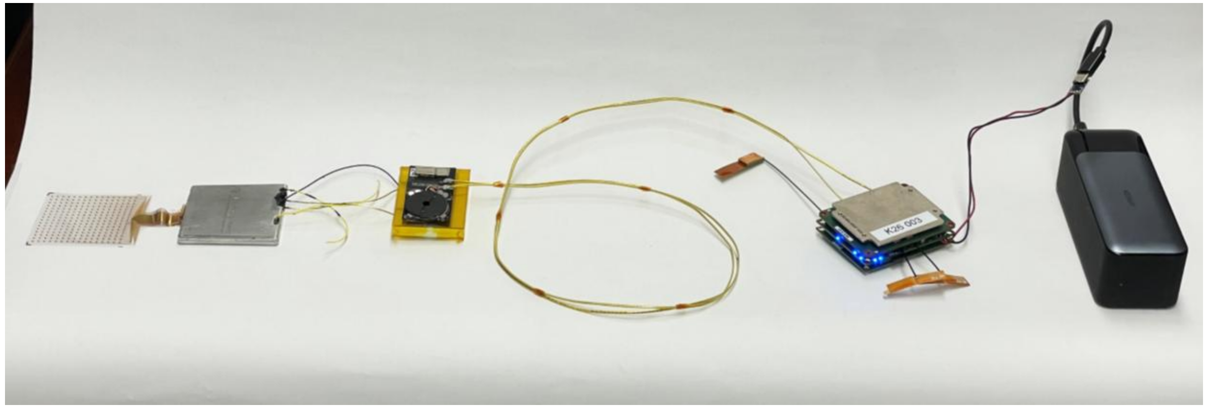
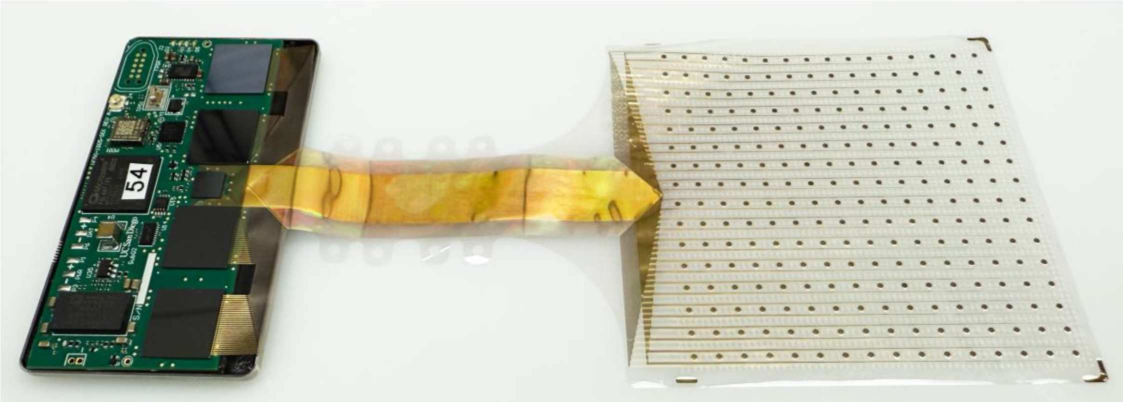
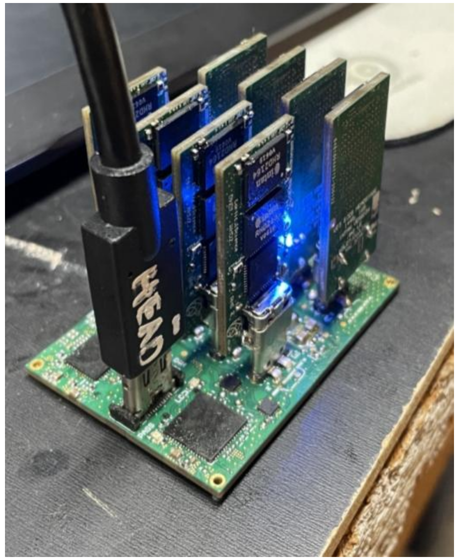
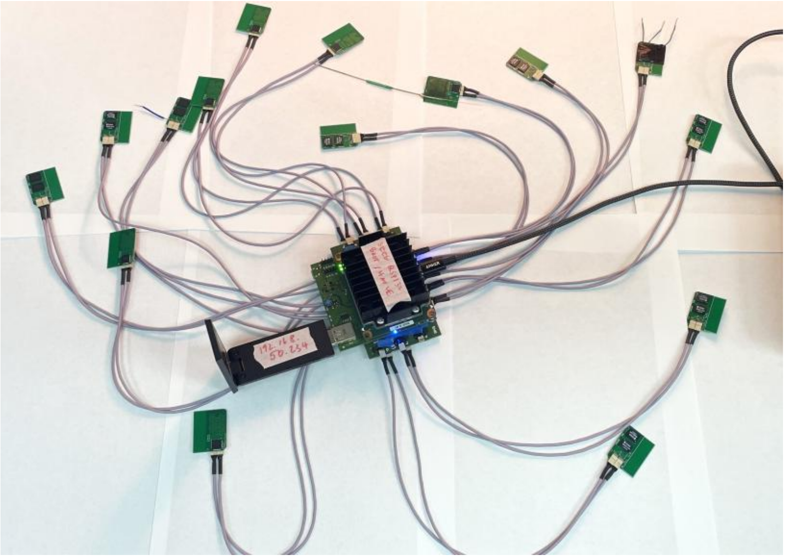
Wireless Neuromonitoring System Project

Hao Le









Hao Le

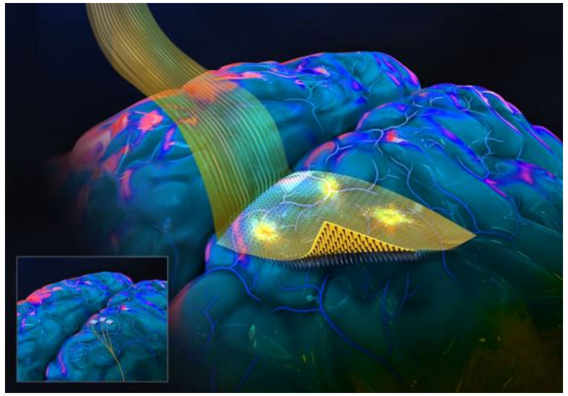
- 2018 – 2022: B.S. in Electrical Engineering, UC San Diego
  - Concentration: machine learning and controls
  - E & M fundamentals; analog & digital circuits; estimation statistics; digital signal processing
  - Research in synthetic data generation for autonomous driving applications
- 2023 – 2025: M.S. in Electrical Engineering, UC San Diego
  - Concentration: systems and circuits
  - Biomedical circuits; RF circuits; VLSI; data networks; 5G transceivers
  - **Hardware and firmware engineer for NIH-funded wireless neuromonitoring project**
- Current occupation: Quartus Engineering
  - Cable harness and PCB design for defense and aerospace opto-mechanical systems
- Pastimes:
  - Oil painting
  - Guitar
  - Fish, spider, and ant keeping

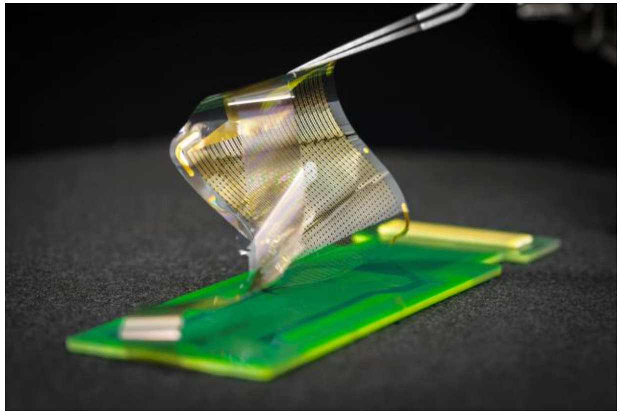
Neuromonitoring Project Goal

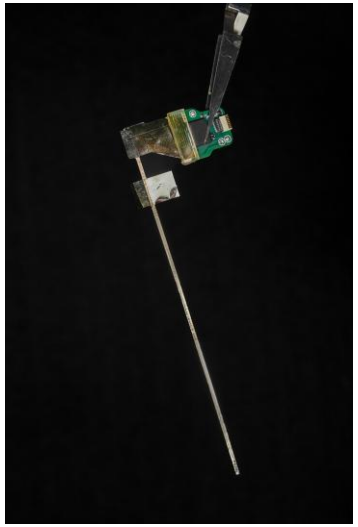
- About a third of people with epilepsy have seizures not controllable by medications – often resection or neuromodulation is required
- Intracranially monitor patients using high-resolution electrodes to acquire a better "picture" of the affected regions
  - Record data of unpredictable episodes
  - Clinicians more informed during surgery
- Make it easy to take home and live life as usual

Neural Interface

- Dr. Shadi Dayeh's Integrated Electronics and Biointerfaces Laboratory
  - Ultra high-density, thin-film surface and depth electrodes
  - Patented "platinum nanorod" interface for low impedance





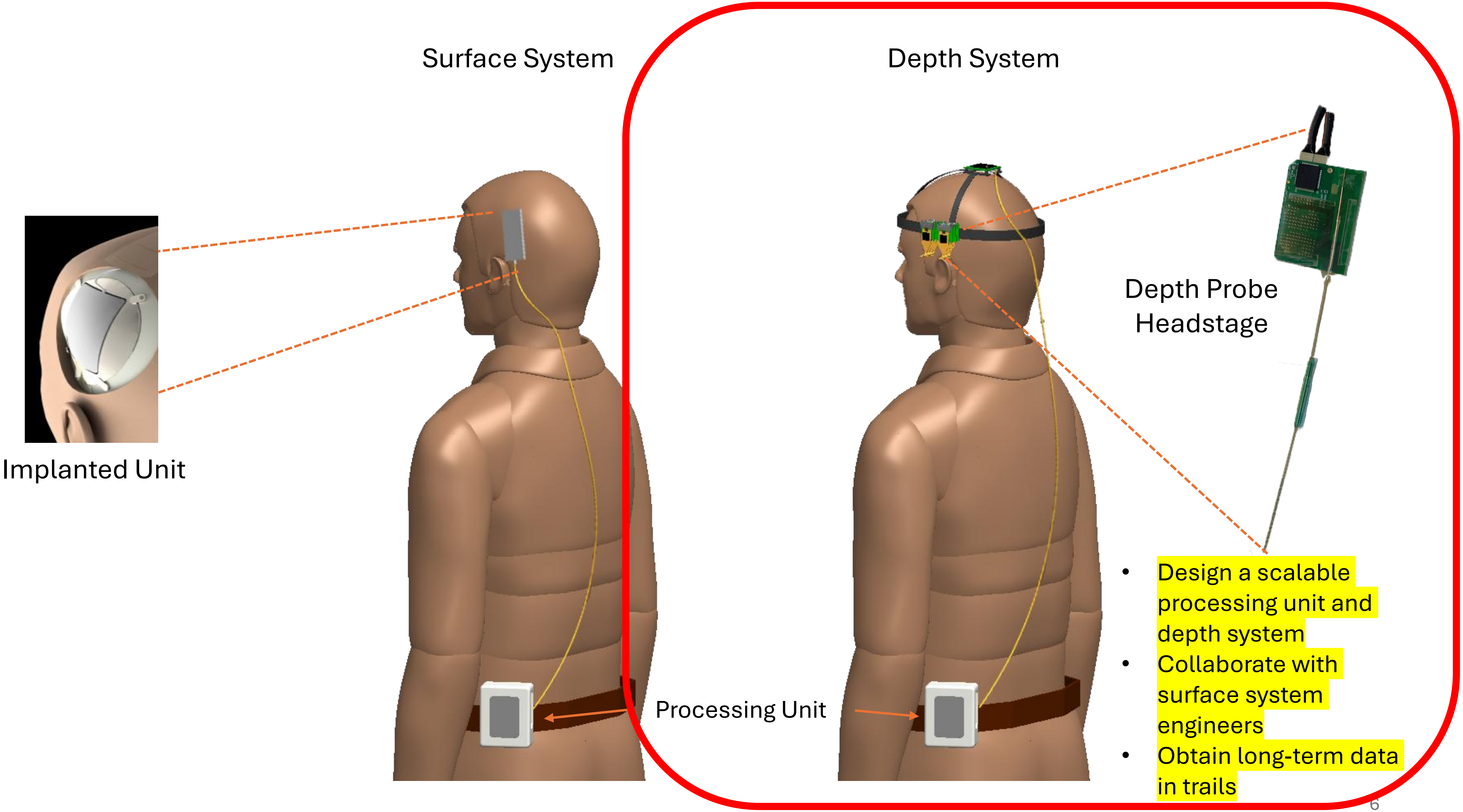


Surface grid
- 4096 recording
- 256 stimulation

Depth probe
- 128 recording
- 16 stimulation

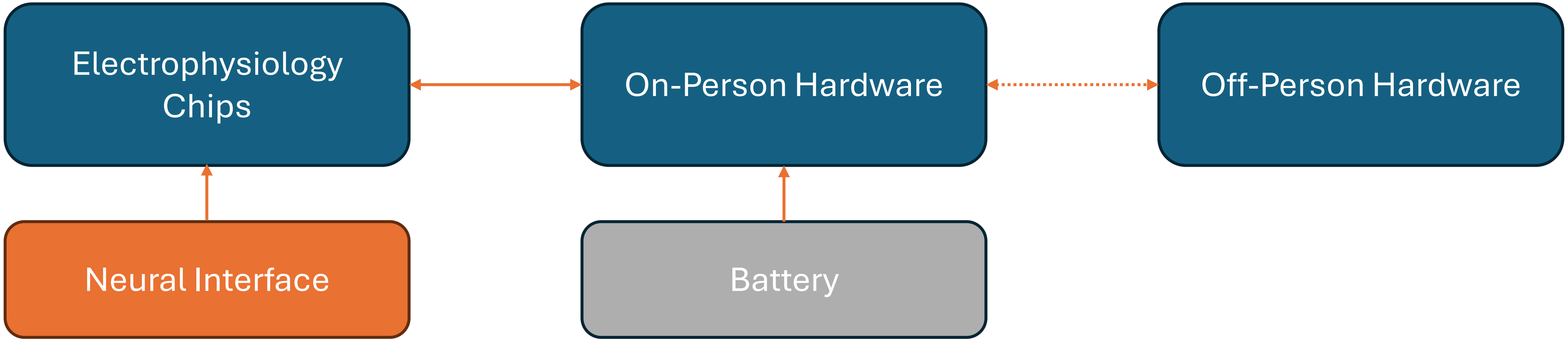
Design Constraints

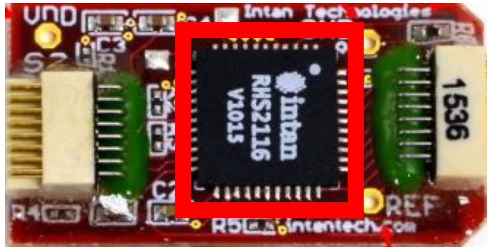
- 1 surface grid; 8 depth probes
  - Total of 6144 channels, 16-bit depth, 2500 samples/sec
  - At least 210 Mbits/sec of throughput
- Surface grid requires subcutaneous implant
  - Transcutaneous power and data delivery
- Neural signal acquisition and stimulation
  - Multiple off-the-shelf chips
  - Many digital buses running in parallel
- Portable and long-lasting battery
  - Data transmission off person entirely wireless
  - Simple disconnect and recharge
- Easy, intuitive interface to use



- Design a scalable processing unit and depth system
- Collaborate with surface system engineers
- Obtain long-term data in trails

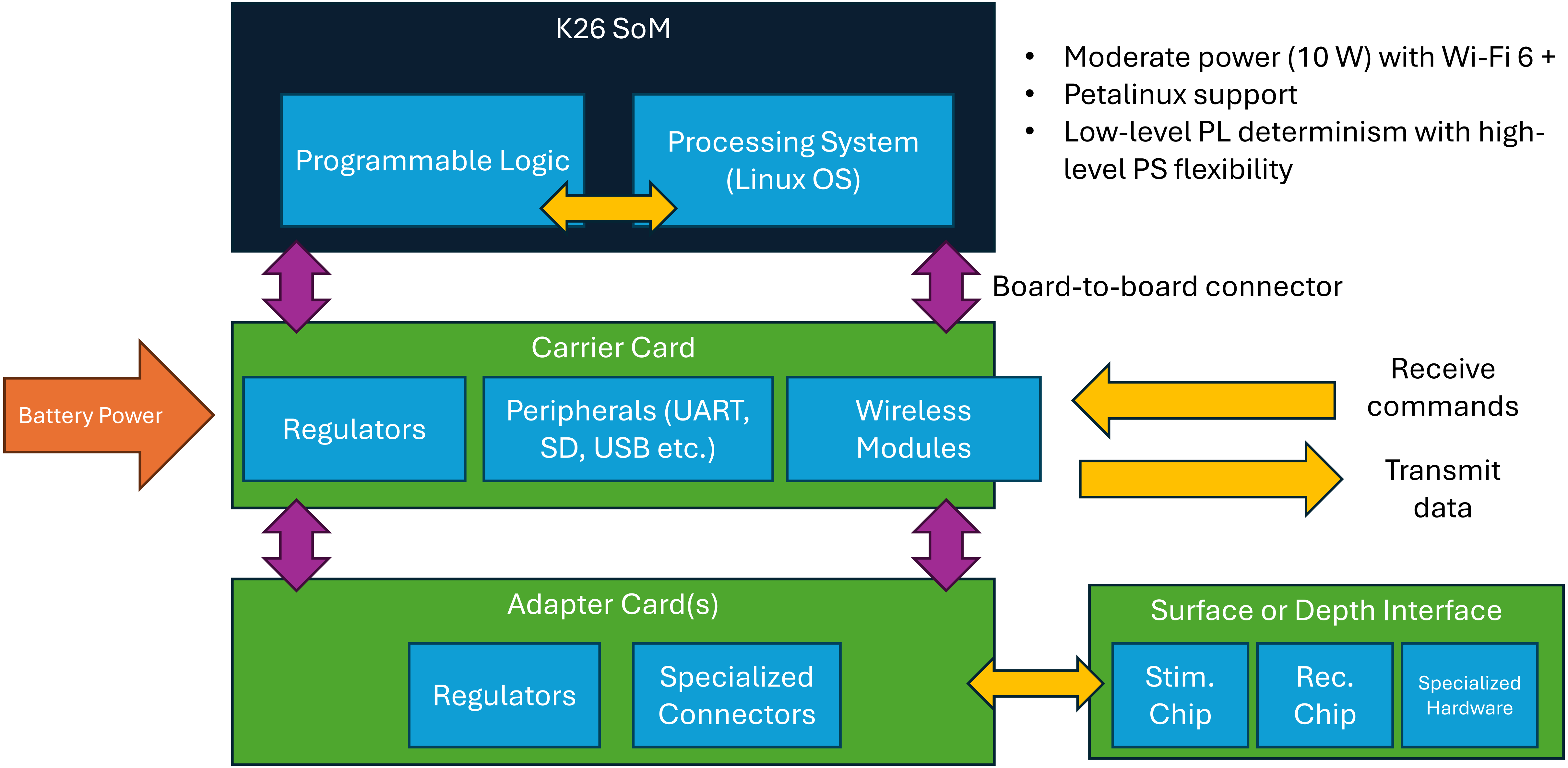
High-Level Architecture





FPGA + Processors

open ephys



- Moderate power (10 W) with Wi-Fi 6 +
- Petalinux support
- Low-level PL determinism with high-level PS flexibility

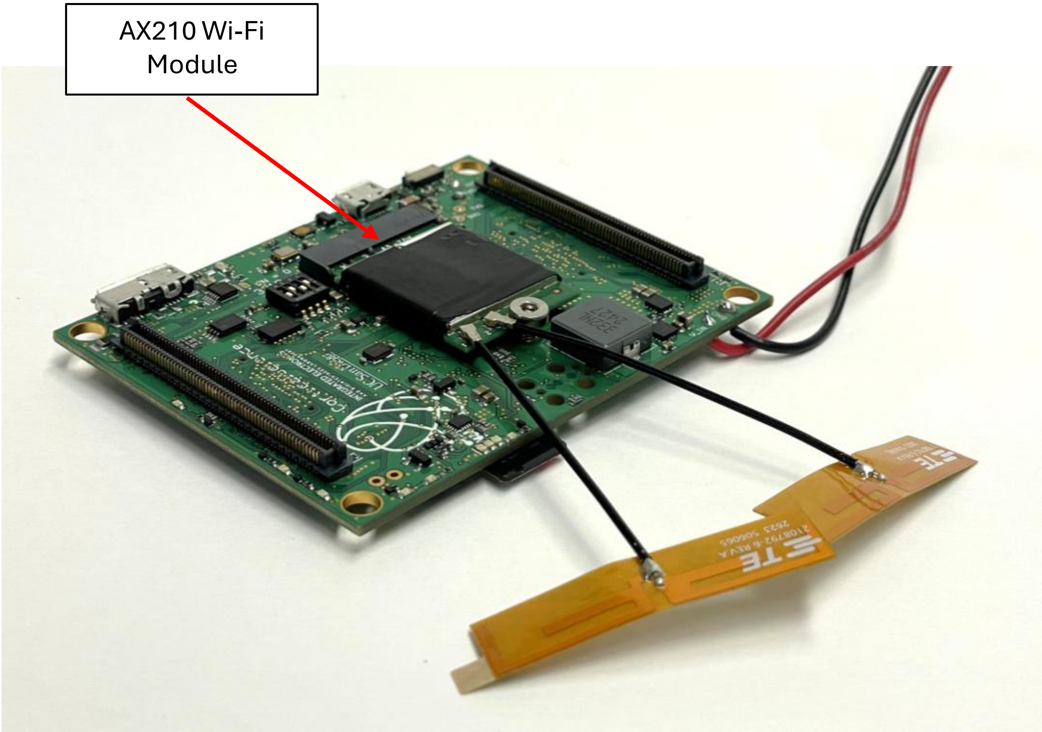
Carrier Card

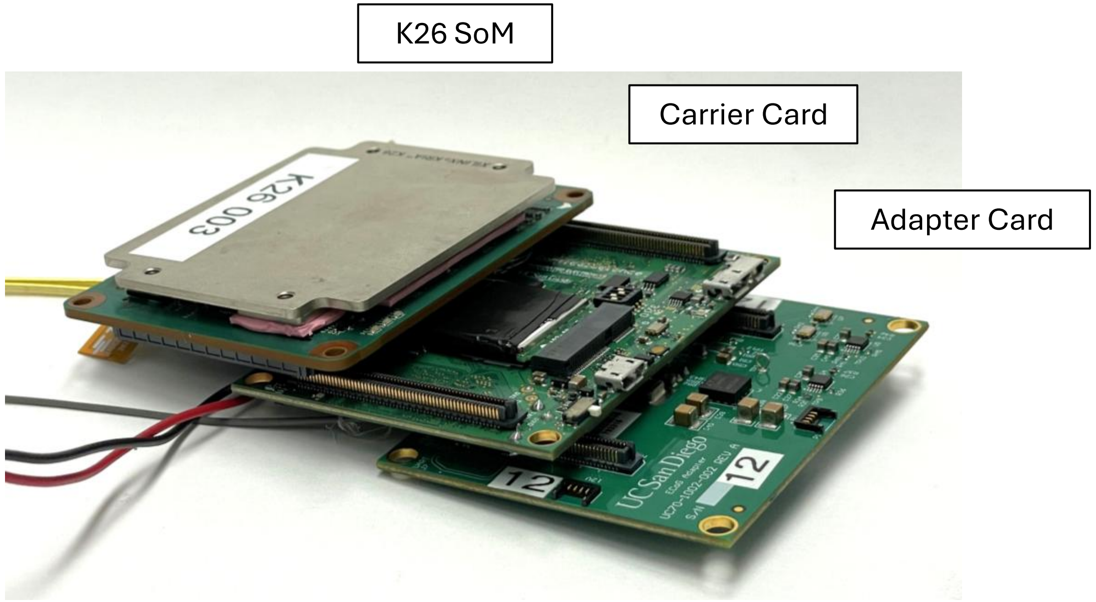
- Interfaces with K26 SoM's HD connectors
- Provides to SoM
  - Power regulation and sequencing
    - USB-C PD 2.0 negotiation for beyond 15 W
  - Memory (SD card and EEPROM)
  - Data peripherals (USB 3.0, Wi-Fi 6E)
    - PCIe over M.2
  - Auxiliary functions (UART, JTAG, current monitoring, accelerometer…)
- Extracts from SoM
  - FPGA I/O down to adapter cards over board-to-board connectors
  - Surface and depth signals coexist
- 8-layer controlled impedance

Top

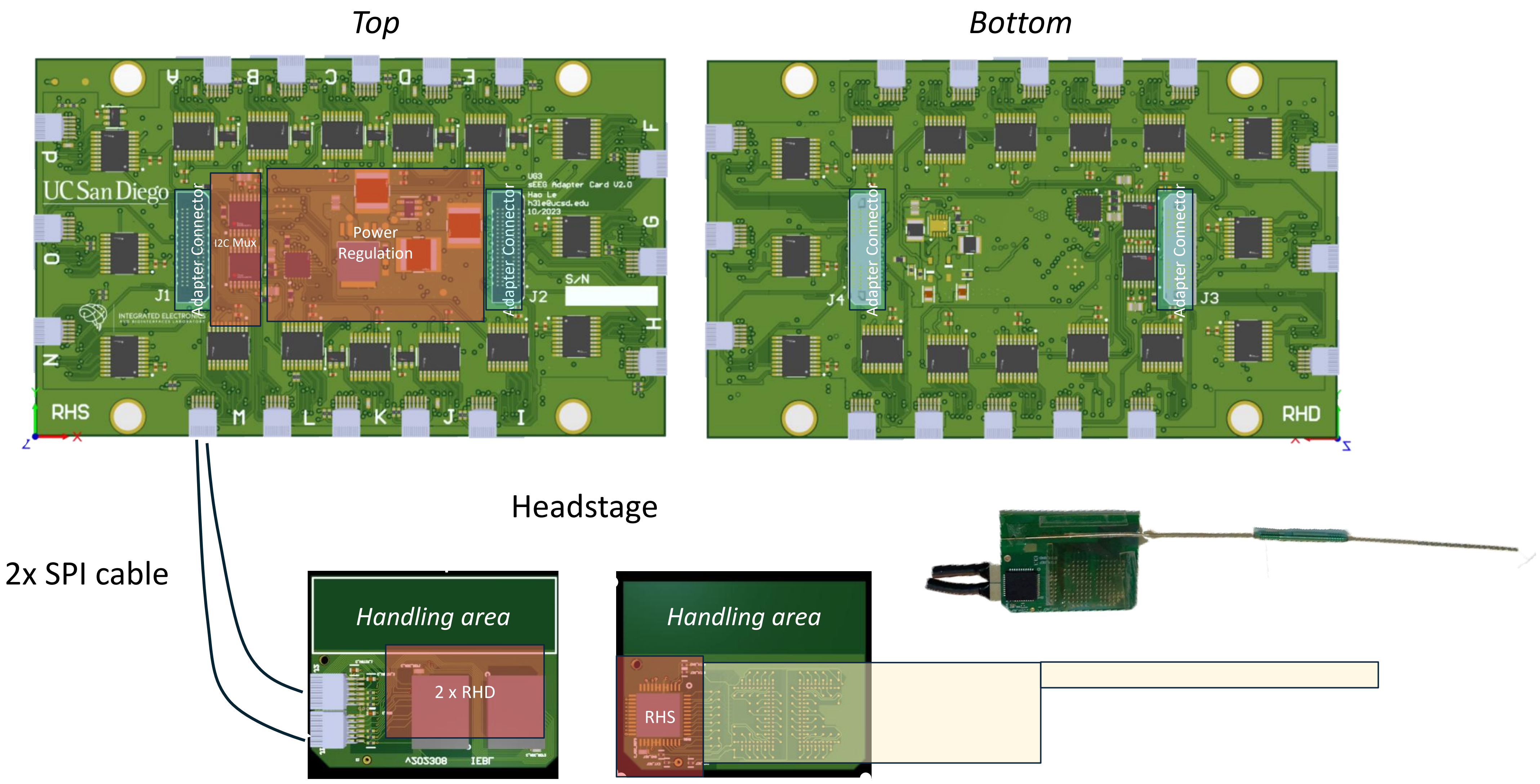
Power

Signal

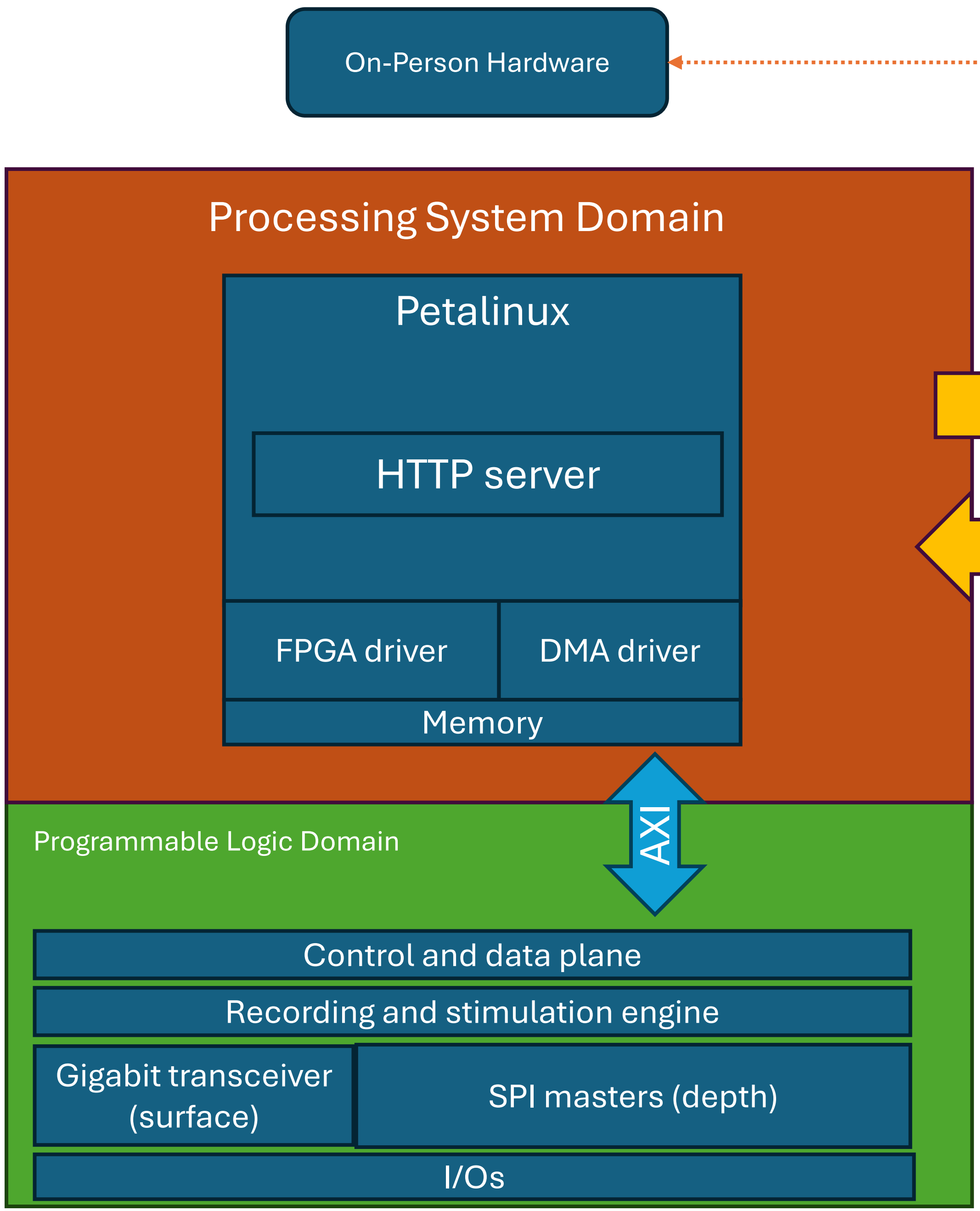


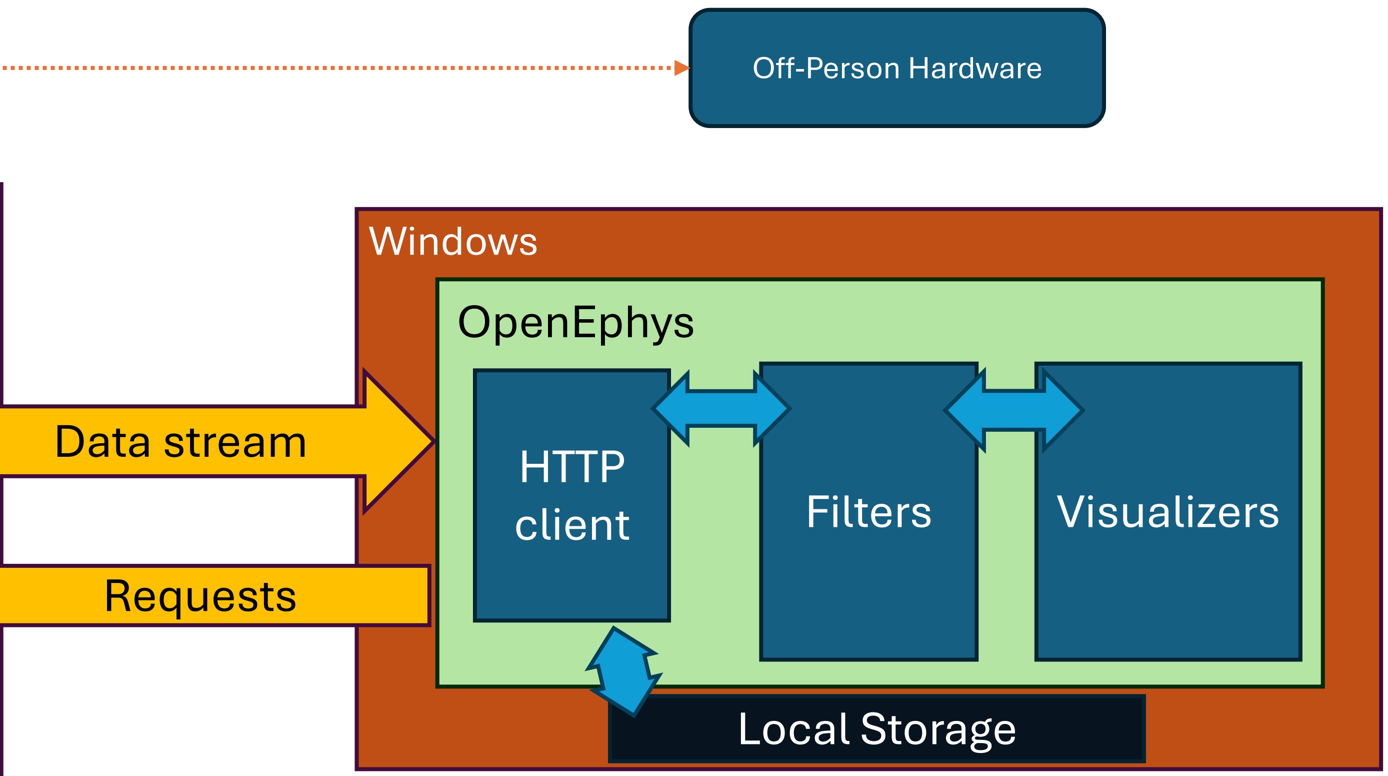


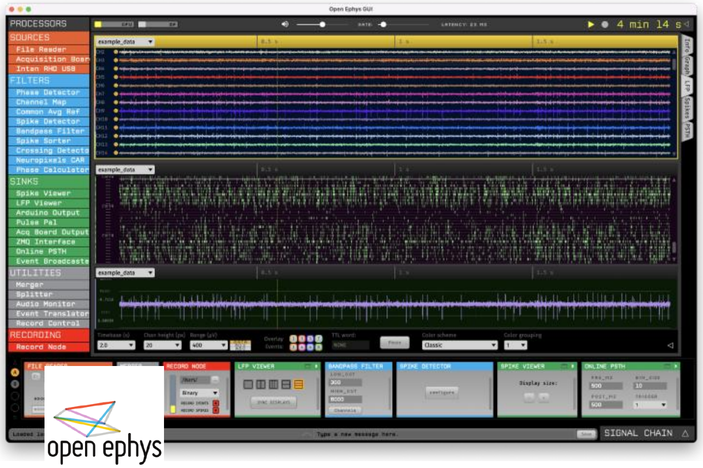
Depth Adapter Card



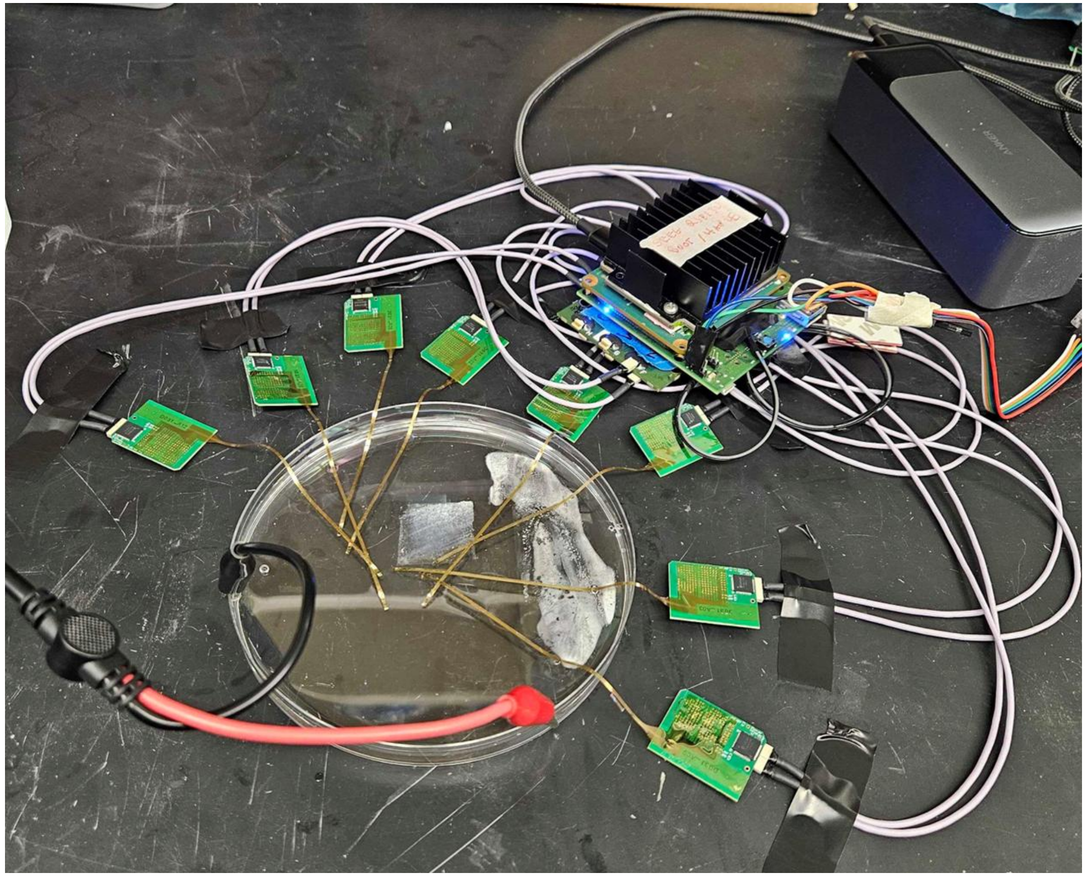
128 recording, 16 stimulation

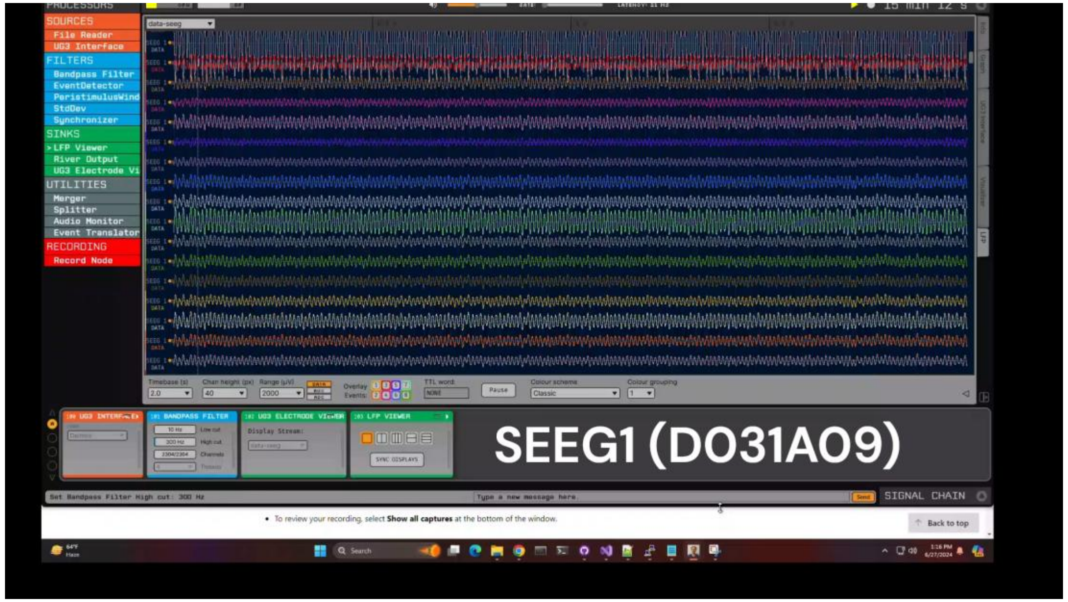






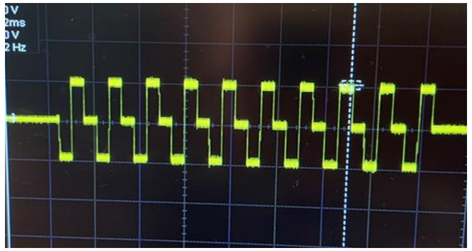
- Open-source GUI platform with community support
- Write backend client code to receive data
- Send data down processing chain to visualize and record
- Custom plugins to further process data



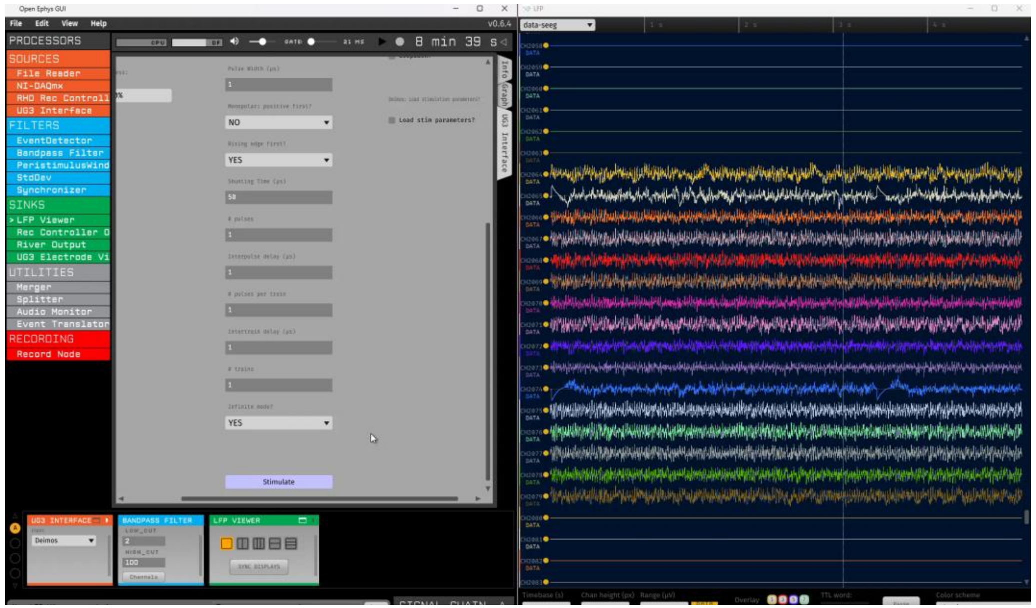


Waveform generator recording validation

- Benchtop validation of 8-depth-probe system
- Recording @ 2.5 kS / s
- 70 us min. stimulation
- OpenEphys as GUI
- Too bulky to wear on head

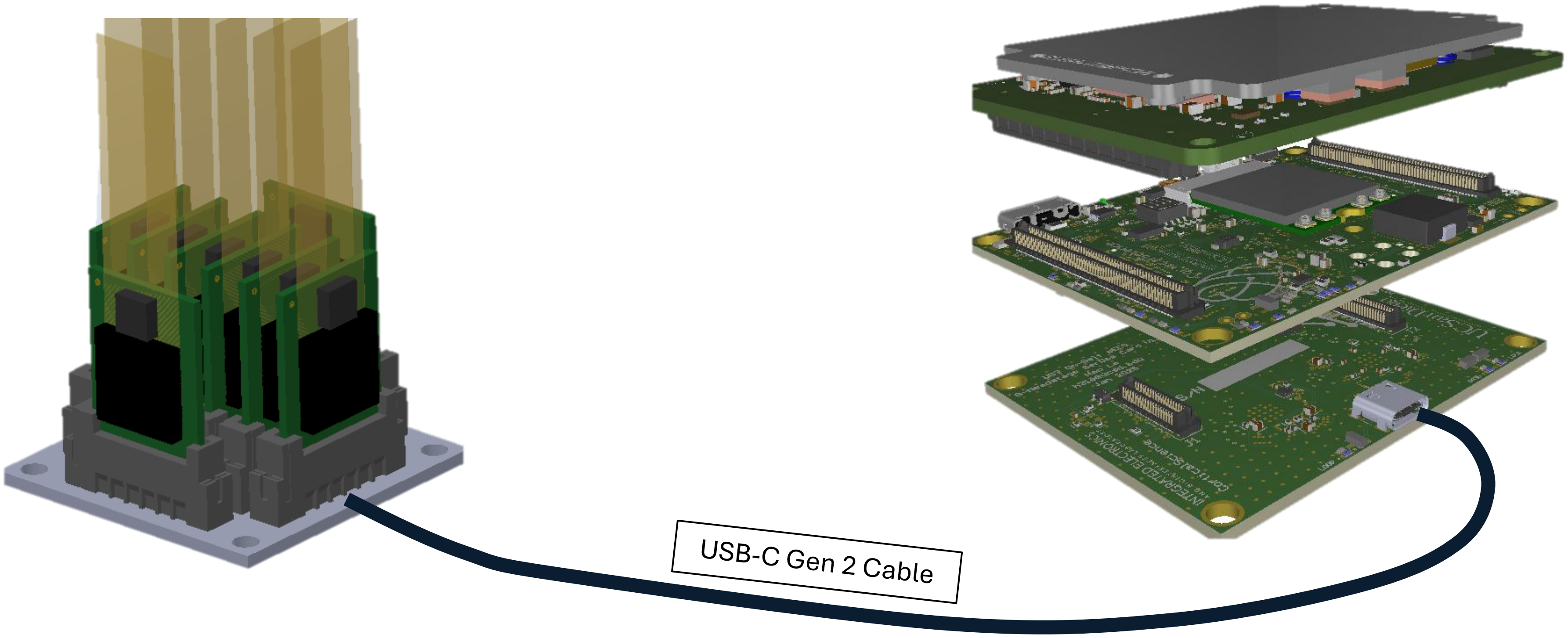


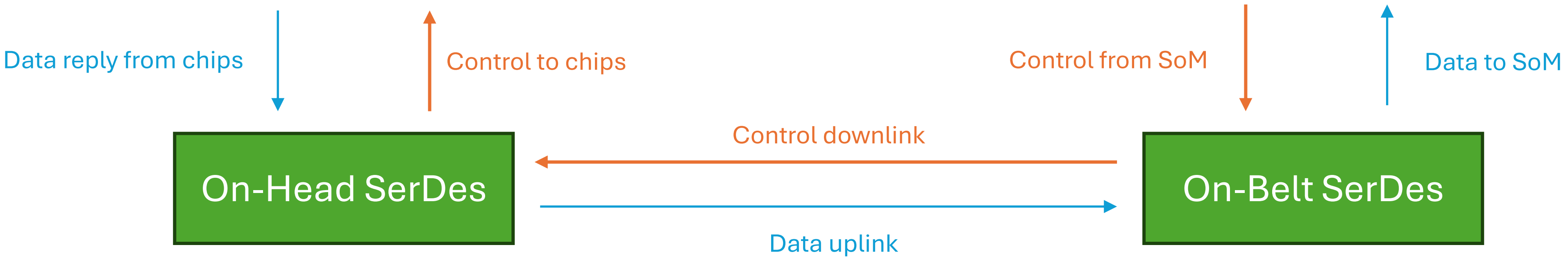
Stimulation train



Stimulation GUI example

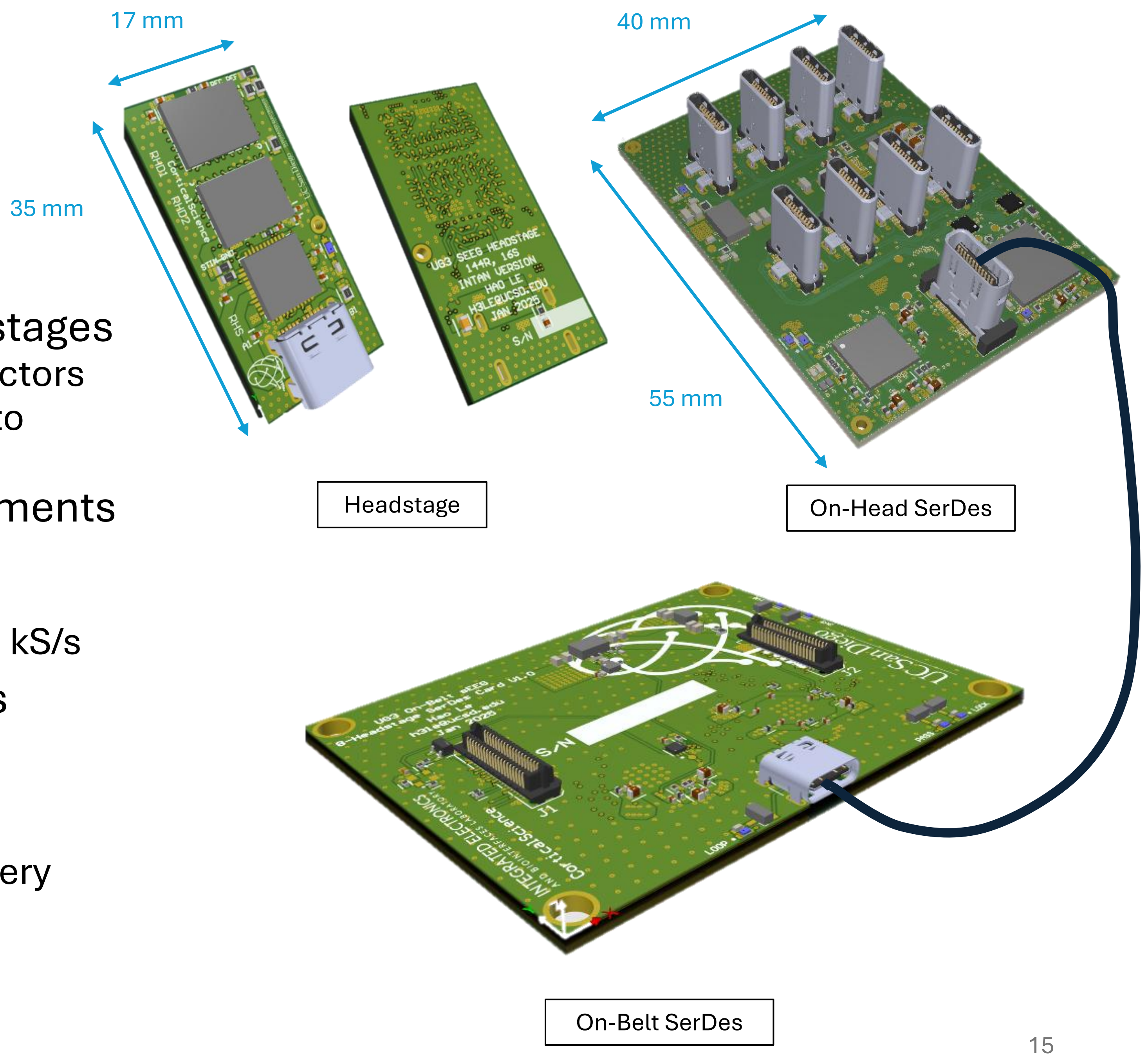
SerDes Design

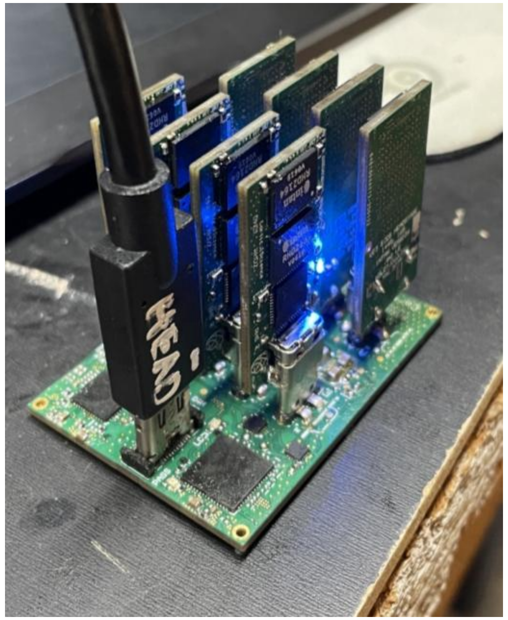


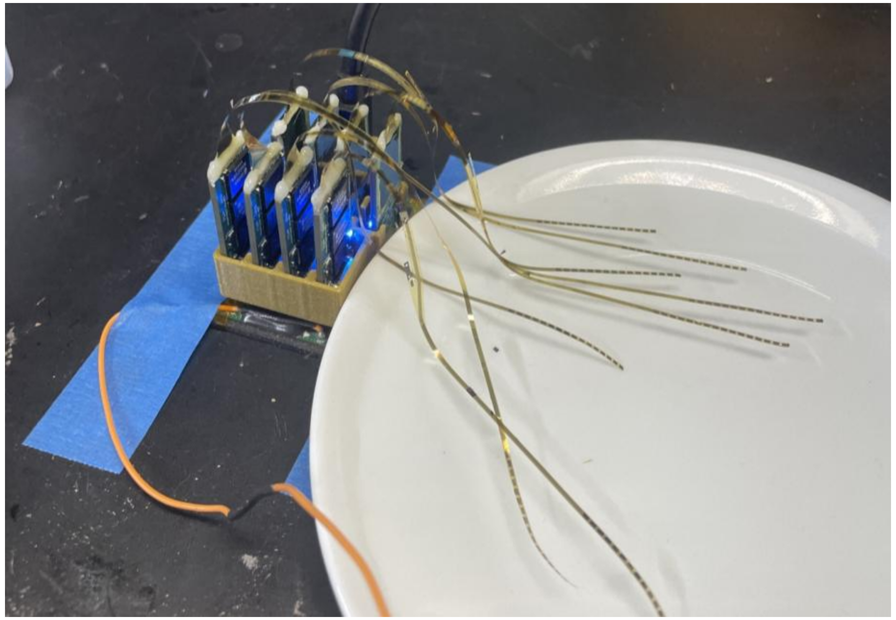


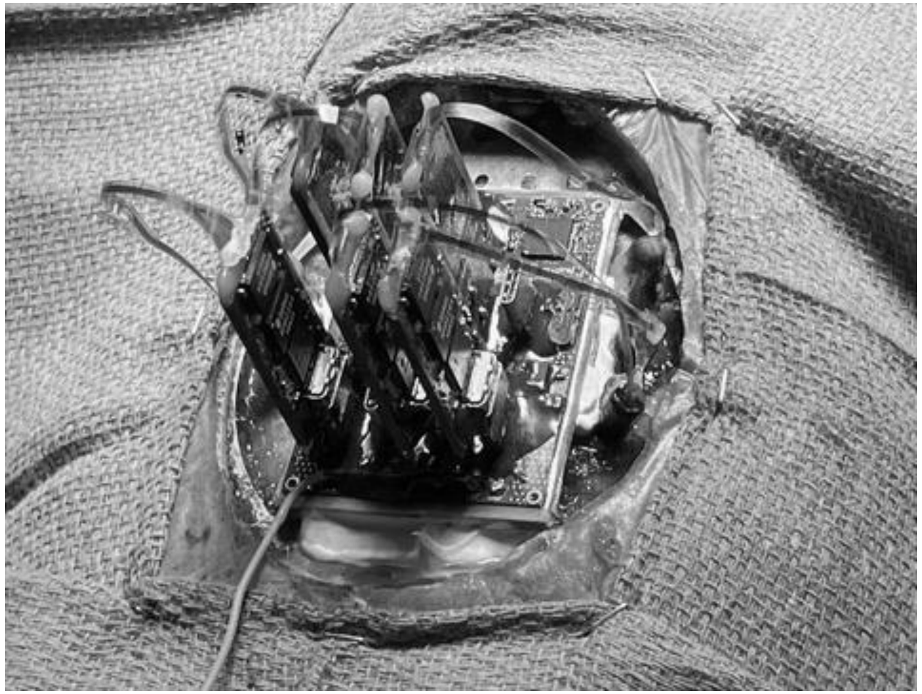
SerDes Design

- Chose USB-C connectors for Headstages
  - Smaller form factor than edge connectors
  - Durable over many use cycles; easy to replace
- SerDes chip pairs from Texas Instruments
  - 75 MHz max I/O clock
  - 2.1 Gbps link rate
  - Able to support all Headstages at 2.5 kS/s
- Single USB-C gen 2 cable chosen as physical link
  - 5 Gbps max link rate
  - (4) standard twisted pairs
  - High current capacity for power delivery

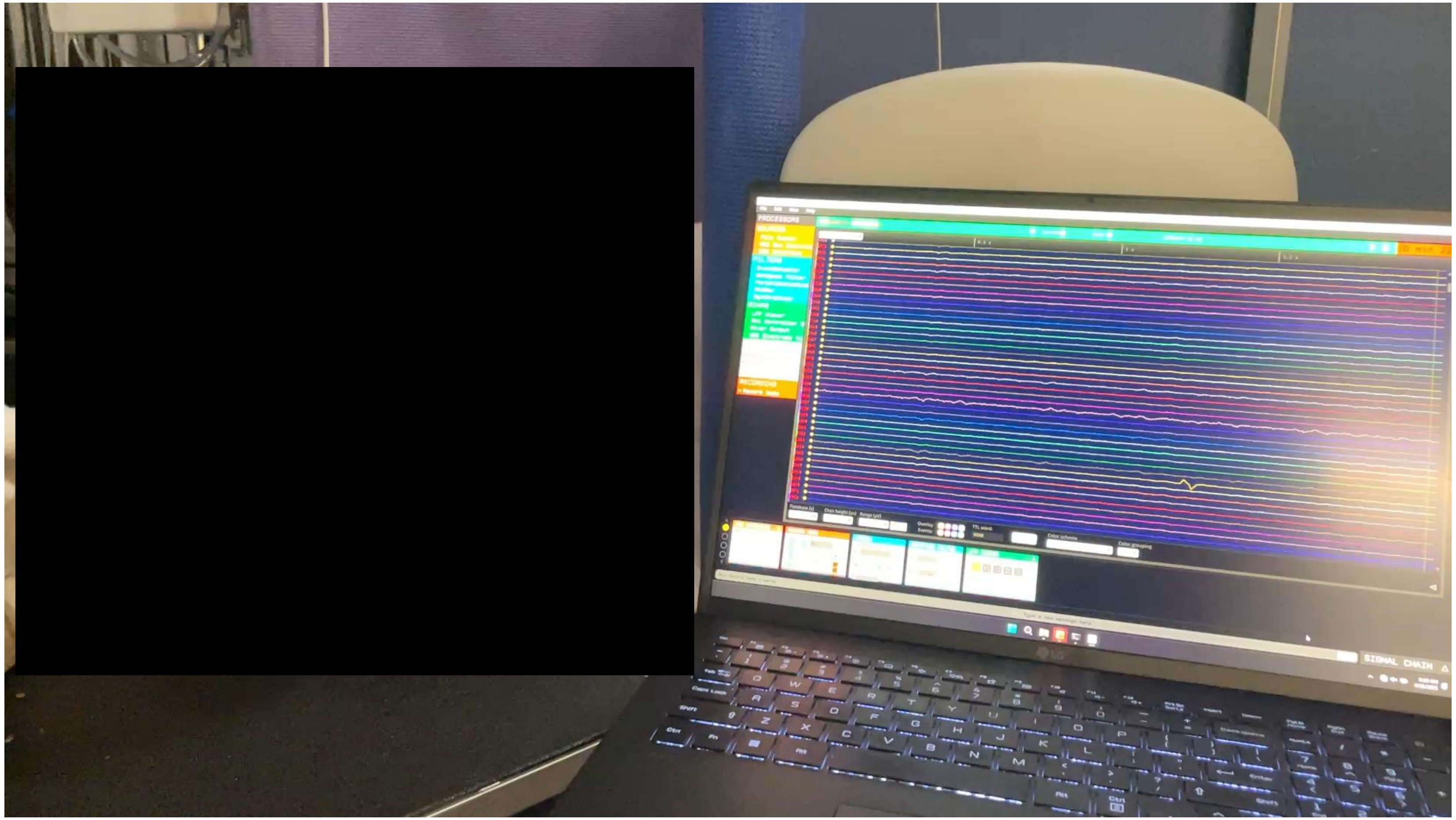


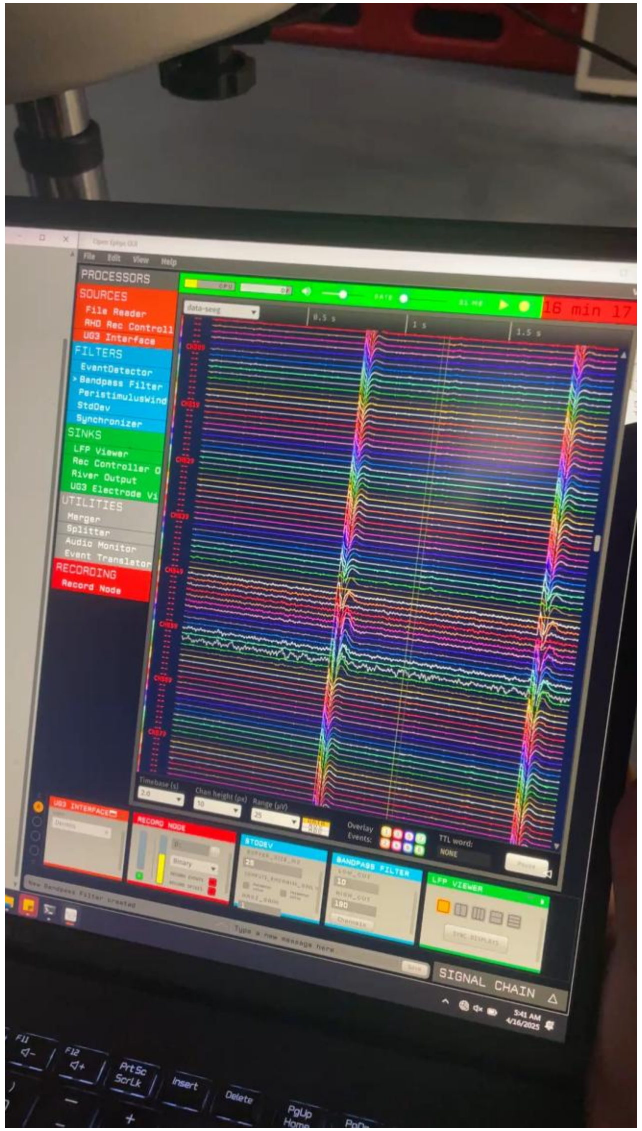

HEAD






Dolly
8246
UCSD Medical Center
120 kVp
20.0 mA
149 mAs
Medtronic

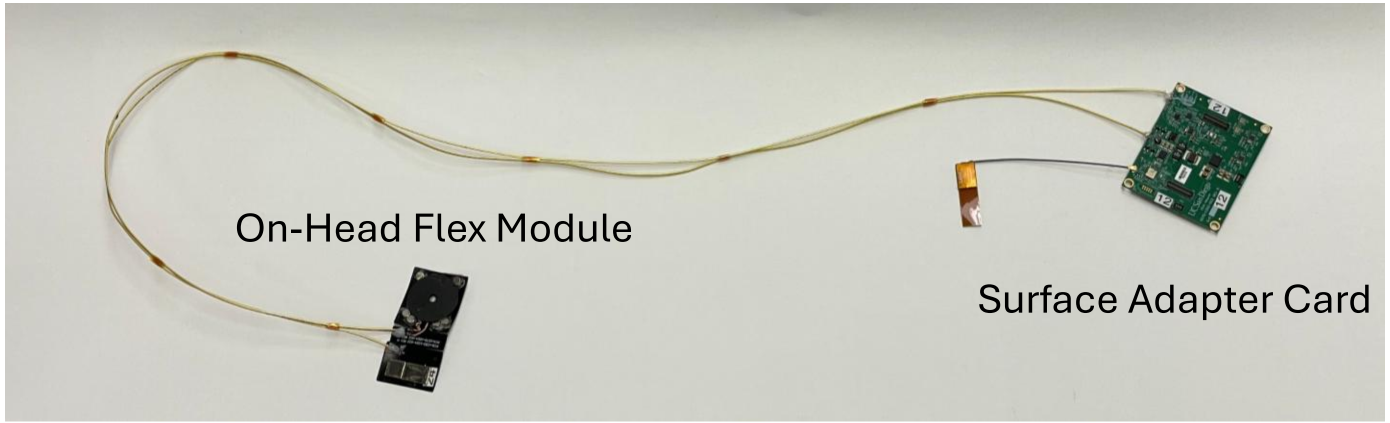


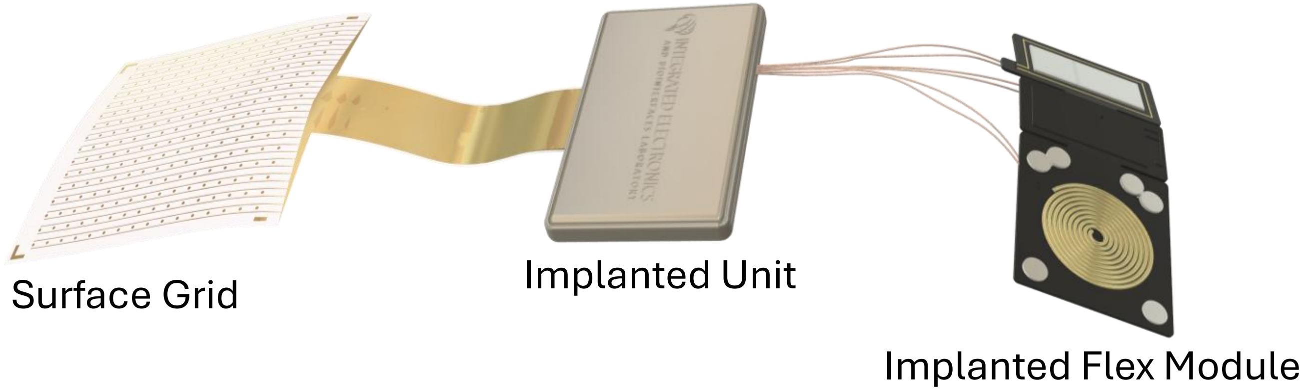


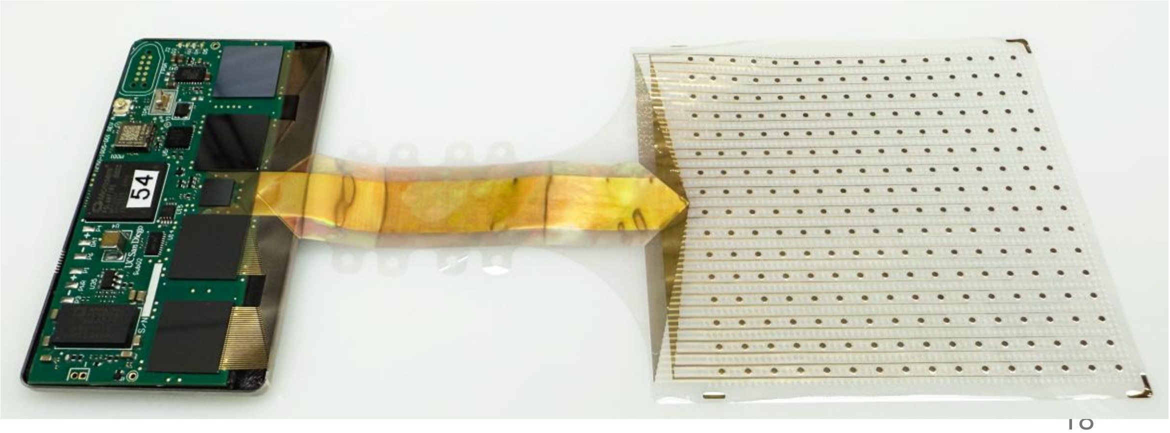
Real-time monitoring and stimulation
8 hours of continuous data on 20,000 mAh battery

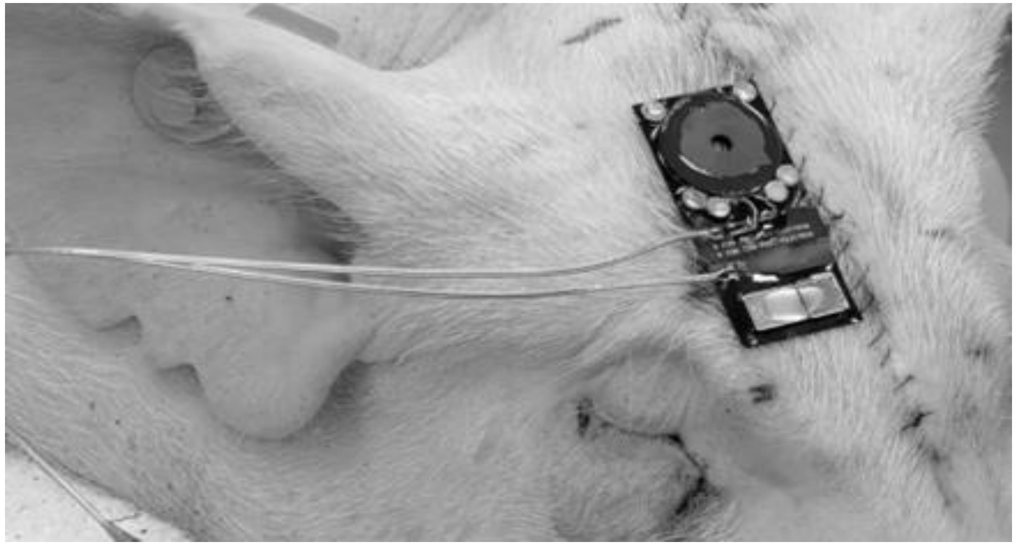
Surface System

- Fully implantable unit containing PolarFire FPGA
- Inductively-coupled transcutaneous links
  - Power downlink
  - Data uplink
- Received data decoded by SoM gigabit transceiver
- Surface adapter card contains
  - BLE module for low-speed control
  - LC tank circuitry for wireless power
  - Twin-axial link to on-head flex module

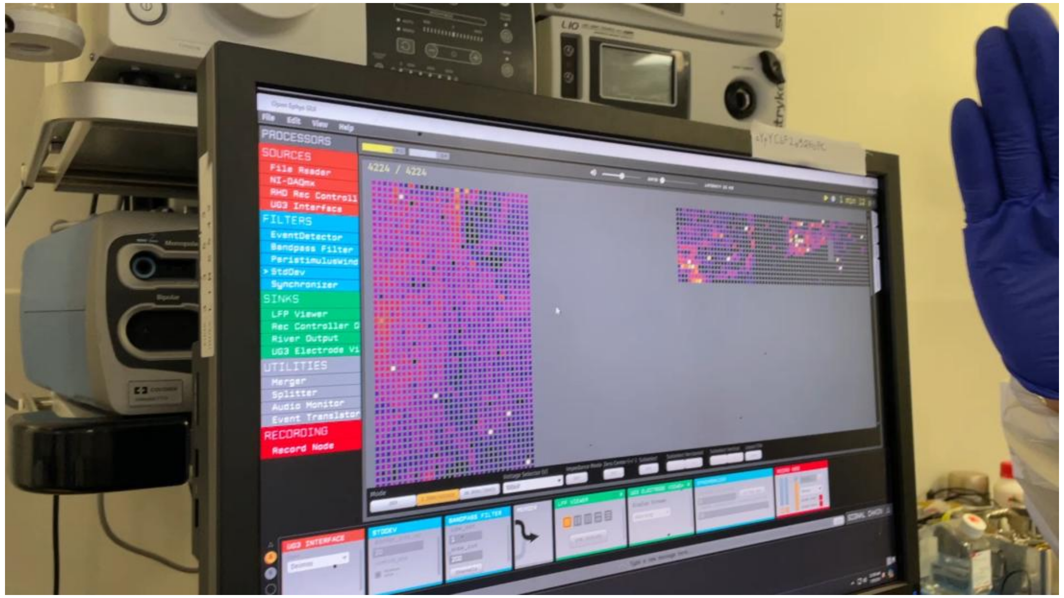




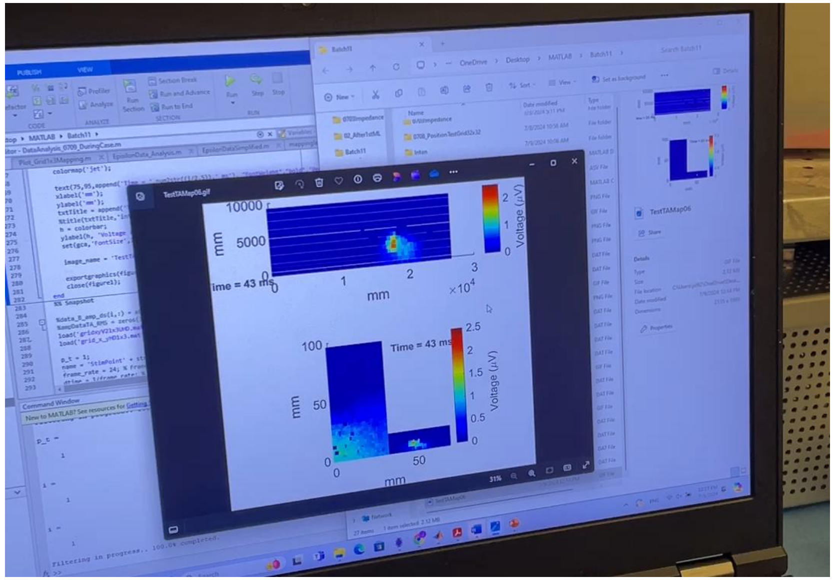




Implant site and external flex module alignment



Real-time electrode viewer during grid re-placement



Stimulation-evoked trial-average potential

Wireless Neuromonitoring System

- Realized a portable, high-channel-count, high-speed, wireless neural data acquisition system
- Central SoM: FPGA + Processing System
- PCBs to enable Wi-Fi connectivity and various peripherals
- Adapting PCBs to enable interface with surface and depth devices
- Crafted downlink control and uplink data pipeline
- Extended open-source GUI platform to control, receive, visualize, and record data stream
- Proved feasibility with several animal cases