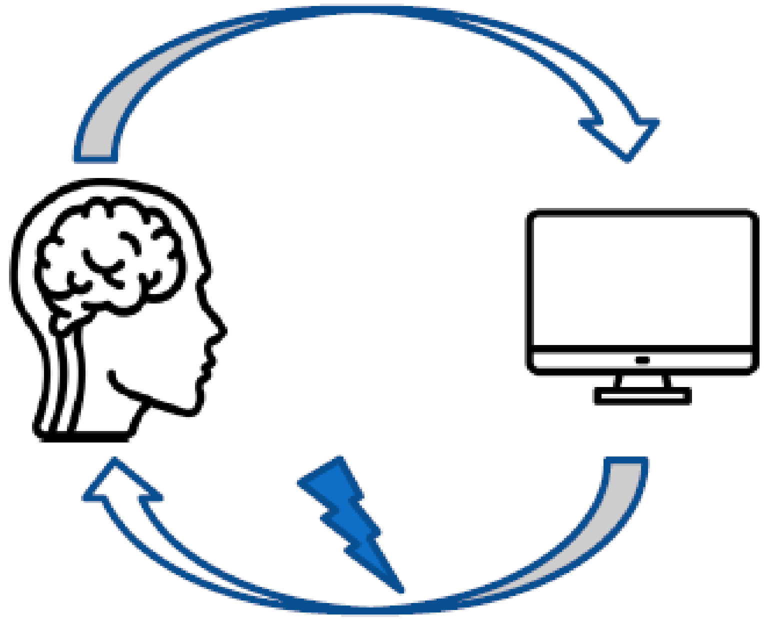
BLACKROCK® MICROSYSTEMS EUROPE

B-CRATOS BCI Webinar – 26-01-2022
Paul Wanda – BRME
CONFIDENTIAL – DO NOT DISTRIBUTE

What can modern neural implants / BCI do?

- **Epilepsy**
  - **Electrical stimulation of cortical tissue to reduce seizure frequency (w/ or w/o closed-loop BCI)**
- Parkinson's, Essential Tremor, Dystonia
  - Electrical stimulation of deep brain structures to reduce symptom severity
- Hearing Loss
  - Electrical stimulation of auditory nerve to detect sound

Detect seizure*
(record on implanted electrodes)



Disrupt seizure
(electrically stimulate on electrode)

B-CRATOS BCI Webinar – 26-01-2022
Paul Wanda – BRME
CONFIDENTIAL – DO NOT DISTRIBUTE

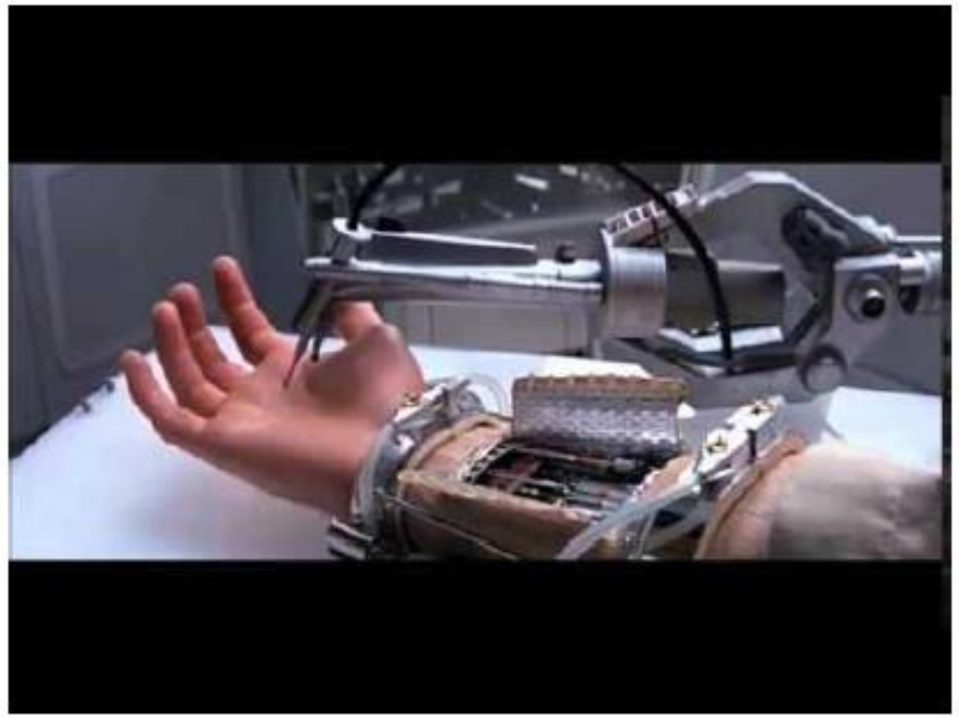
What are the limitations and challenges?

- Channel count & signal bandwidth
  - Current devices support only a few channels of data/stimulation (for billions of neurons)
  - Wireless technologies insufficient to transmit large amounts of raw neural data
  - Modern algorithms (for complex control) rely upon access to multiple brain regions, redundancy, rich signal content, etc.
- Processing Power
  - Challenge including on-board processing components for complex algos (within power, size limits)
- Wires, Physical Size & Portability
  - Long inflexible wires: Bowstringing/Scar tethers
  - Percutaneous connectors: Infection risk
  - Aesthetics & user adoption for everyday use
- Battery technology
  - Bulkier devices
  - Surgeries to replace batteries
  - Risk of failure
- Closing the loop
  - Flexibility in feedback control algorithms

B-CRATOS BCI Webinar – 26-01-2022
Paul Wanda – BRME
CONFIDENTIAL – DO NOT DISTRIBUTE

BLACKROCK® MICROSYSTEMS EUROPE

What does B-CRATOS expect to address?



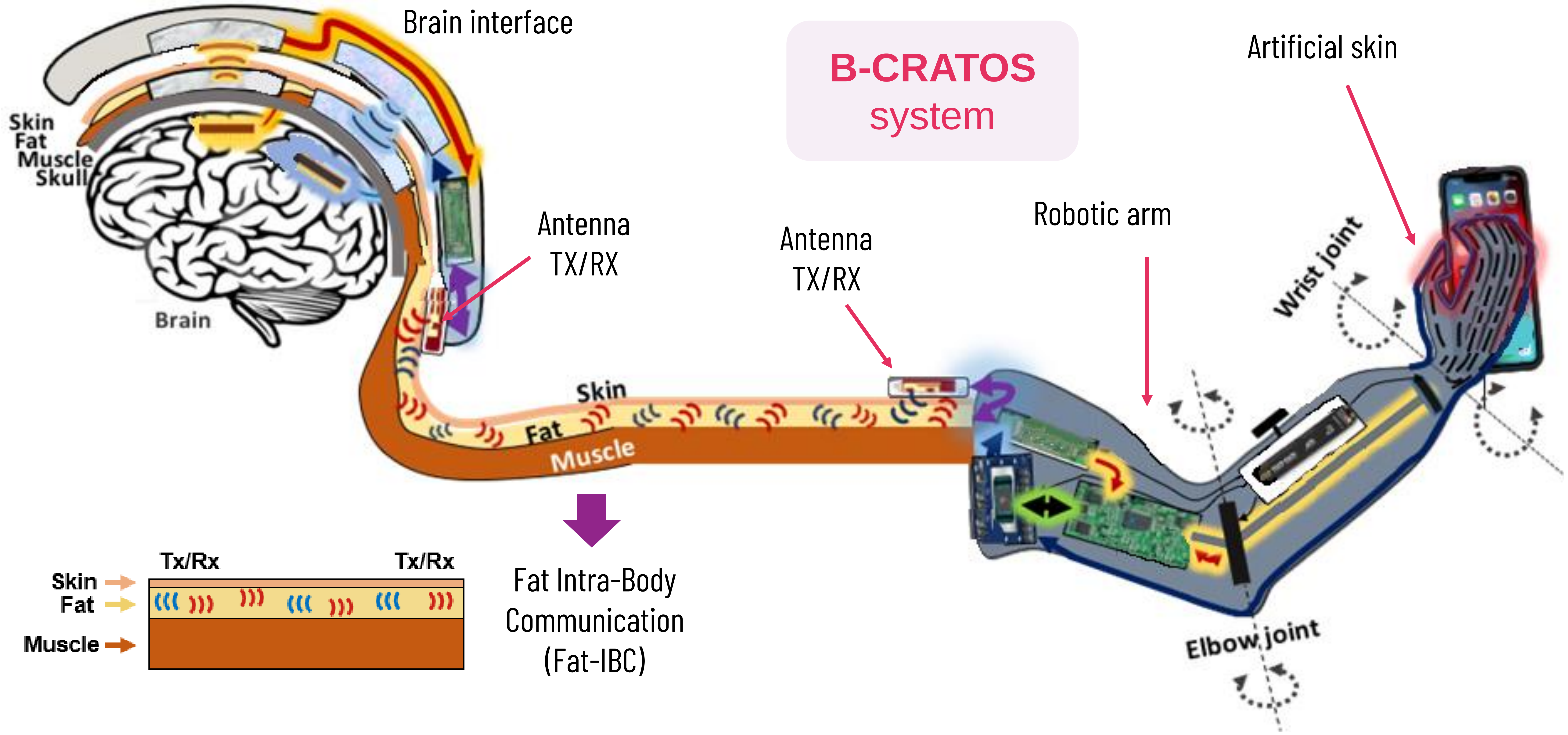
- B-CRATOS is developing a new proof-of-concept brain implant device
  - High Channel/Resolution: Utah Electrode Array (31 of 34 human BCI implants)
  - Batteryless: Continuous wireless power transfer from an external wearable device
  - Wireless data transfer: High data rate (30 Mbps) using RF backscatter
  - Compact, hermetically-sealed design for subcutaneous implantation on the skull
  - Processing and control of stimulation delivery externalized to "close the loop"
- B-CRATOS will link this implant device to external prosthetics and computational modules for decoding and stimulation control
  - In-body microwave propagation technique through subdermal body fat (Fat-IBC)

B-CRATOS BCI Webinar – 26-01-2022
Paul Wanda – BRME
CONFIDENTIAL – DO NOT DISTRIBUTE

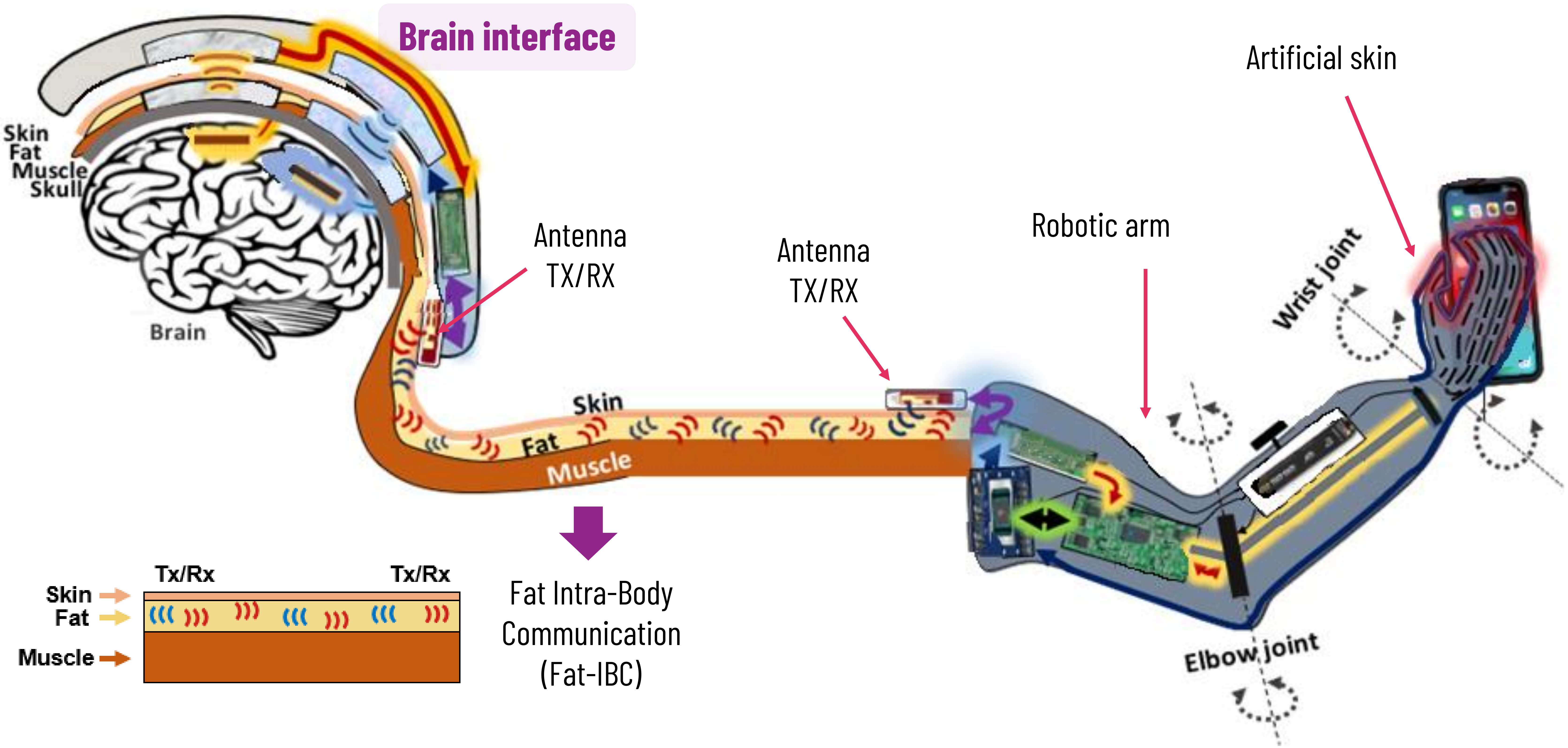
BLACKROCK® MICROSYSTEMS EUROPE

Overview of the project

B-CRATOS
system

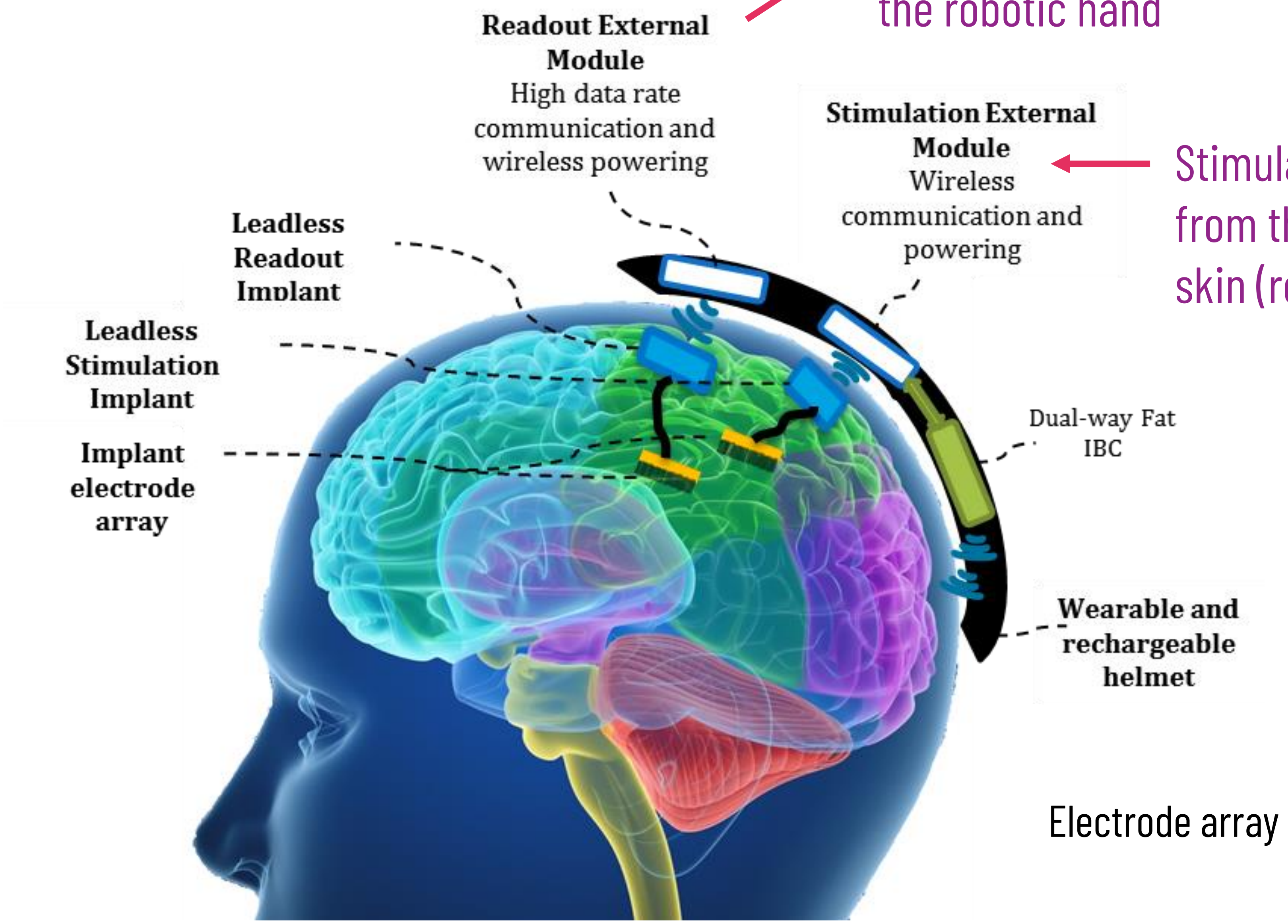


Overview of the project



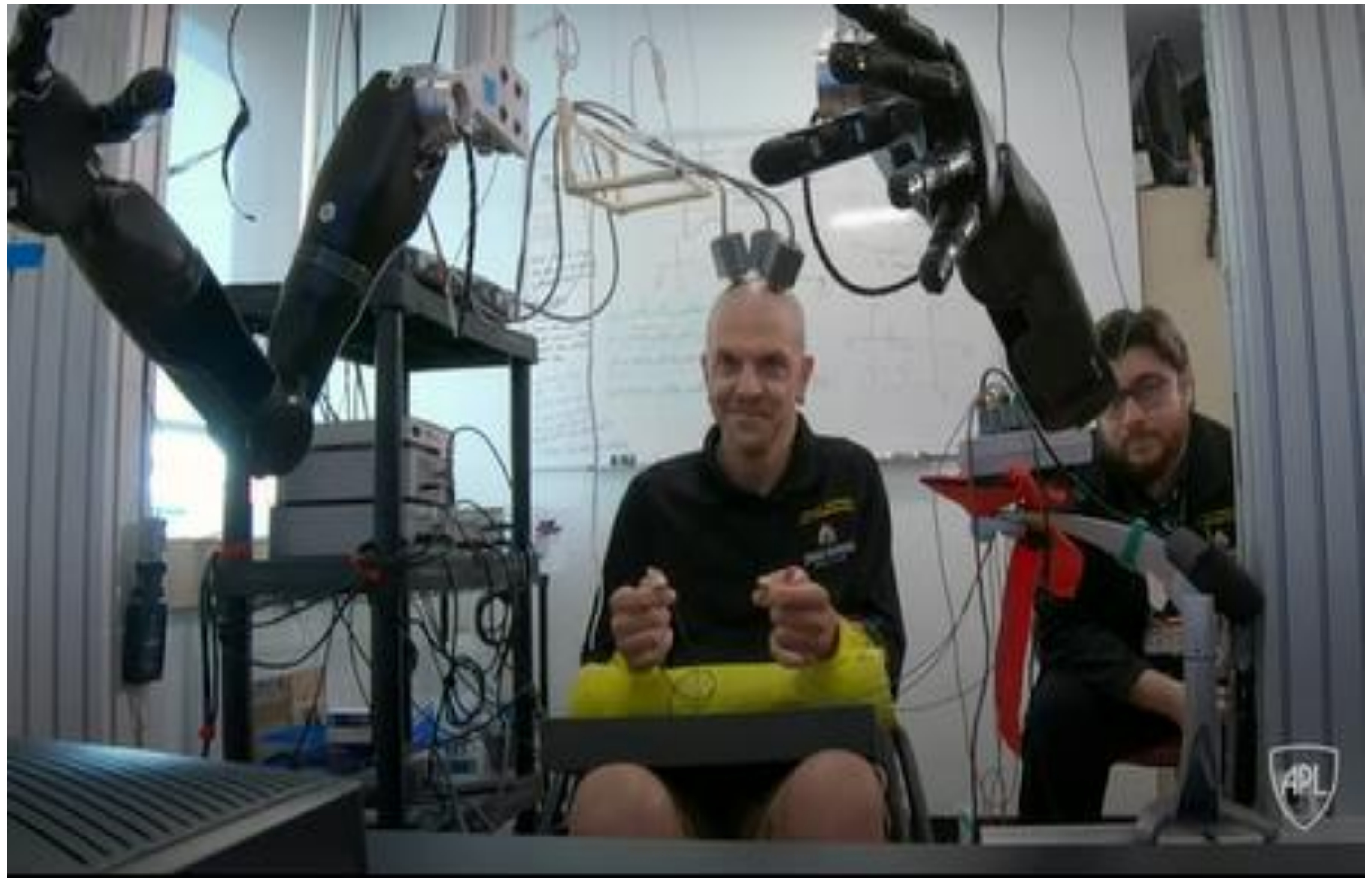
Brain interface

Readout of neural inputs to be sent to the robotic hand



Stimulations readout from the artificial skin (robotic hand)

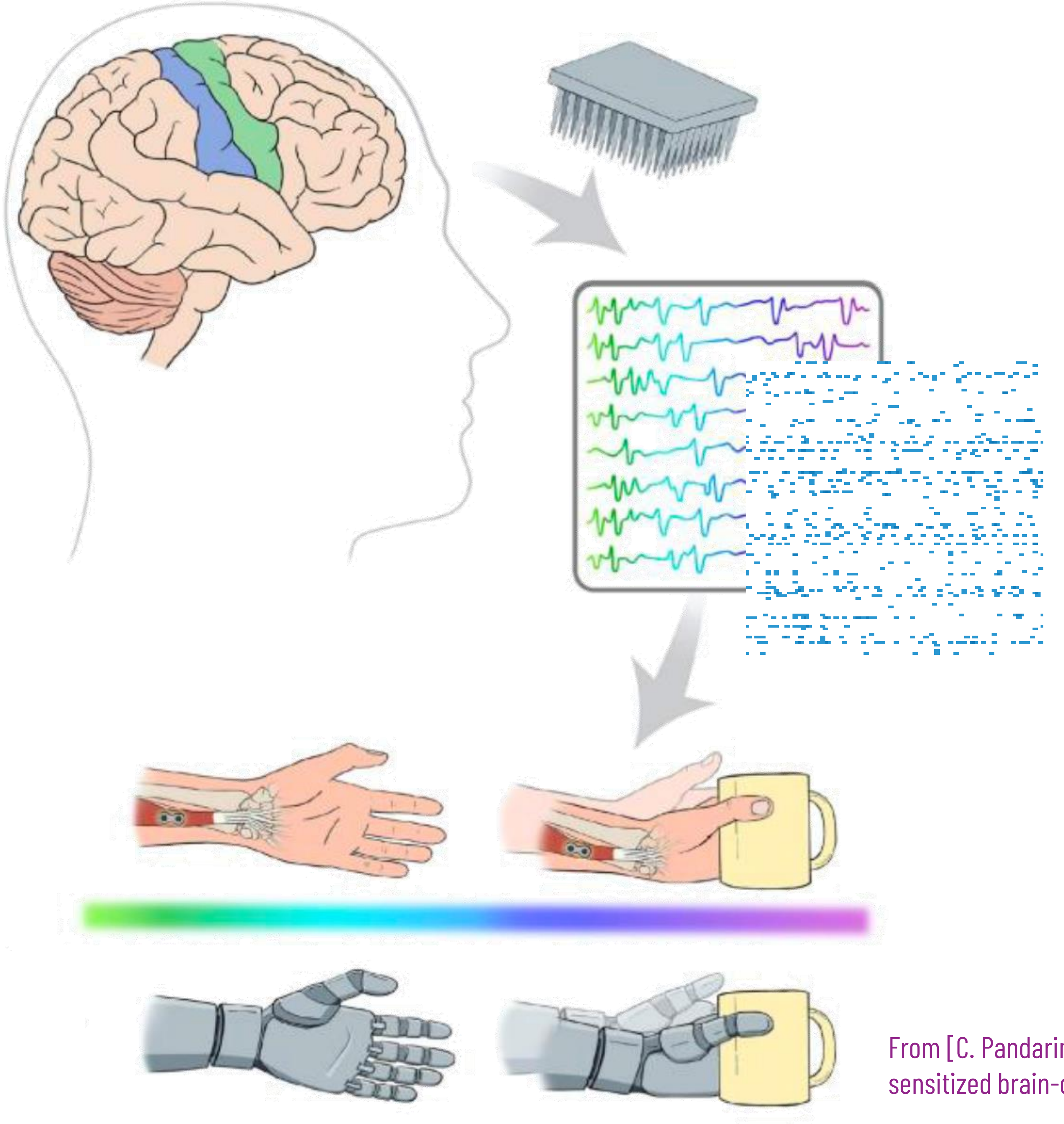
Electrode array



- Power and data exchange between a readout brain implant and the external system.
- Battery-less readout of high-bandwidth cortical signals and low-latency stimulation control.

Neural decoding

Fondazione LINKS – Passion for Innovation
Funded by the European Union
NTNU Norwegian University of Science and Technology
BLACKROCK MICROSYSTEMS



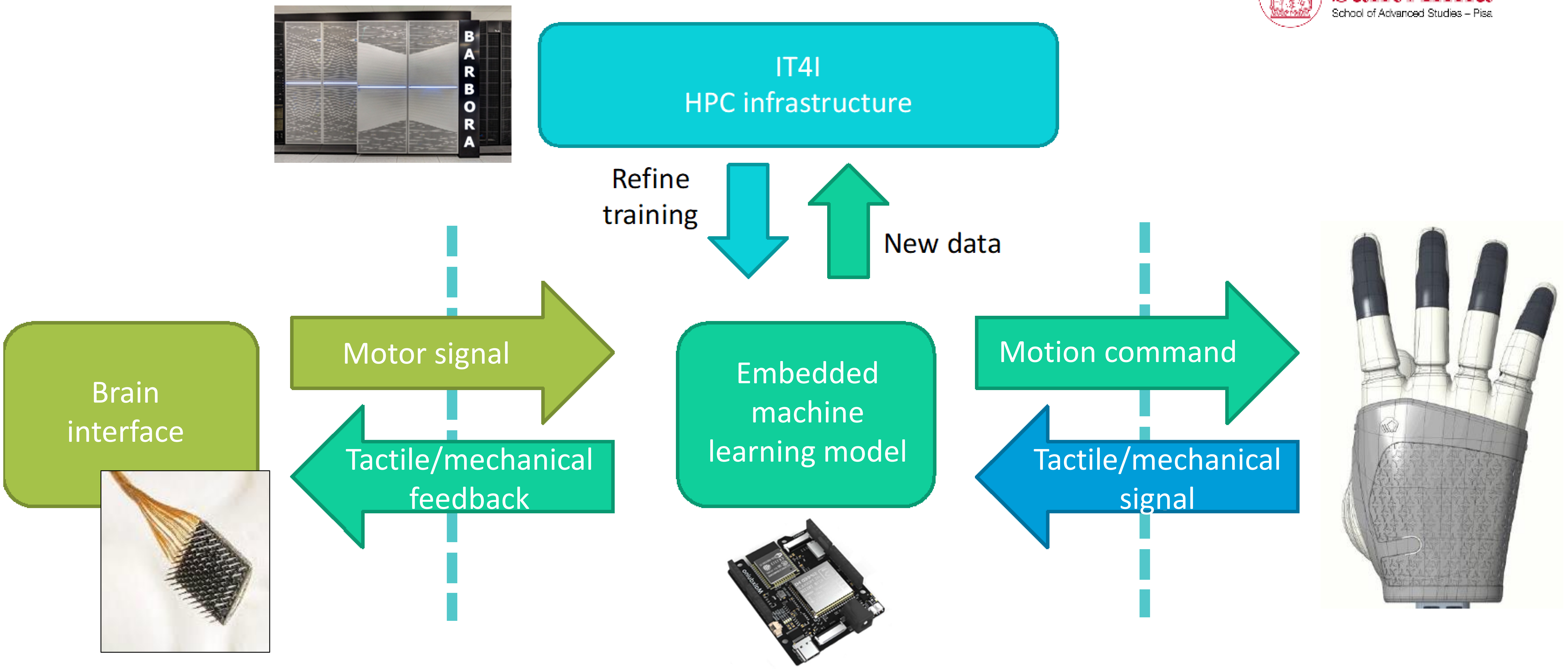
GOAL: translate the signal from brain implants into commands for a prothesis

Main steps:

- Brain electrodes pick up analogue signals from large neuron populations.
- Post-processing is applied to identify individual neurons and to convert the signal to “spike-trains”: multi-channel time series of binary data.
- Decoding algorithm is applied to convert the signal to command for the prothesis.

From [C. Pandarinath and S. J. Bensmaia, “The science and engineering behind sensitized brain-controlled bionic hands,” *Physiol. Rev.*, vol. 102, no. 2, 2022].

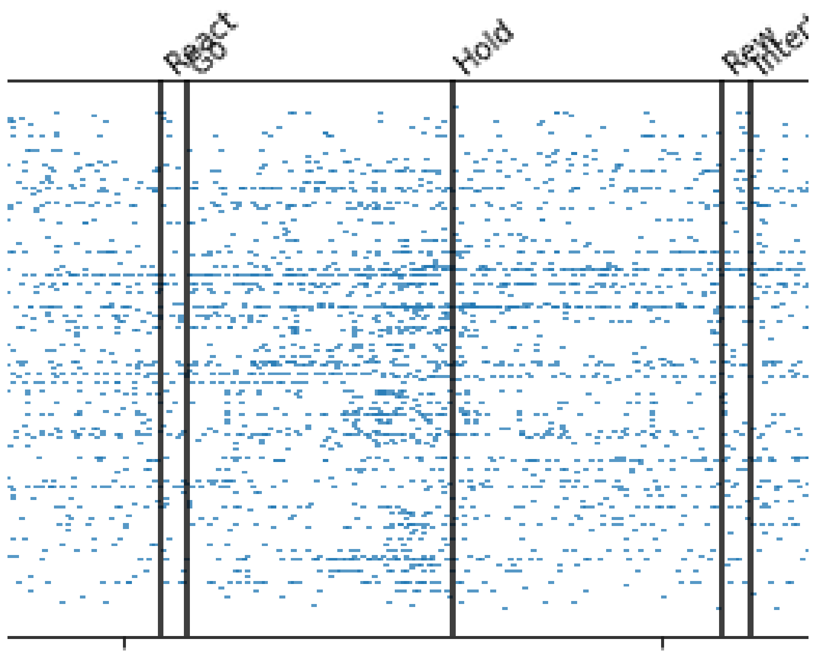
LINKS computational module



LINKS computational module

LINKS computational board should

- Translate motor cortex signal into **commands for MIA Hand**
- Read eSkin signal and **encode feedback** for sensory stimulation
- Collect data for online training of the ML/DL model on HPC infrastructure
- Work with **low power supply** ~5W

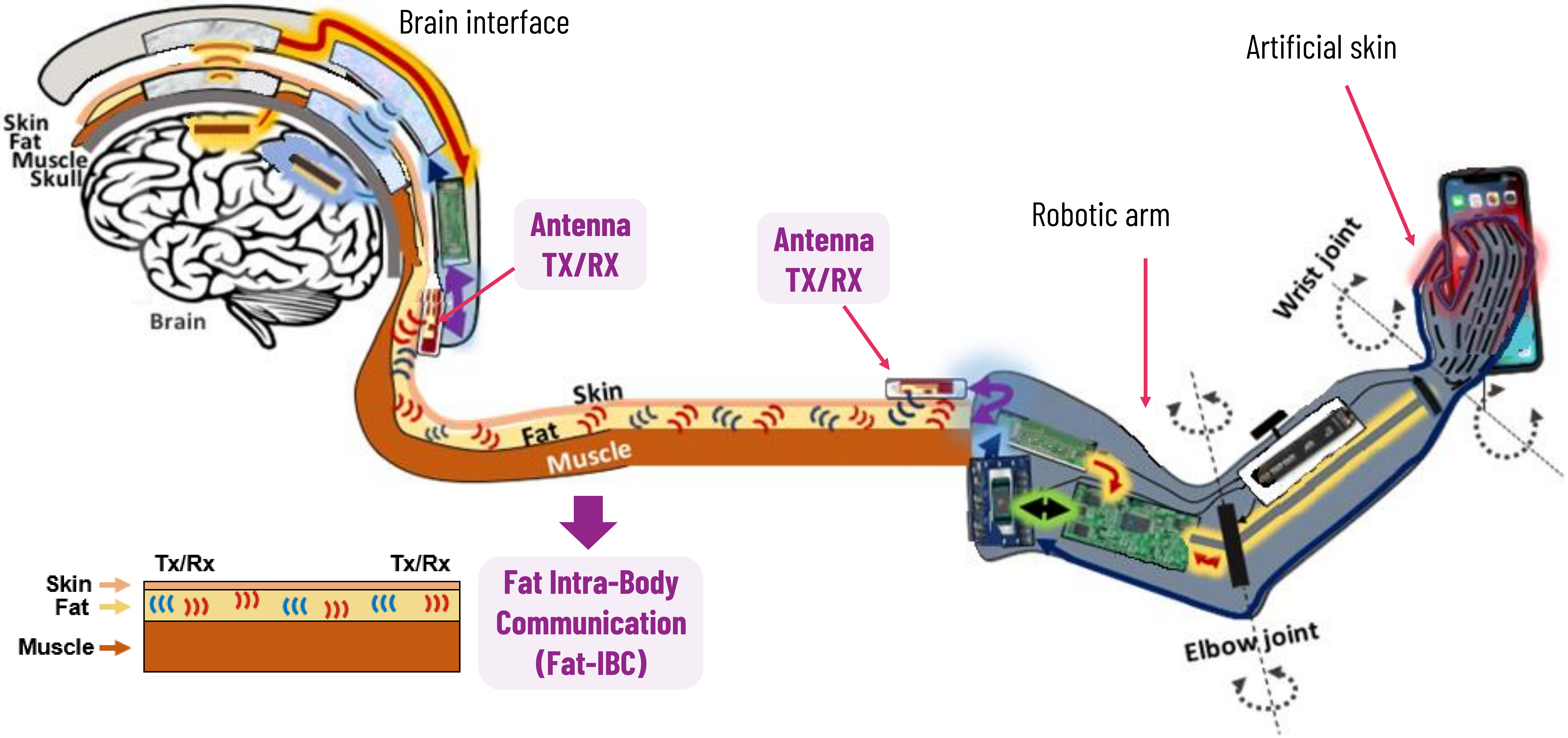


LINKS computational module

Main challenges:

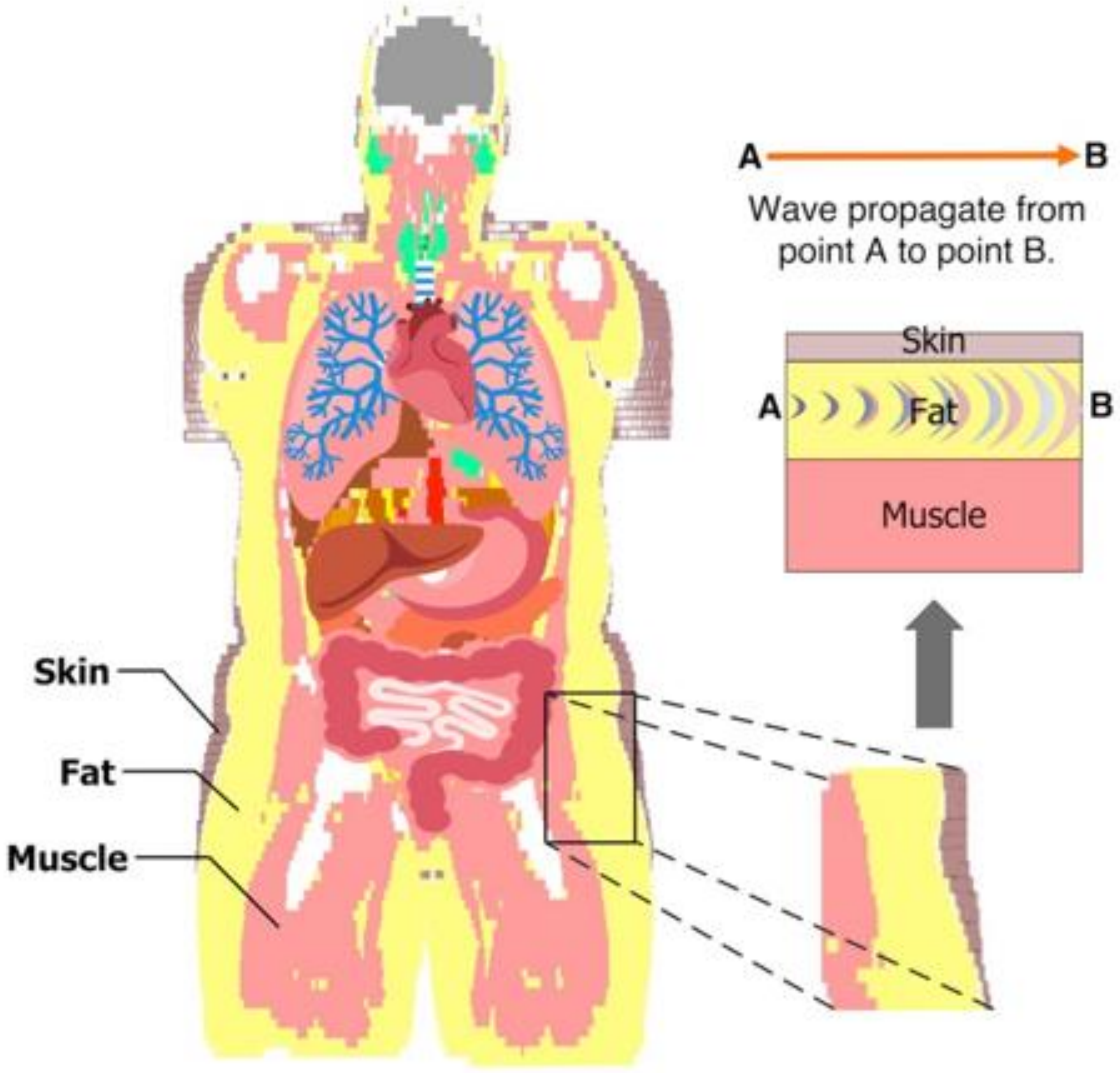
- Perform multiple real-time tasks with **low power consumption**
- Implement **large DL models on small devices**
- Go beyond well known decoding tasks → needed to **move the effort of learning from the patient to the ML/DL model**
  - i.e. reuse model between trials → unsupervised (re-)training
  - i.e. reuse model across individuals
- Implement functional brain-based control loops

Overview of the project



Fat Intra-Body Communication (Fat-IBC)

Fat Intra-Body Communication (Fat IBC)



Asan, N.B., et al., "Characterization of the fat channel for intra-body communication at R-band frequencies", *Sensors*, vol. 18, no. 9, 2018.

- Fat intra-body communication (Fat-IBC) is an innovative technique that exploits the very low electrical conductivity σ of the fat tissue layer as a channel for electromagnetic signals [1,2]
- This technique is really promising for the implementation of wireless, in-body, Brain-Machine-Body connectivity.

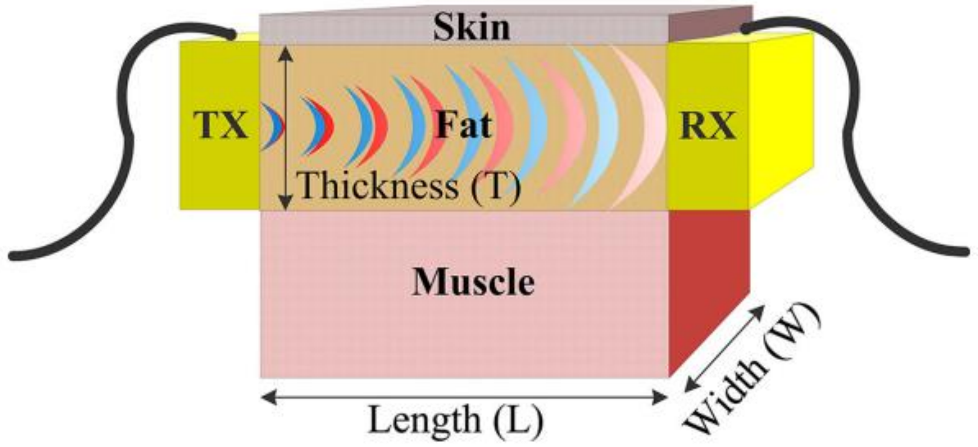
Tissue	ε_r	σ (S/m)
Skin	38.57	1.58
Fat	5.328	0.11
Muscle	53.29	1.82

[1] N. B. Asan, D. Noreland, E. Hassan, S. Redzwan Mohd Shah, A. Rydberg, T. J. Blokhuis, P.-O. Carlsson, T. Voigt, and R. Augustine, *Healthc. Technol. Lett.*, vol. 4, no. 4, 2017.

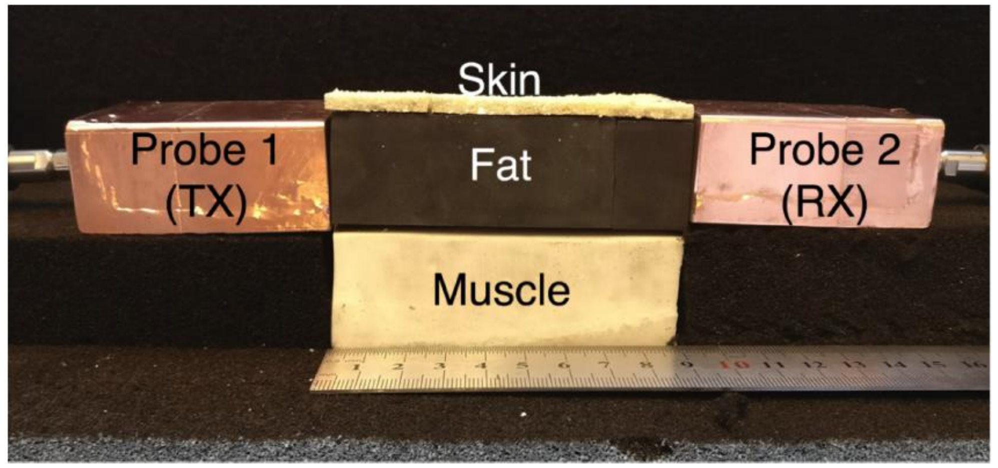
[2] N. B. Asan, C. Pérez Penichet, S. Redzwan Mohd Shah, D. Noreland, E. Hassan, A. Rydberg, T. J. Blokhuis, T. Voigt, and R. Augustine, IEEE J. Electromagn., *RF, Microw. Med. Biol.*, vol. 1, no. 2, pp. 43-51, 2017.

Fat Intra-Body Communication (Fat IBC)

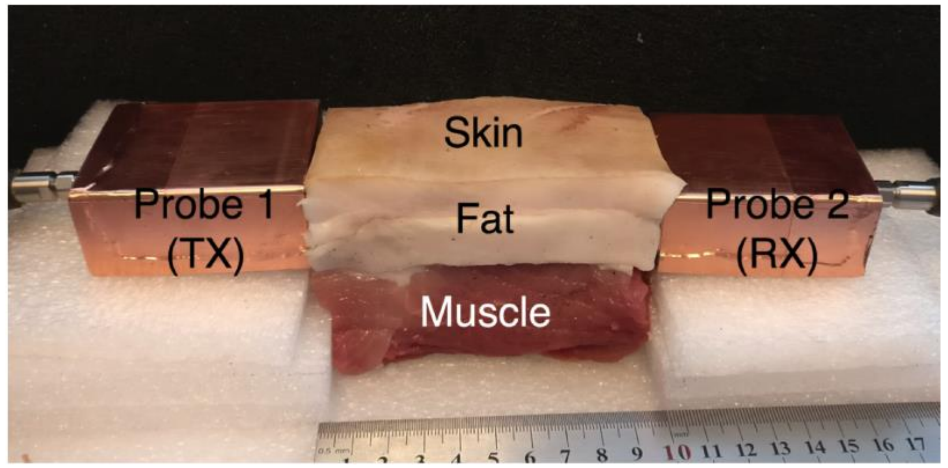
Simulation



PHANTOM

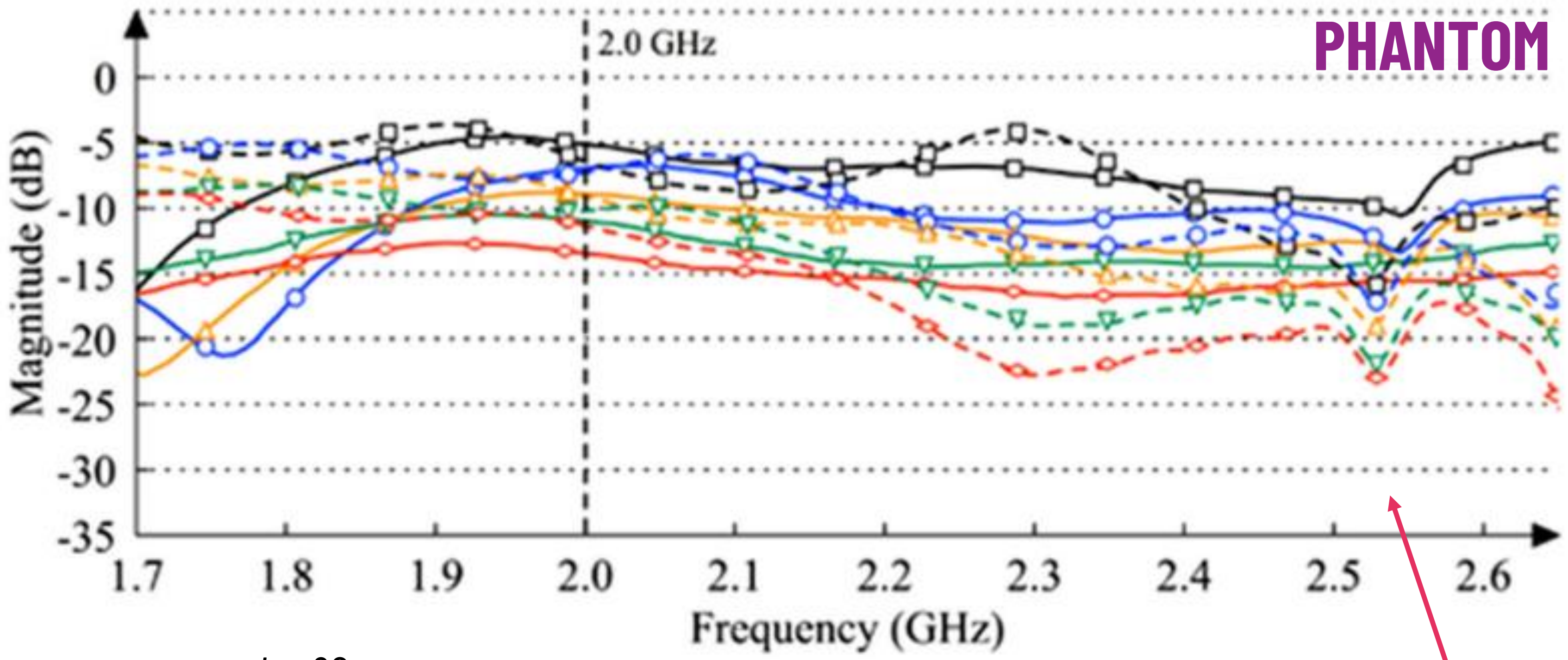


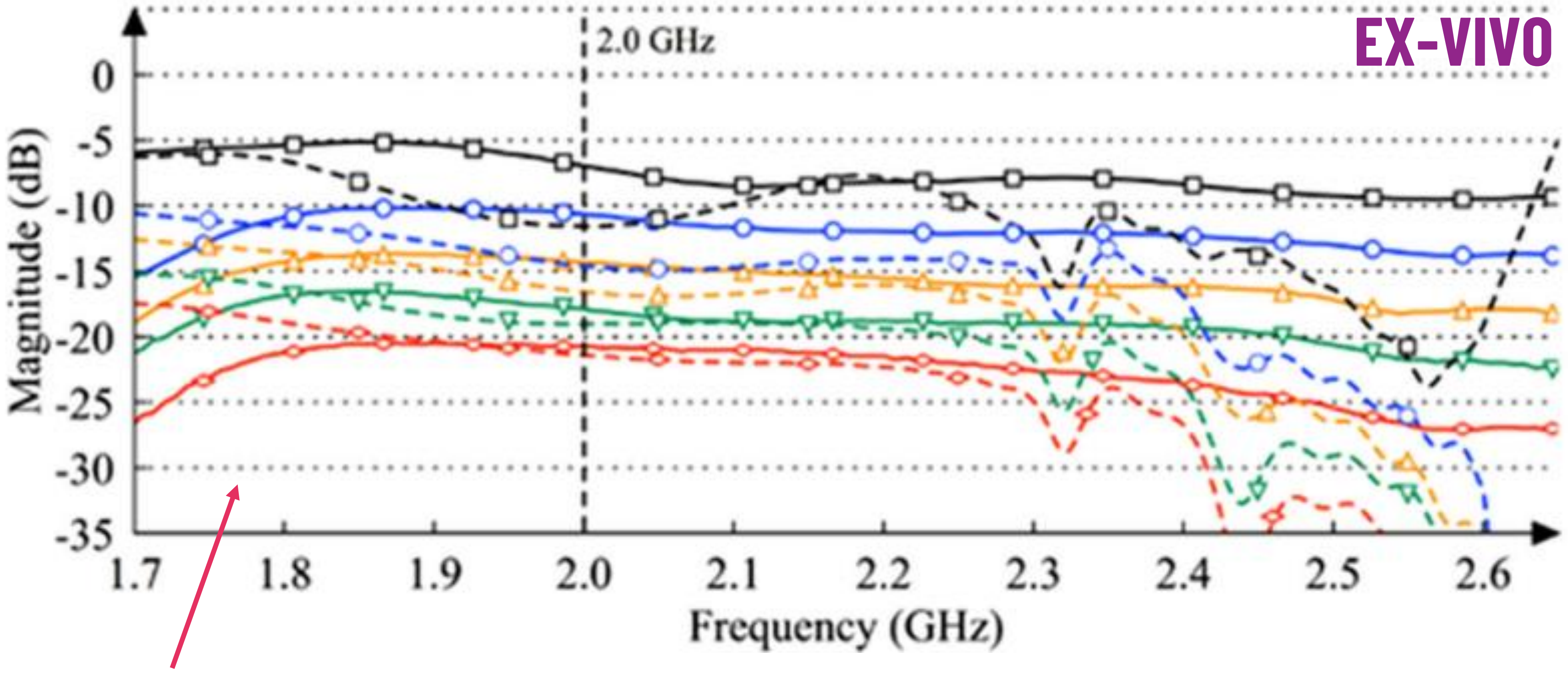
EX-VIVO



UPPSALA UNIVERSITET

Porcine belly tissue





- *L* = 20 mm
- *L* = 40 mm
- *L* = 60 mm
- *L* = 80 mm
- *L* = 100 mm

- Simulation (dashed)
- Measurement (solid)

Transmission coefficient

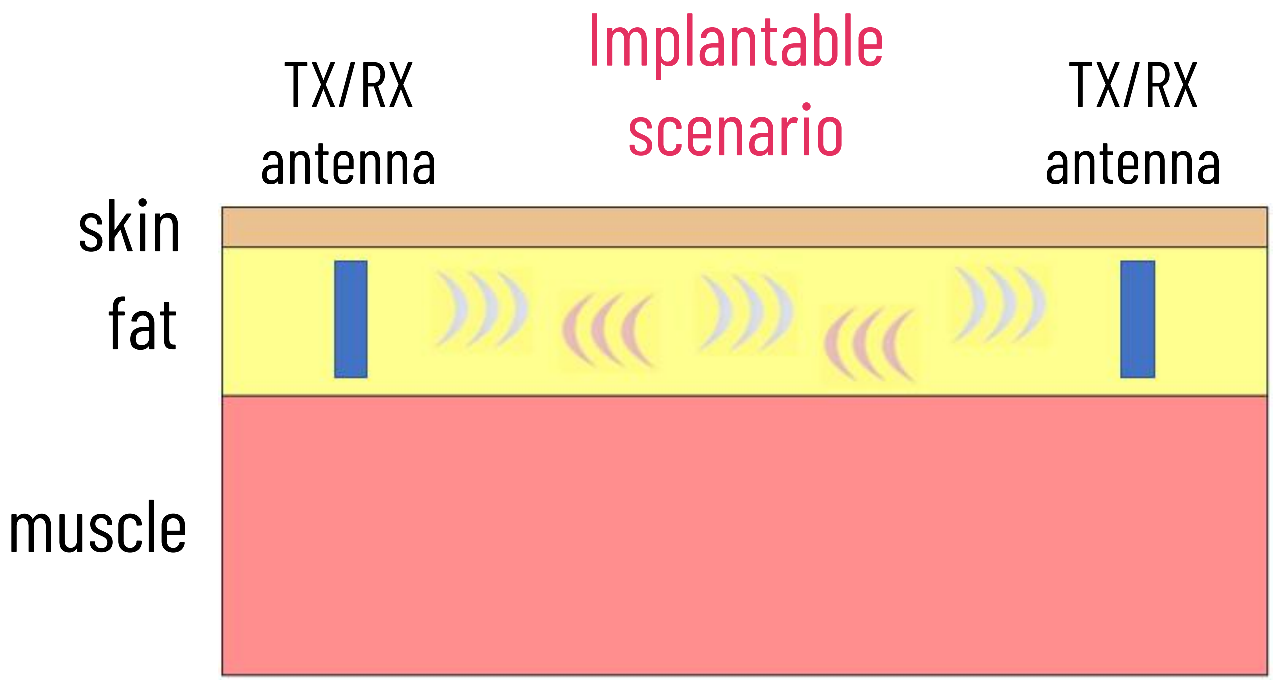
UPPSALA UNIVERSITET

Asan, N.B., et al., "Data Packet Transmission Through Fat Tissue for Wireless IntraBody Networks", *IEEE J. Electromagn. RF Microw. Med.*, vol. 1, no. 2, 2017.

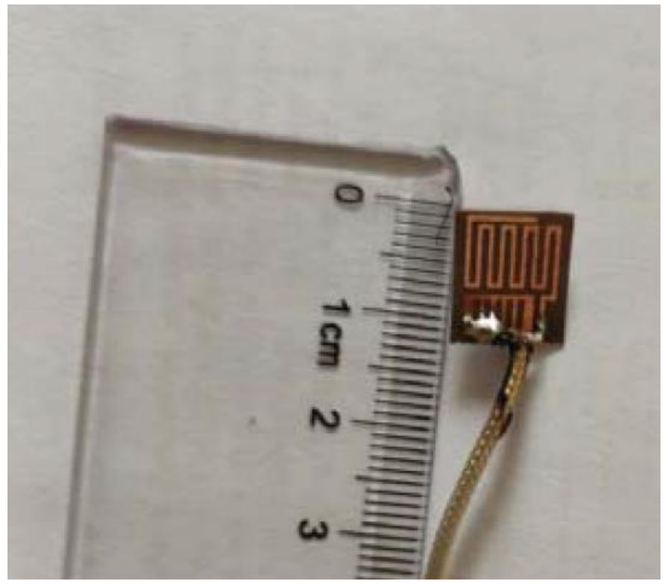
FONDAZIONE links PASSION FOR INNOVATION
Funded by the European Union
UPPSALA UNIVERSITET

Fat Intra-Body Communication (Fat IBC)

Antenna and circuitry design

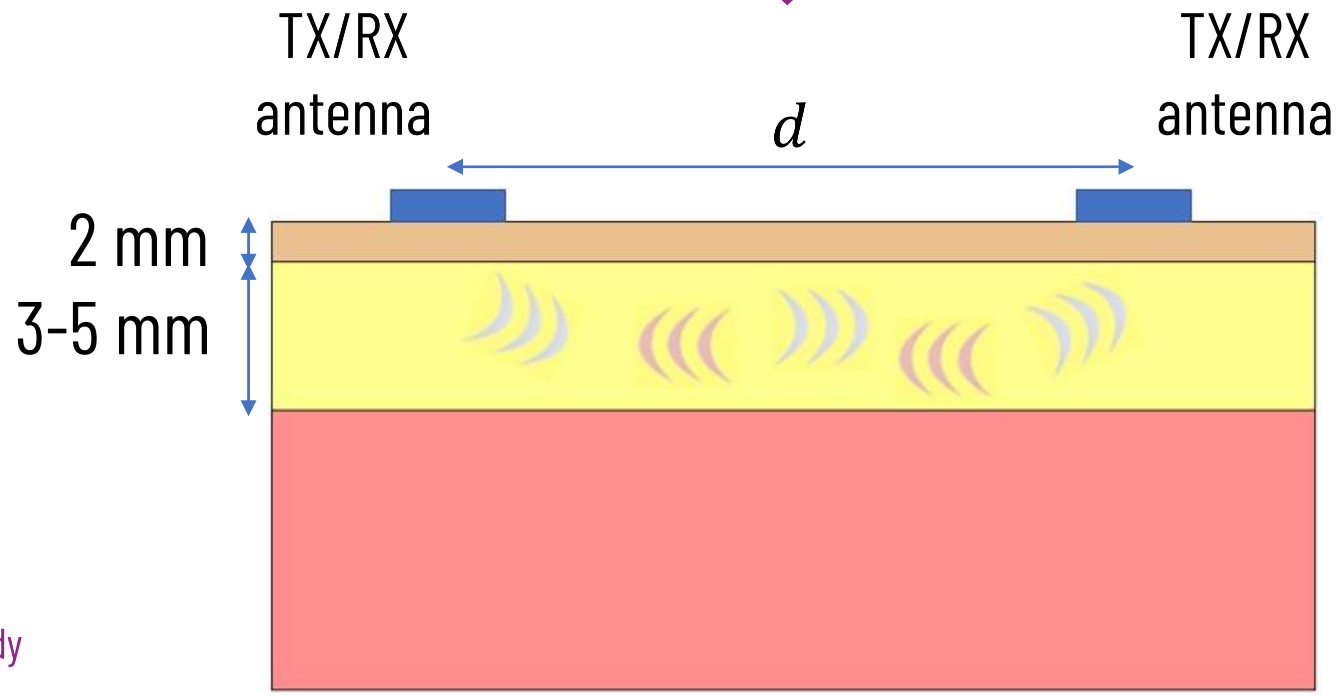


- The communication between the antennas occurs in the subcutaneous fat layer (Fat-IBC) exploiting the very low electrical conductivity of the fat tissue layer ($\sigma = 0.11$ S/m).
- For the realization of a demonstrator in the context of B-CRATOS, “not implantable” antennas will be designed and optimized.

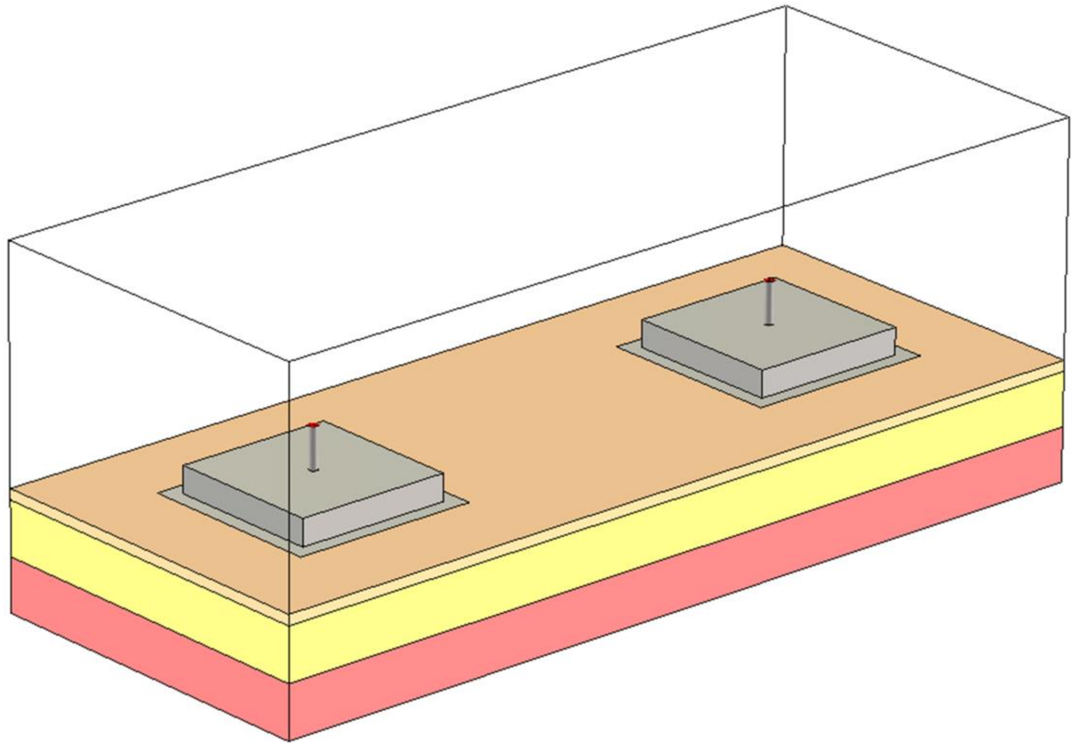


UPPSALA UNIVERSITET

Mandal, B., et al., “Low Profile Implantable Antenna for Fat Intra-Body Communication”, *EUCAP 2020.*

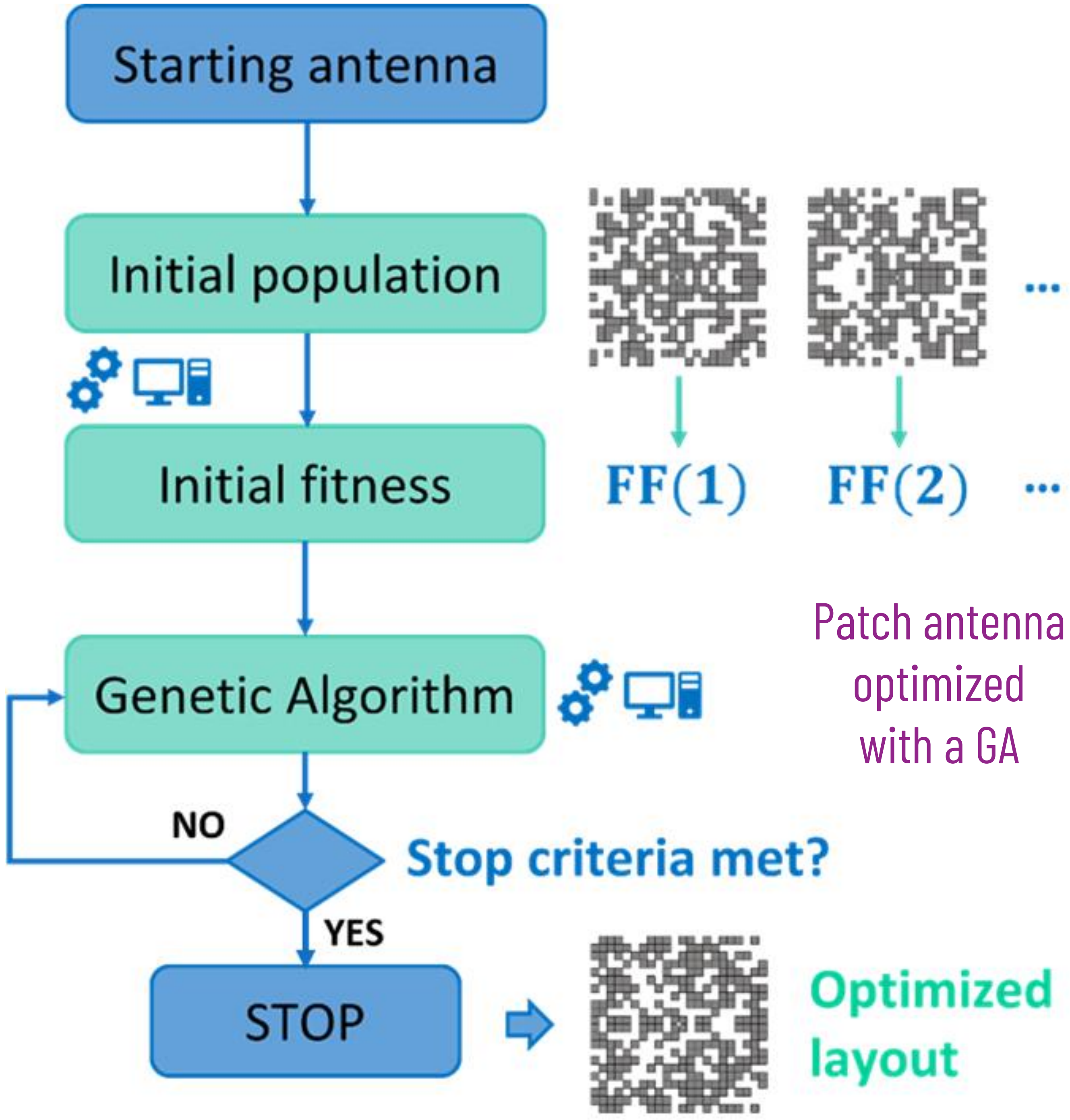


$f = 2.44$ GHz



Fat Intra-Body Communication (Fat IBC)

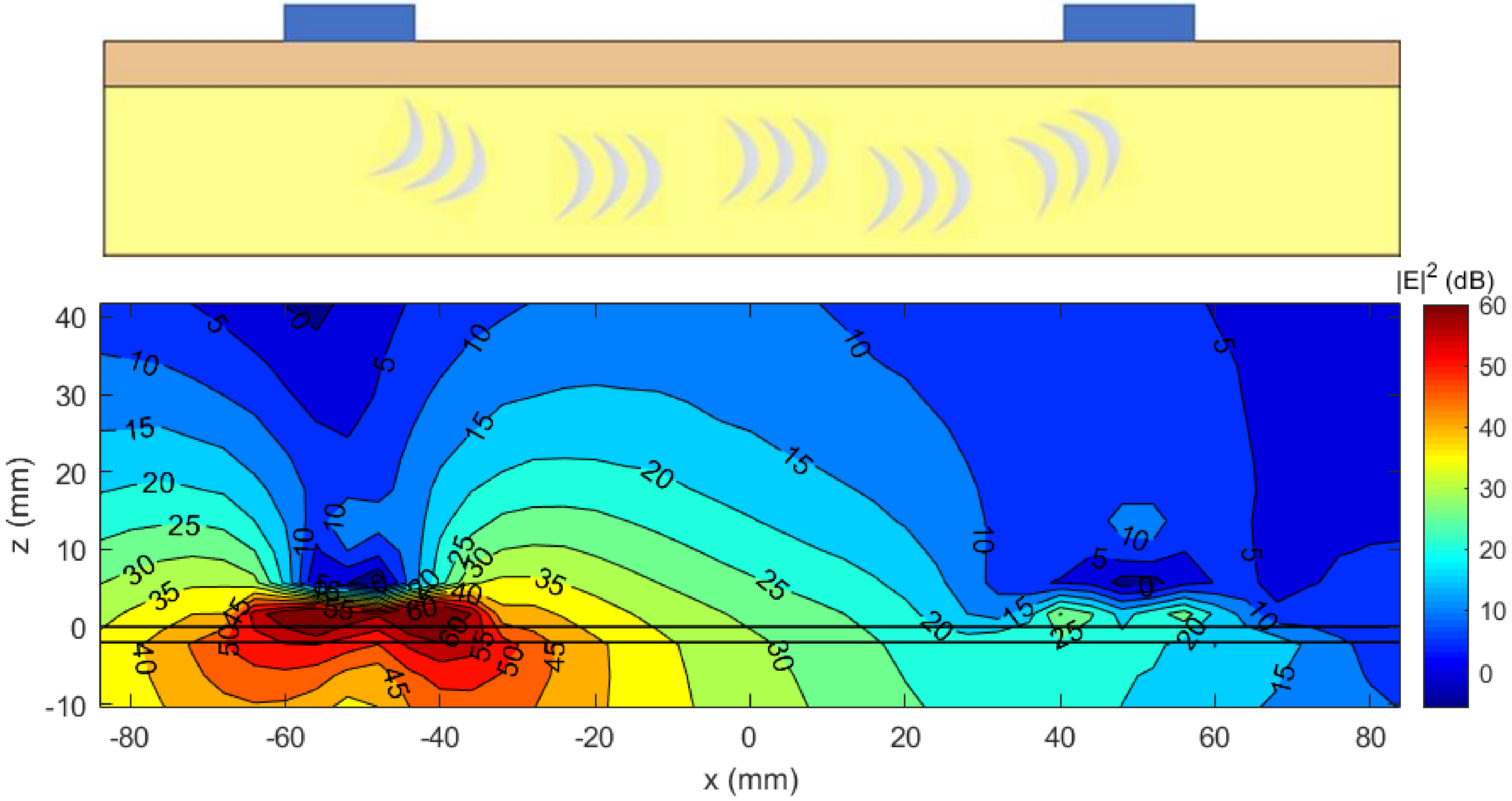
Antenna and circuitry design



Patch antenna optimized with a GA

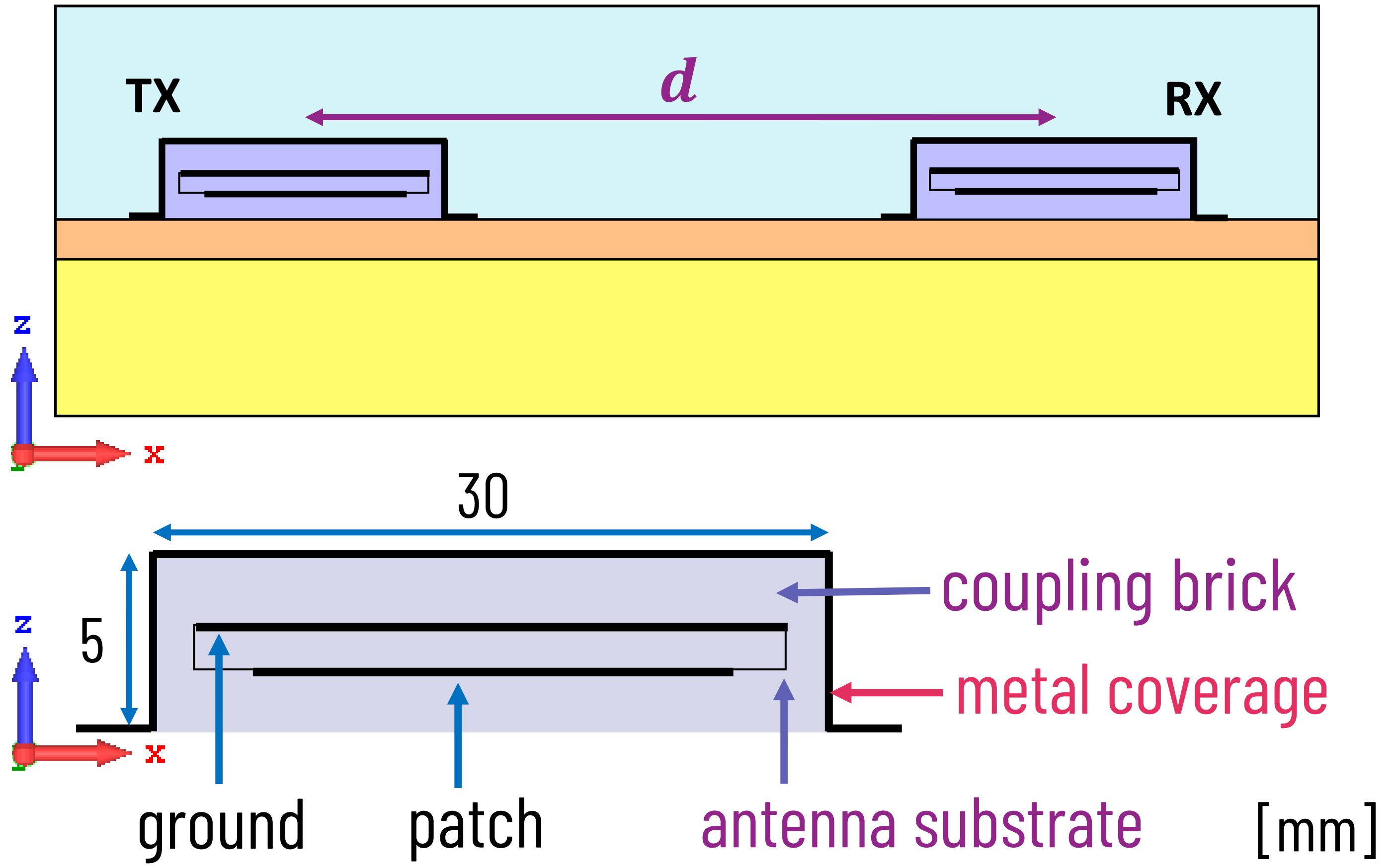
Gaffoglio, R., et al., "Pixel Optimization via Genetic Algorithm of a Flat Epidermal Antenna for Fat Channel Communication", *EUCAP 2022*.

- Epidermal (external) antennas are considered for non-invasive testing on Non-Human Primates (NHPs)
- Not trivial antennas must be designed to favor the electromagnetic coupling in the subcutaneous fat layer



Fat Intra-Body Communication (Fat IBC)

Antenna and circuitry design

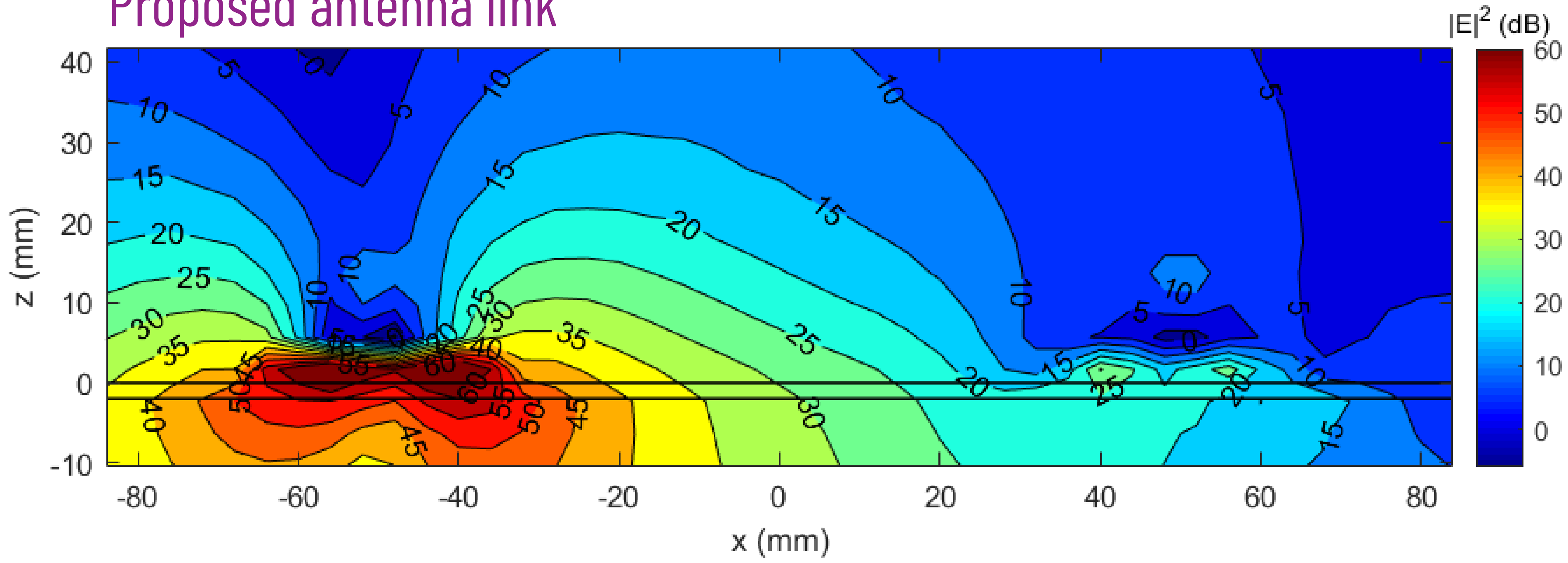


Design proposed by LINKS:

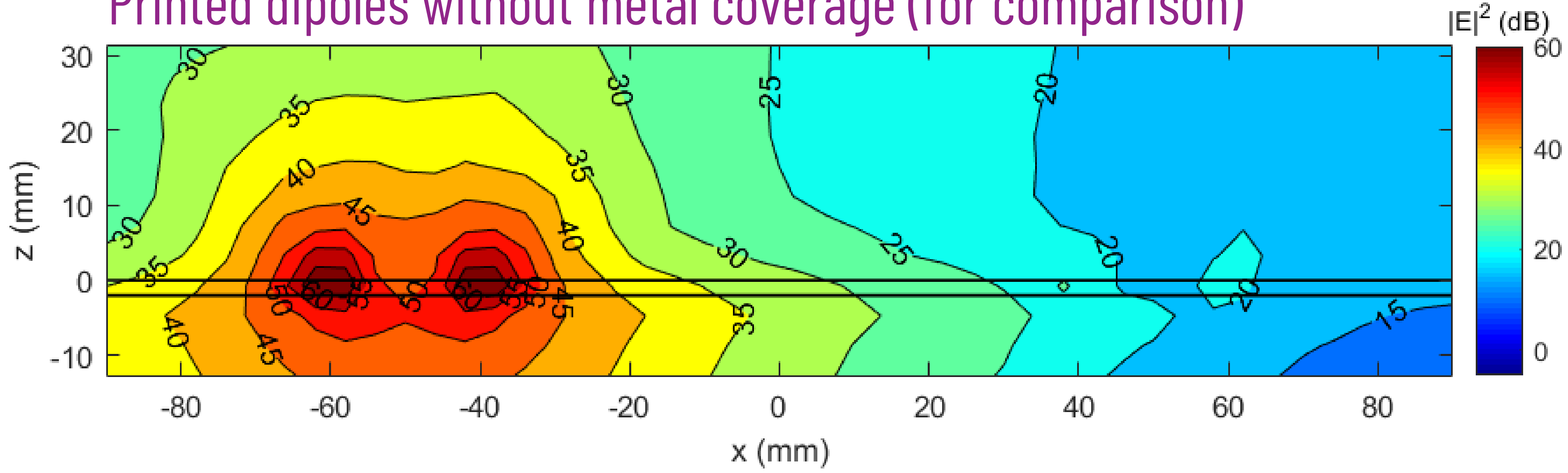
- dielectric brick to favor the EM coupling in tissues
- metal coverage around the brick to minimize the EM propagation through the air and demonstrate the Fat IBC

Isolines of $|\mathbf{E}|^2$ on the $y = 0$ plane

Proposed antenna link

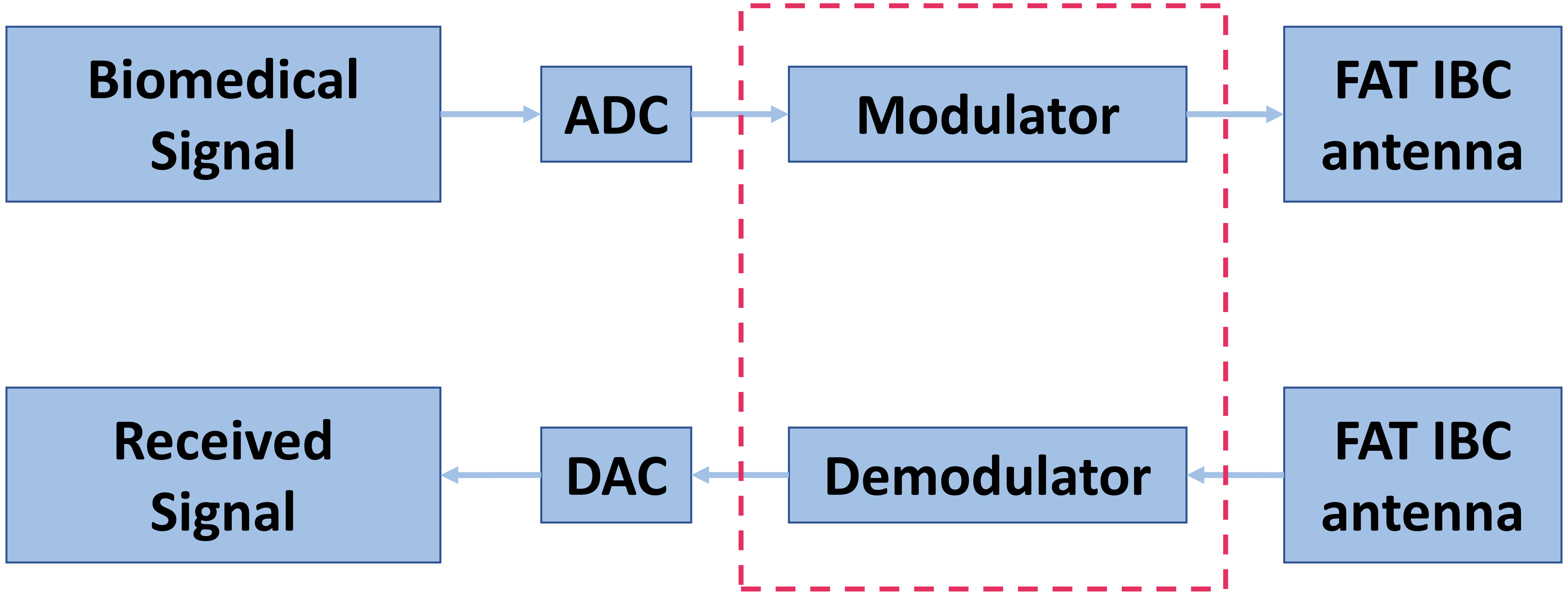


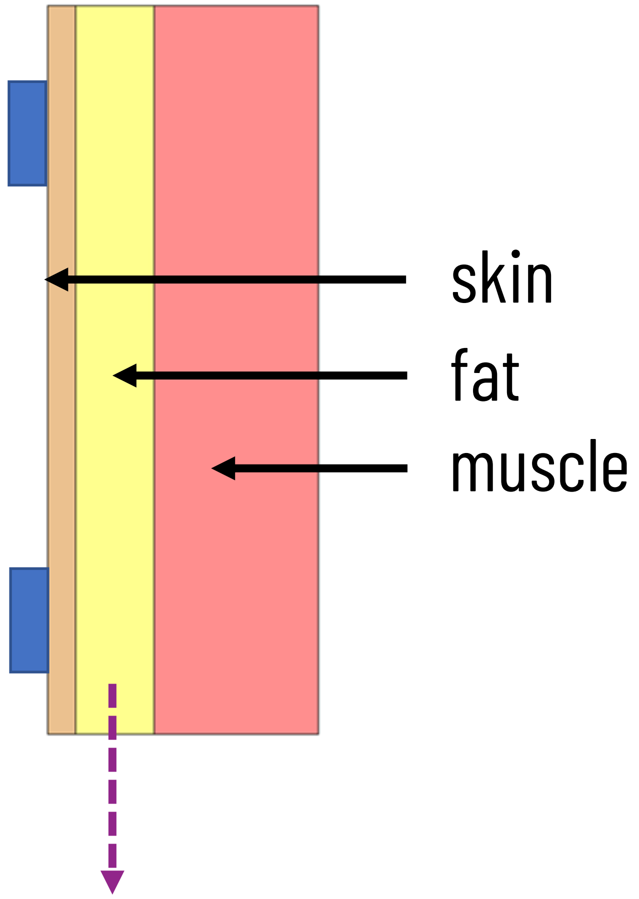
Printed dipoles without metal coverage (for comparison)



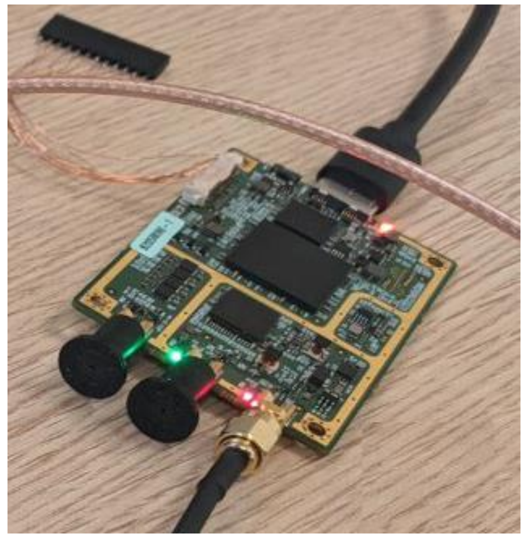
Fat Intra-Body Communication (Fat IBC)

Antenna and circuitry design





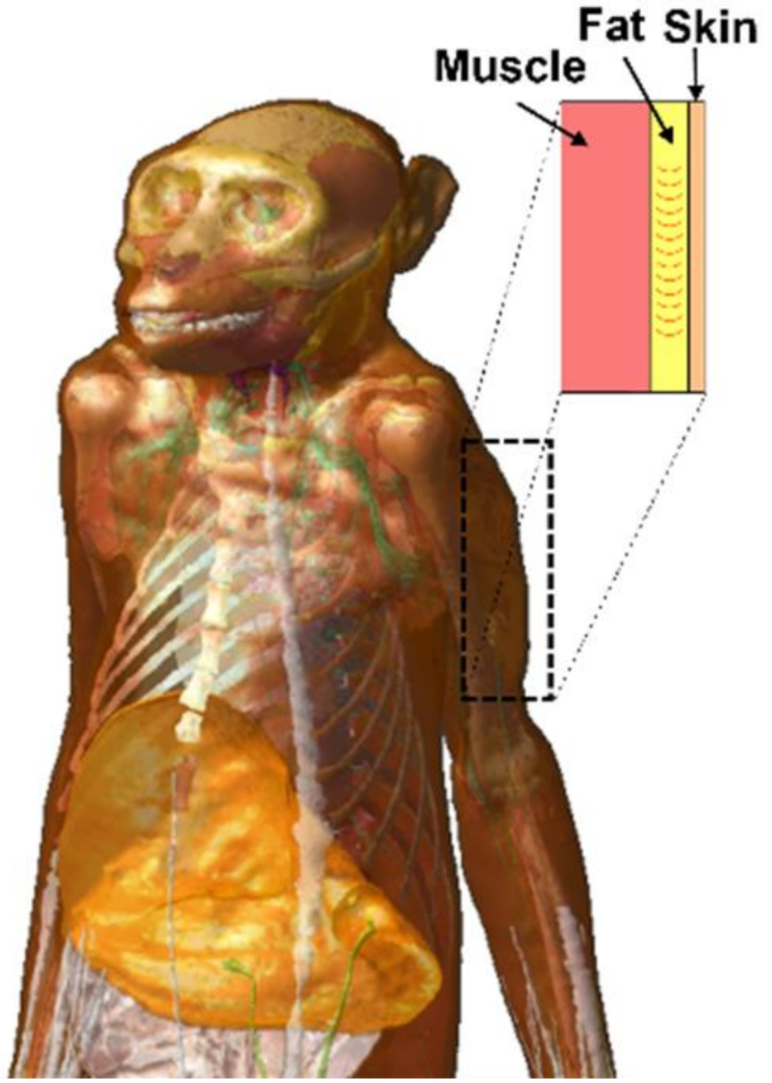
Modulation/demodulation electronics needed to carry/read the information on/from the propagating signals



The subcutaneous fat layer serves as communication channel

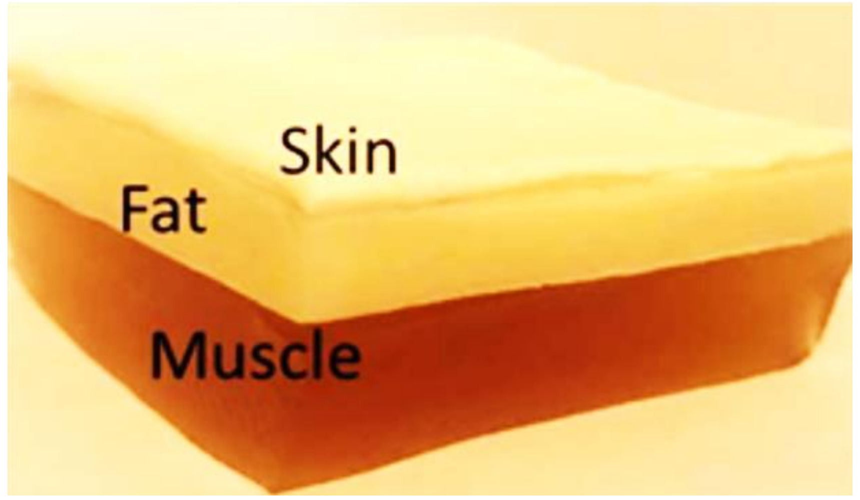
Fat Intra-Body Communication (Fat IBC)

Tissue phantoms fabrication



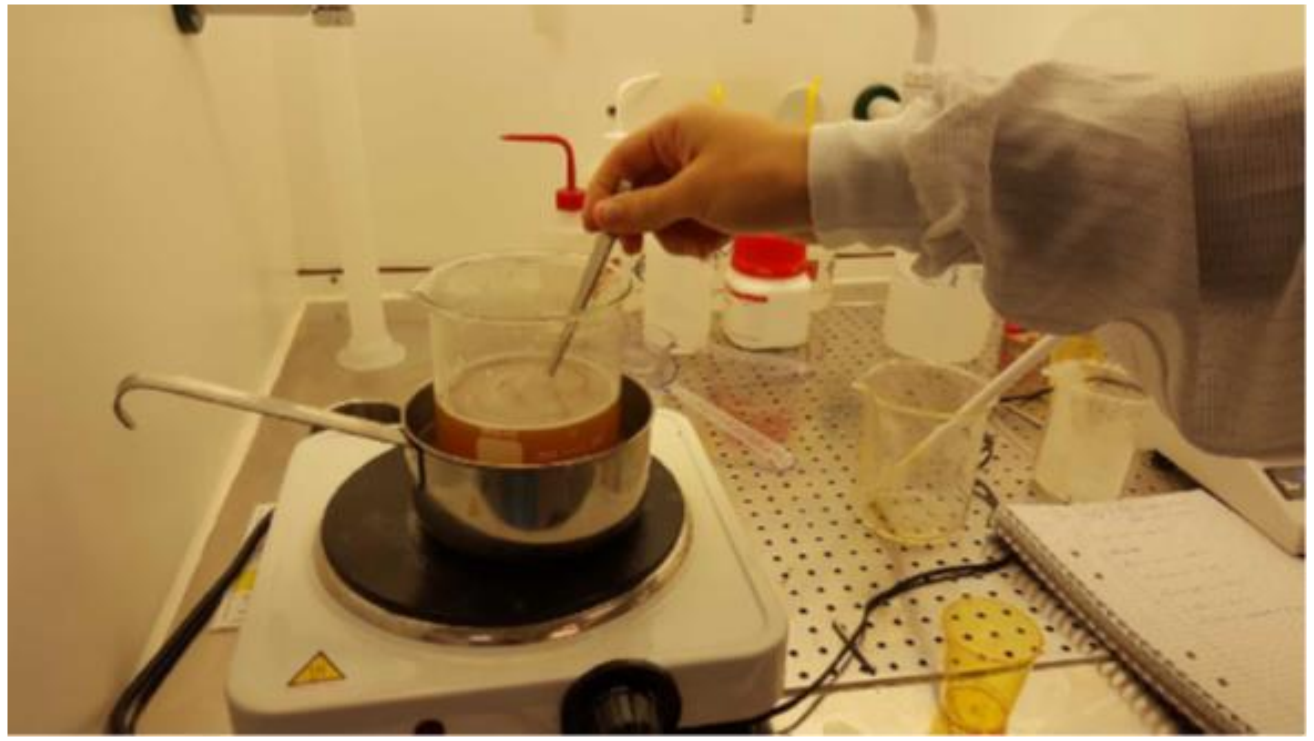
Tissue	ε_r	σ (S/m)
Skin	38.57	1.58
Fat	5.328	0.11
Muscle	53.29	1.82

1

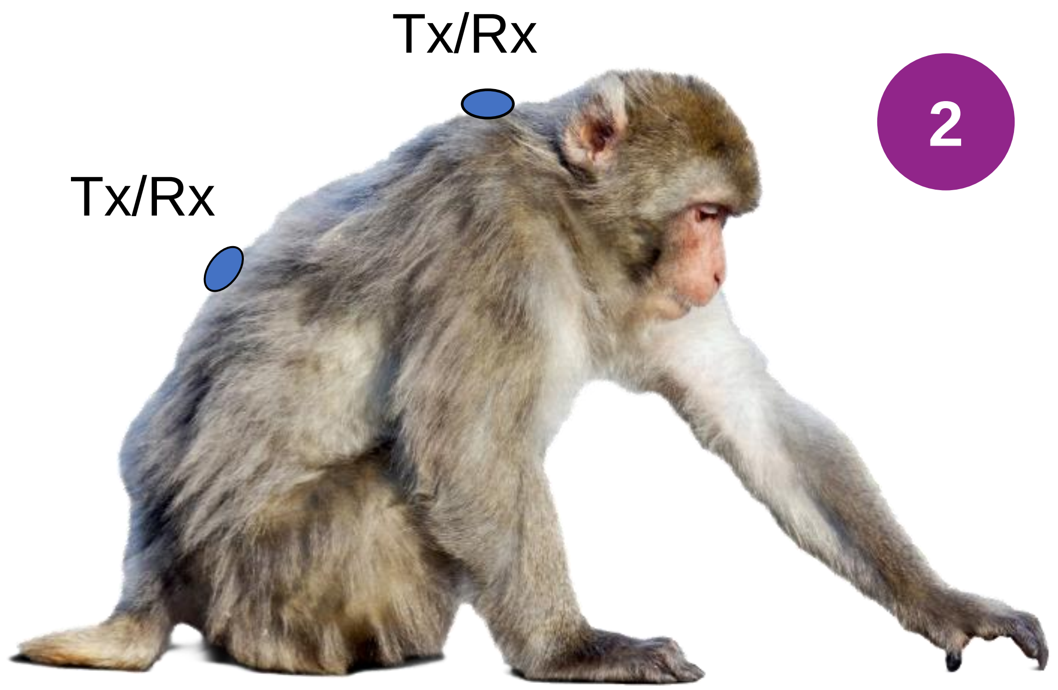


Phantoms fabrication at the Uppsala University

UPPSALA UNIVERSITET

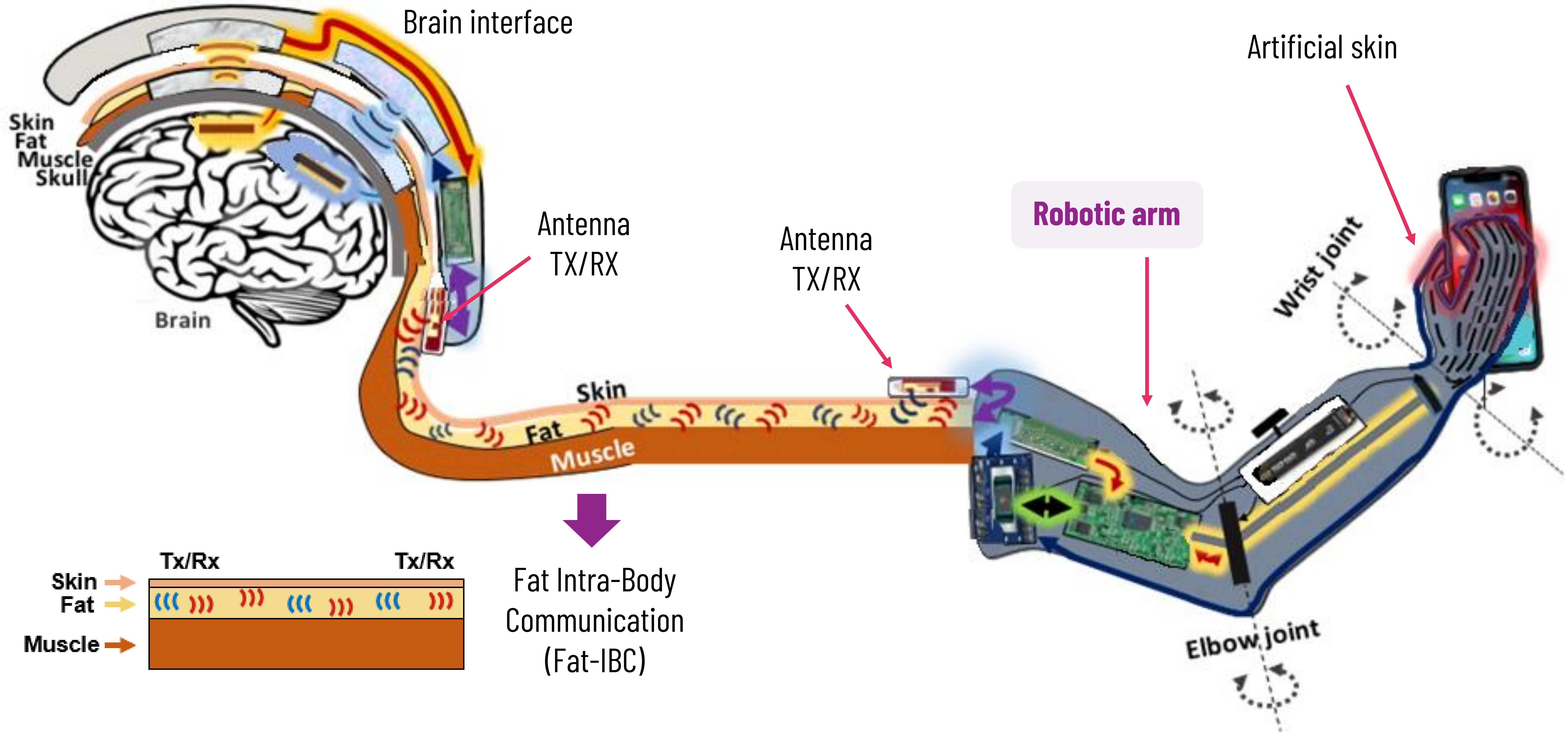


1. The performance of the designed antennas is first validated using phantoms (reproducing the dielectric characteristics the different tissues)
2. In vivo validation of the B-CRATOS platform technologies will be performed on non-human primates (NHPs)



2

Overview of the project



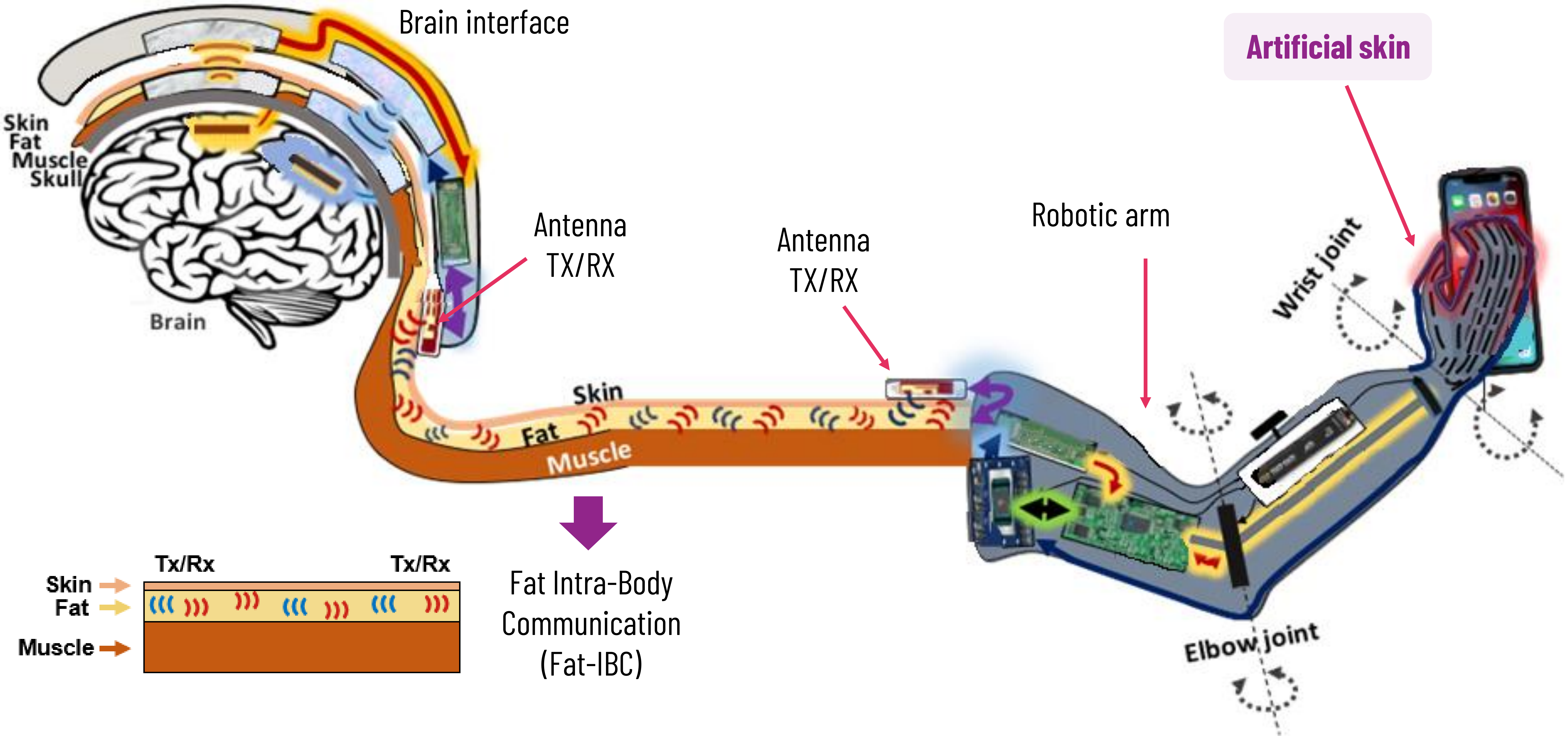
Fat Intra-Body Communication (Fat-IBC)

Biomechatronic prosthetic arm

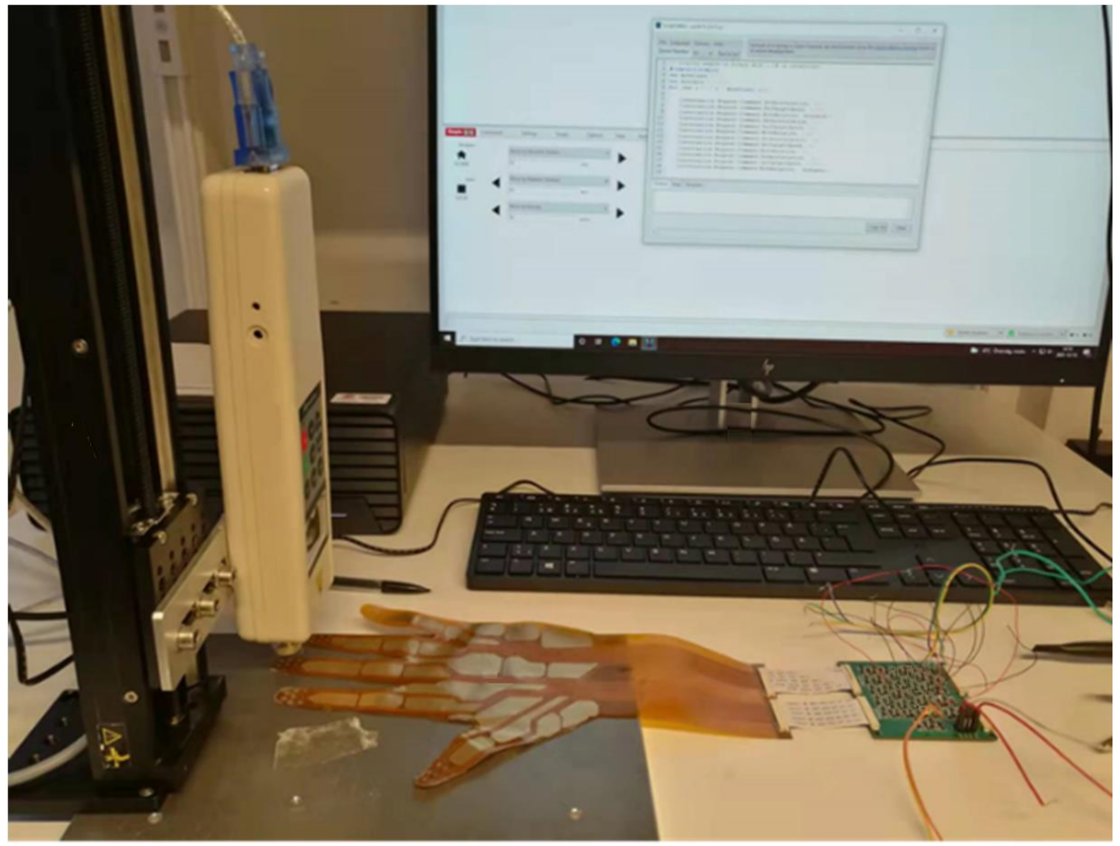
Electric anthropomorphic dexterous hand, suitable in: social and/or humanoid collaborative robots, bio-automation, ergonomics, prosthetics, human-machine interface research.

Sant'Anna
School of Advanced Studies – Pisa

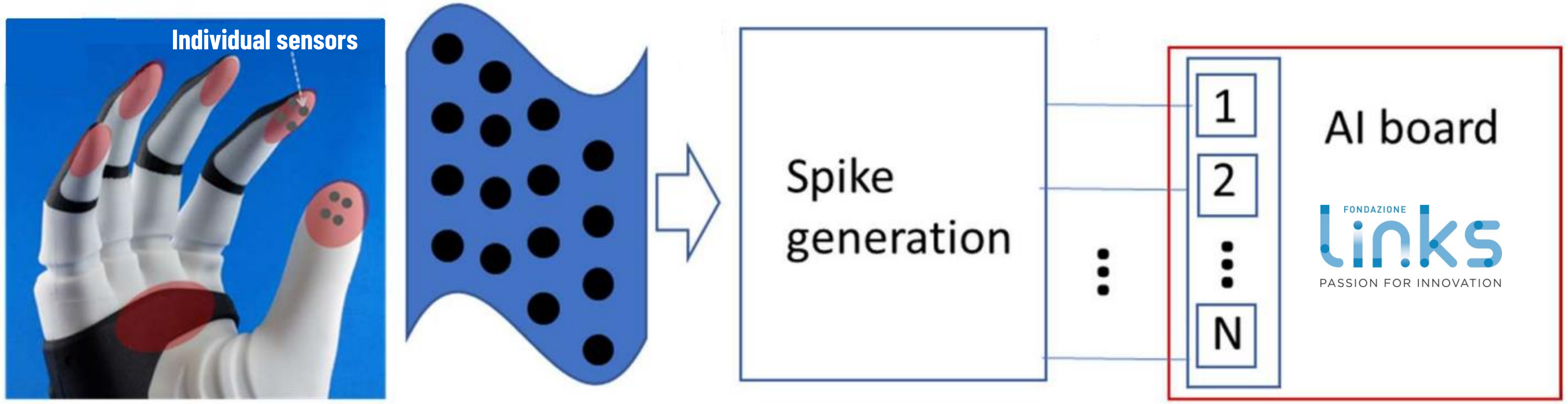
Overview of the project



Artificial skin

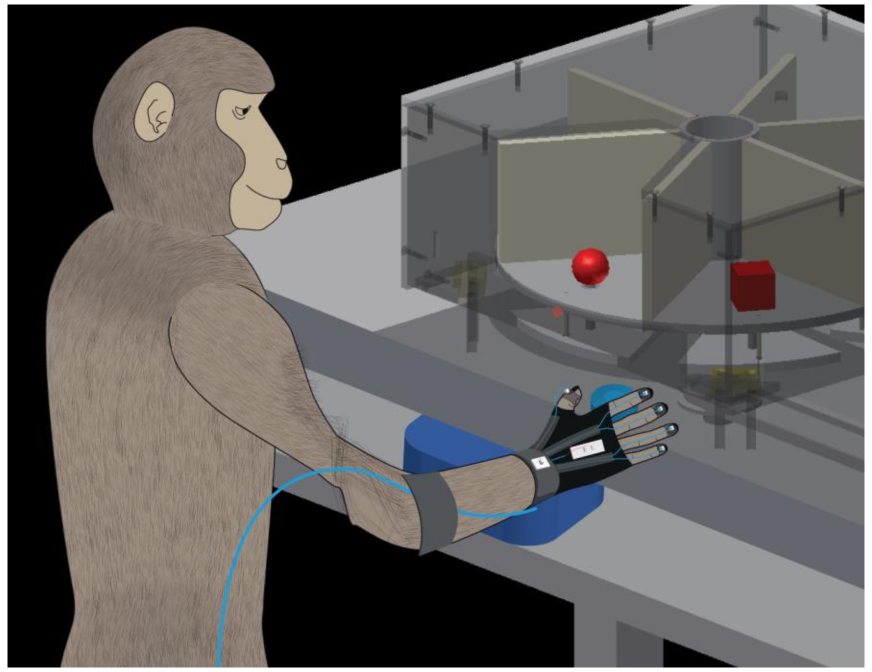


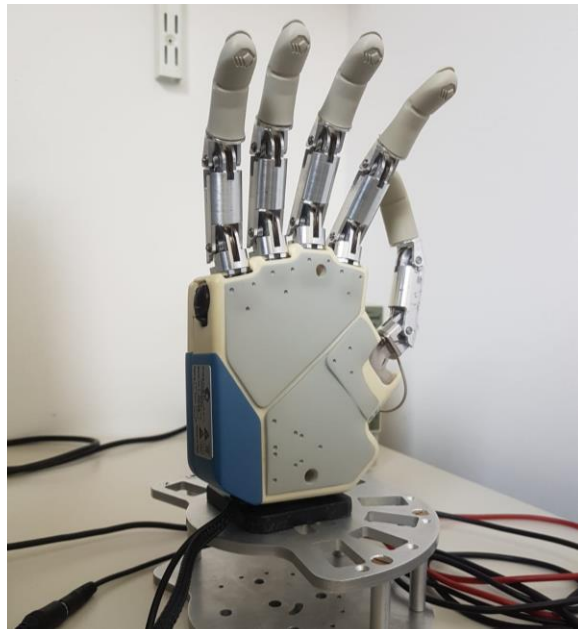
- The multi-institution team of researchers and engineers at Scuola Superiore Sant'Anna and Uppsala University are collaborating to integrate a human-like prosthetic limb with a high-resolution electronic skin (or "eSkin").
- Machine learning/AI techniques for real-time decoding of neural signals into movement actuation signals and touch feedback into meaningful brain stimulation commands are developed at Fondazione LINKS.

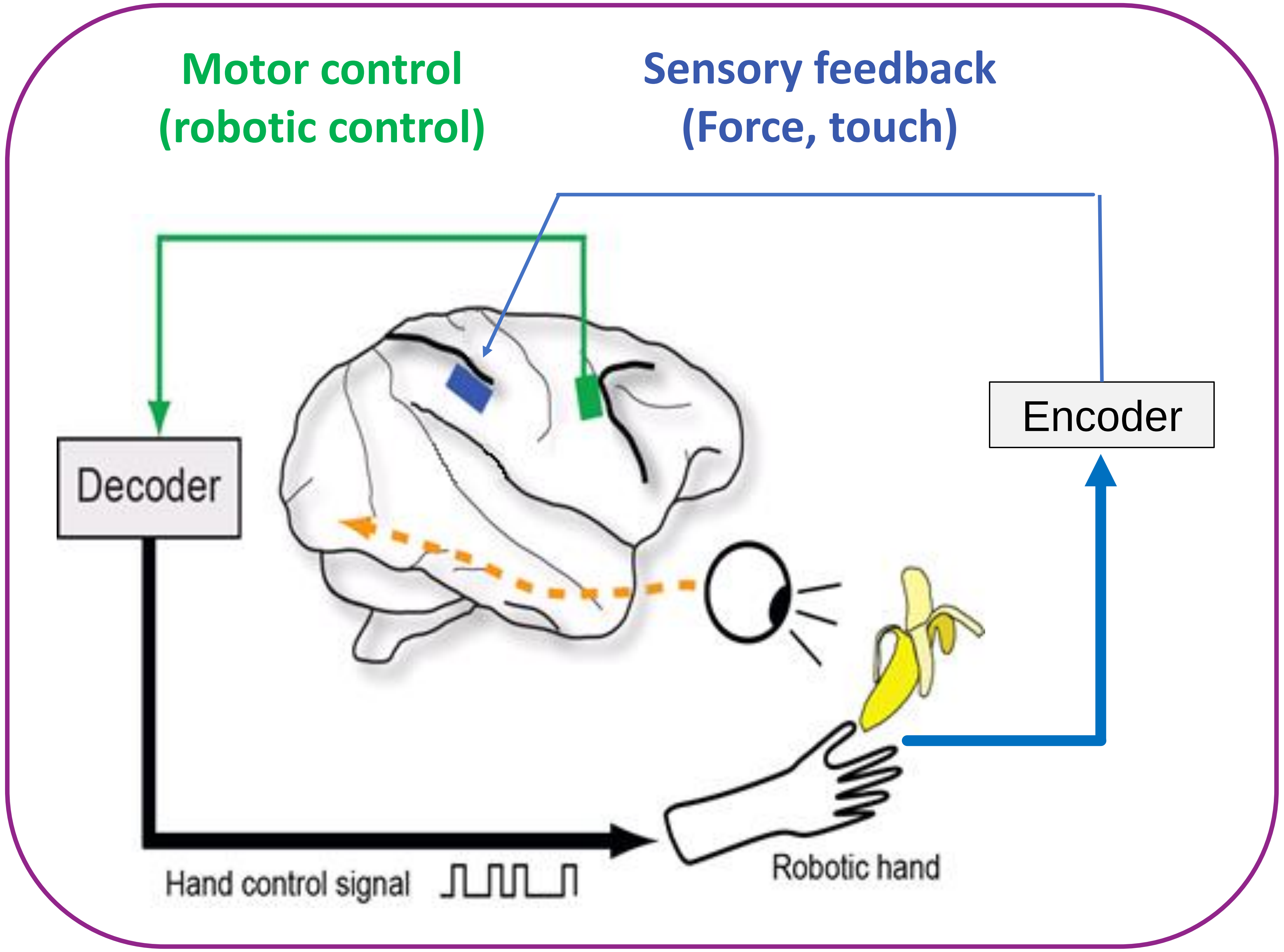


Non-Human Primate (NHP) testing

- Testing of Fat-IBC communication technology in non-human primates (NHP)
- Demonstration of closed-loop (full-duplex) motor decoding and tactile stimulation using Fat-IBC in NHP







Thank you for your attention.

Questions?

To learn more about the B-CRATOS project, please visit:

https://b-cratos.eu

Follow our progress!

Twitter: b_cratos
Linkedin: b-cratos
ResearchGate: B-CRATOS

Politecnico di Torino
1859

BIENNALE TECNOLOGIA
TORINO, 10-13 NOV 2022
Tecnologia è Umanità