IEEE brain

IEEE Brain Initiative

Society Members Research Activities (North America)

Presenter: Roman Genov, University of Toronto

(Contributors are credited throughout the slides)

CAS

Circuits and Systems Society
and
Solid-State Circuits Society

IEEE BRAIN Workshop
Dec 14th 2015 New York

SSCS

Integrated Circuits Interfacing with the Brain

- Neural recording and neural stimulation
  - Both invasive and non-invasive
  - Recording: electrical, chemical, and optical
  - Stimulation: optical stimulation/optogenetics, current/charge-mode
- Closed-loop neural interfaces
  - Responsive neurostimulators (epilepsy), neurotransmitters control
- Neuronal modeling
  - Silicon neurons, spiking neural networks
- Other related topics (not discussed)
  - Wireless communications (transcutaneous)
  - Wireless powering (inductive, ultrasound)
  - Signal/information processing
  - In vivo applications (animal studies, clinical, wellness)

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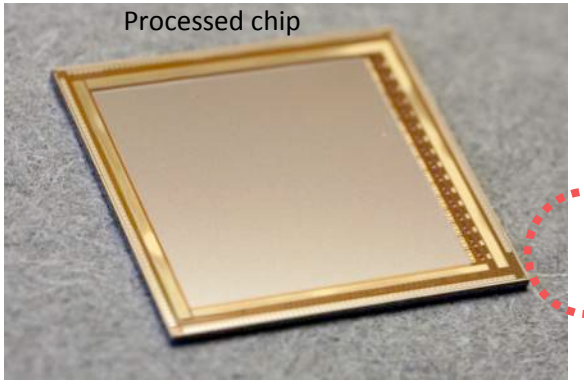
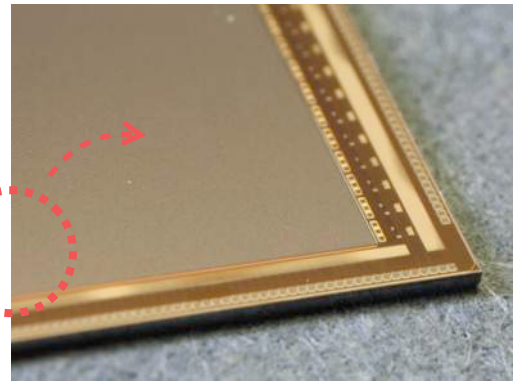
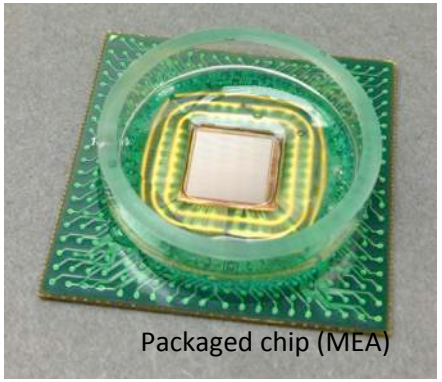
Ken Shepard Columbia University

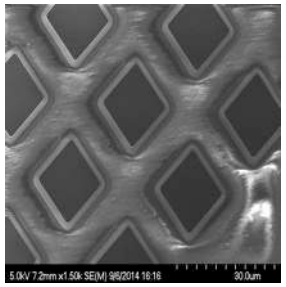
Ultra-high-density multielectrode array

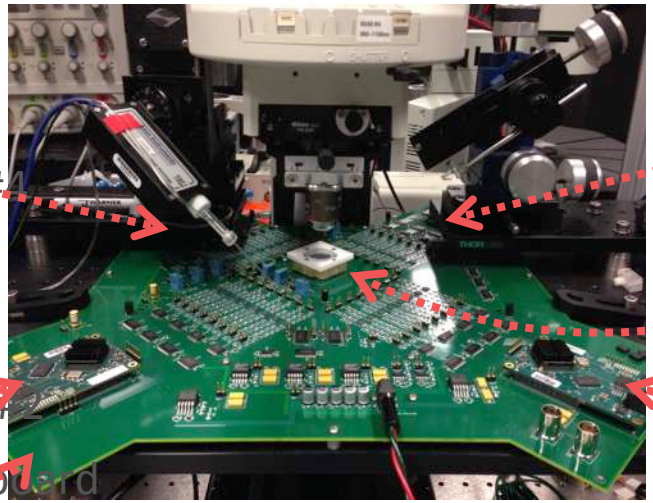
65k amplifiers, data rate almost 3 GB/s.

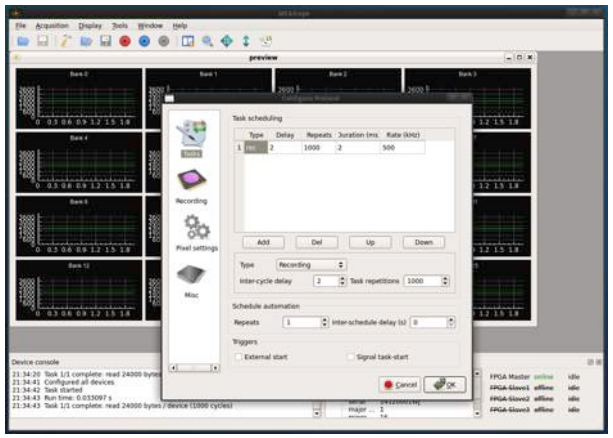








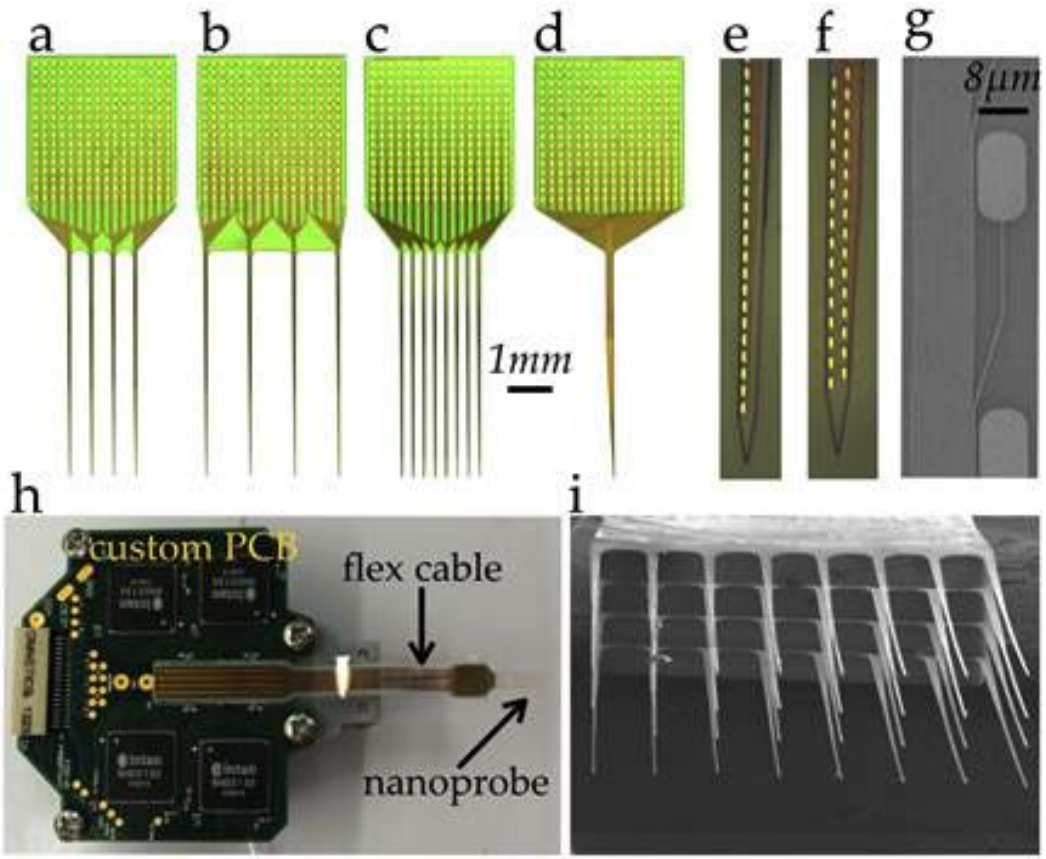




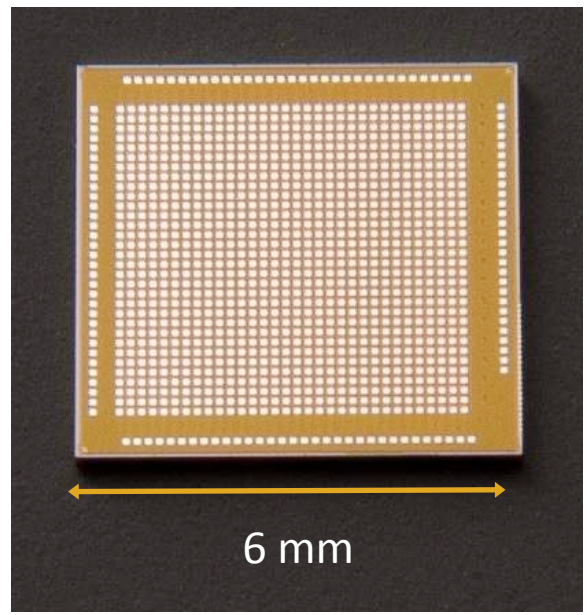
18,000 lines of Verilog; 38,000 lines of C++

Neural probe chip: electronics for in vivo shank electrodes

Caltech shanks



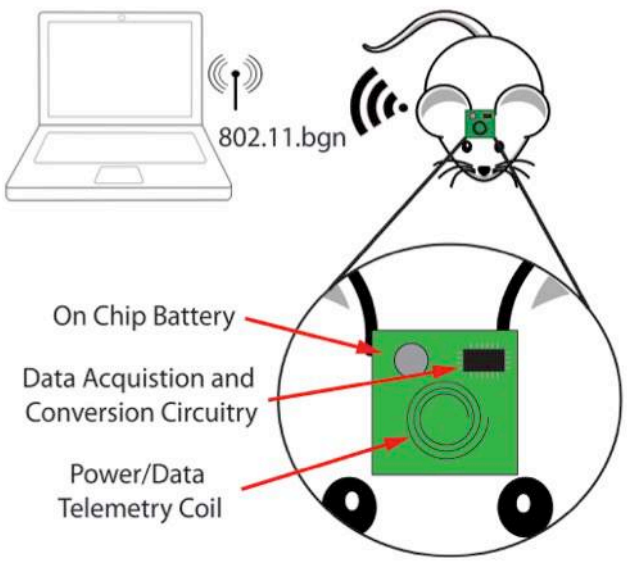
- 1024 channels
- 125-μm electrode pitch
- Multi-function: voltage recording, stimulate, current recording, current/voltage course
- Low-power
- 8 μV rms noise

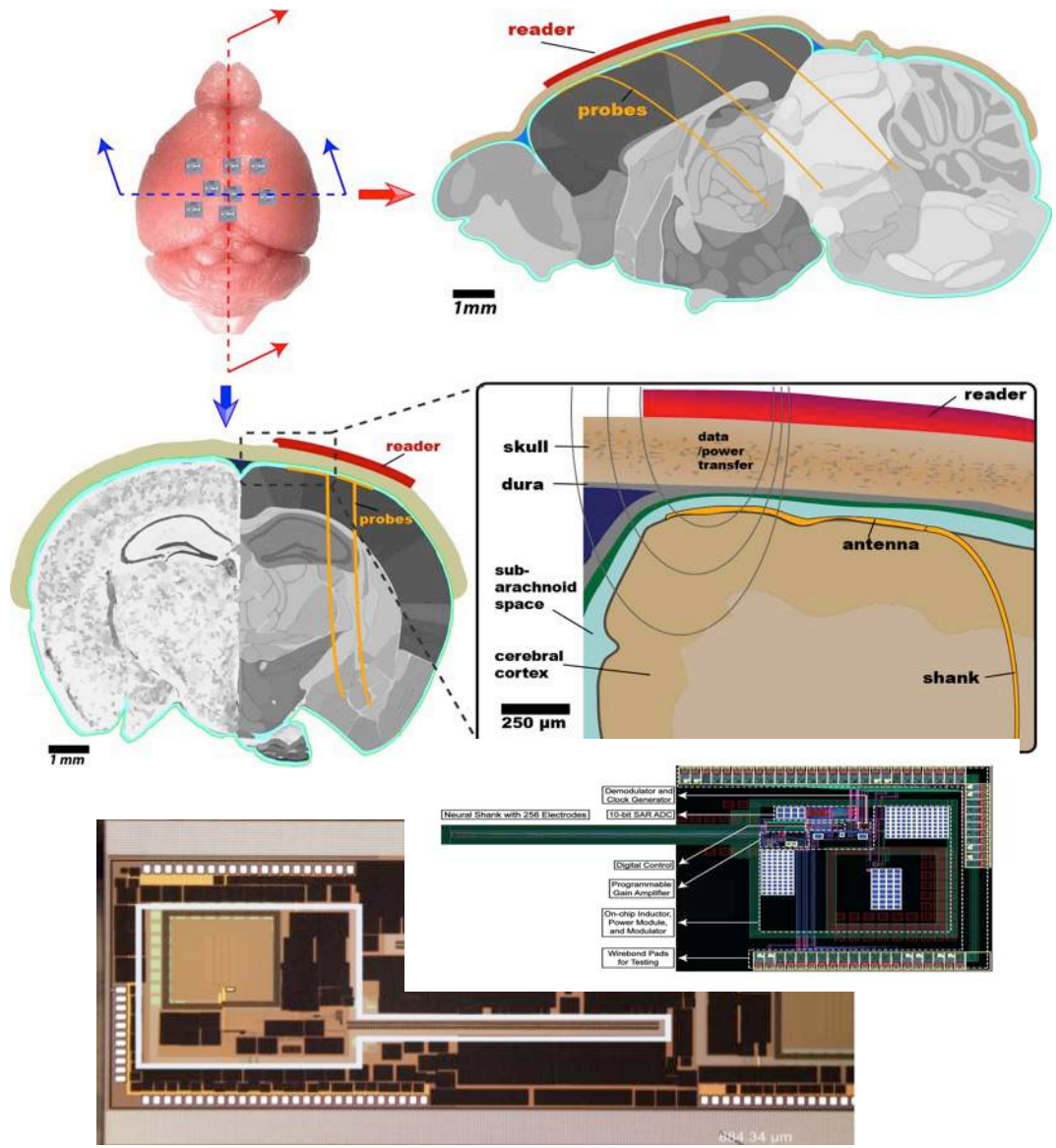


Collaboration with Michael Roukes, Thanos Siapas, Caltech, Andreas Tolias, Baylor

Fully implanted wireless probes

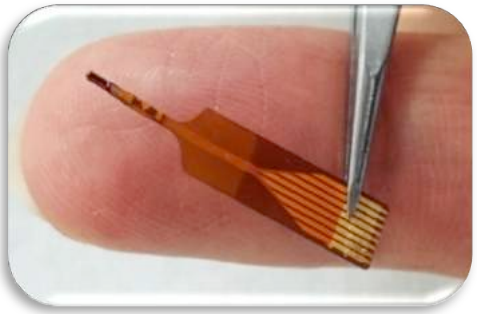
- Eliminate wires through the skull
- Flexible CMOS makes shanks themselves less invasive

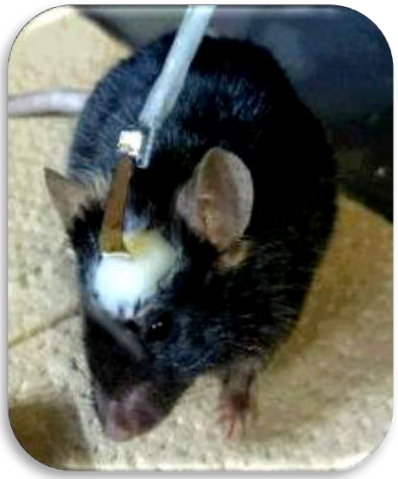


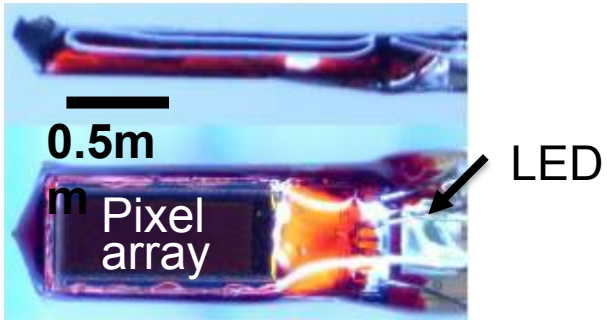


Jun Ohta
Nara Institute of Science and Technology, Japan

Contact CMOS imaging device *in vivo* - Deep brain -



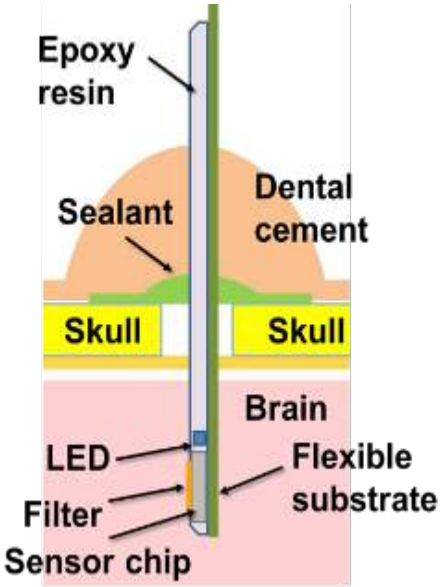


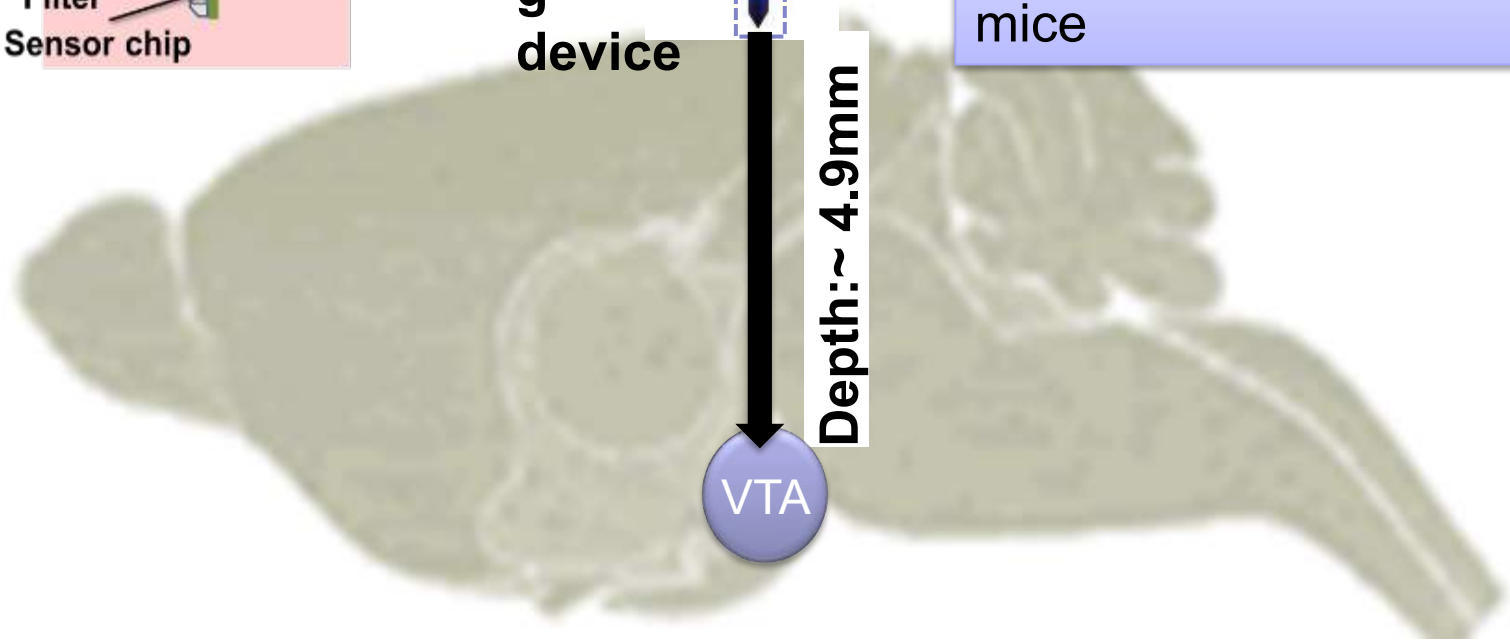


- ✓Small Size and Light Weight : ~0.5mm^{w}×0.2mm^{t}, ~ 0.02g
  - → Freely-moving
  - → Multi-point implantation
  - → Deep brain implantation
- ✓Resolution : ~10μm

Type	Needle shape for deep brain
Die size	450 μm x 1500 μm
Pixel number	40 x 120
Array size	300 μm x 900 μm
Pixel size	7.5 μm x 7.5 μm
Fill factor	35%
Pixel structure	3T-APS
Technology	AMS 0.35 μm CMOS
Fluorescence filter	On-chip high-pass
Exc. light source	Chip LED
Coating	Parylene-C

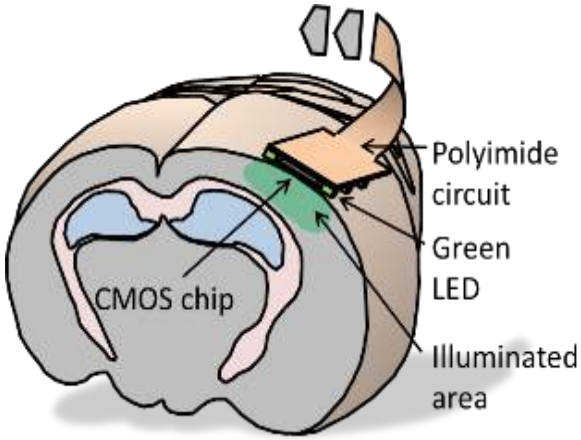
Deep brain implantation



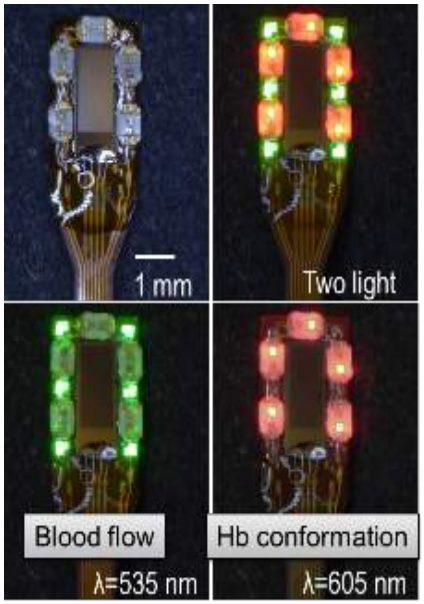


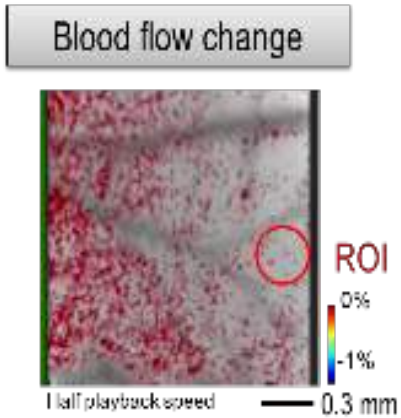
Observation of Dopamine activity in VTA region by administrating alcohol in TH-GFP Transgenic mice

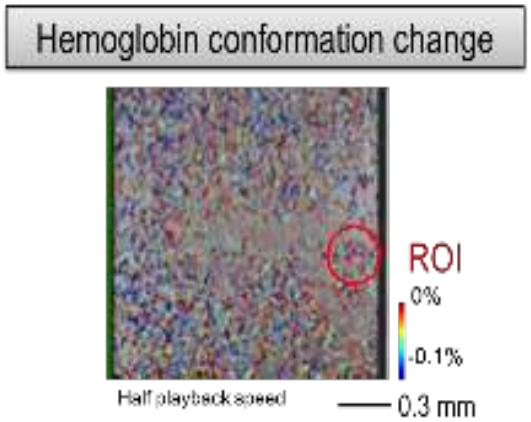
Contact CMOS imaging device *in vivo*
- Brain surface -



Type	Planar shape for brain surface
Die size	1000 μm x 3500 μm
Pixel number	120 x 268
Array size	900 μm x 2010 μm
Pixel size	7.5 μm x 7.5 μm
Fill factor	35%
Pixel structure	3T-APS
Technology	0.35 μm CMOS 2P3M
Light sources	535 nm LED for blood flow 605 nm LED for Hb change







Polystim Neurotechnologies

Mohamad Sawan, Professor, Canada Research Chair
Polytechnique Montréal

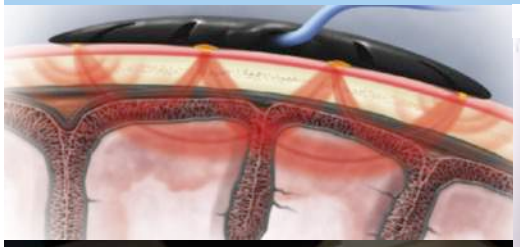
Montreal, 5 Dec, 2015.

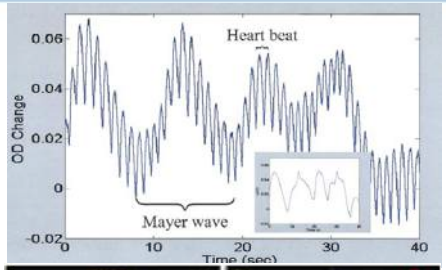
POLYTECHNIQUE MONTRÉAL
WORLD-CLASS ENGINEERING

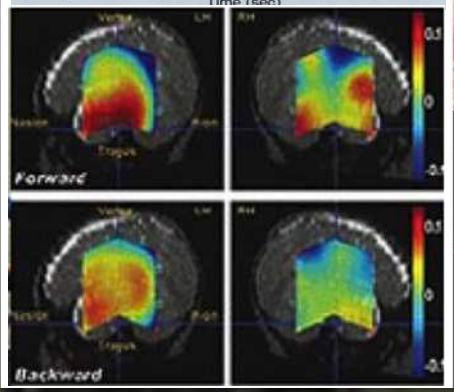
POLYSTIM Neurotechnologies

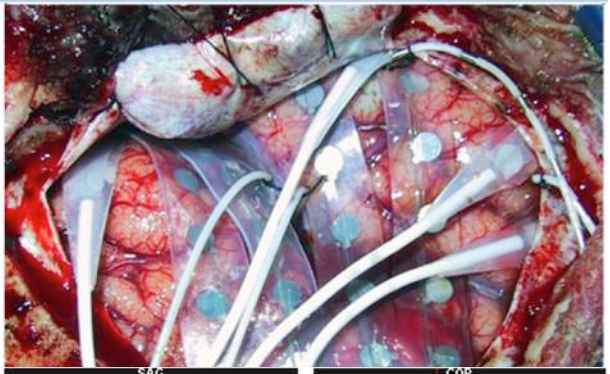
RESMIQ
Regroupement Stratégique en Microsystèmes du Québec

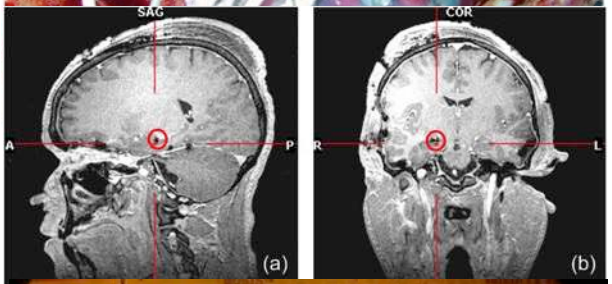
BMI: 32 EEG-256 fNIRS Wearable Epileptic Seizure Detector

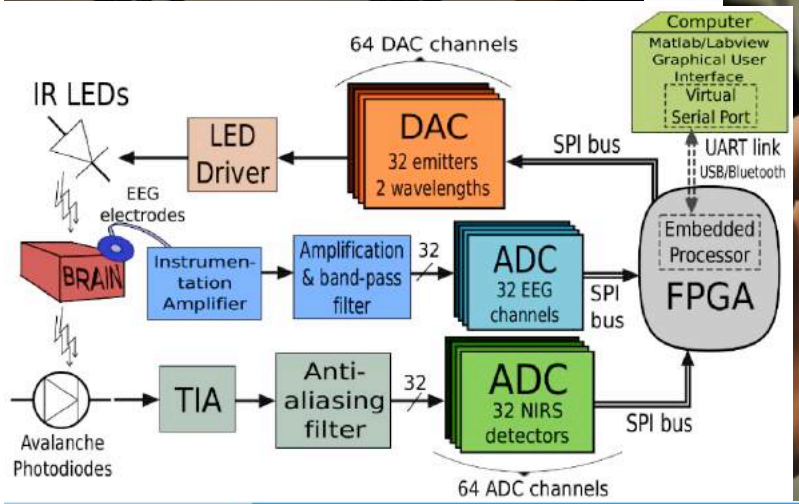


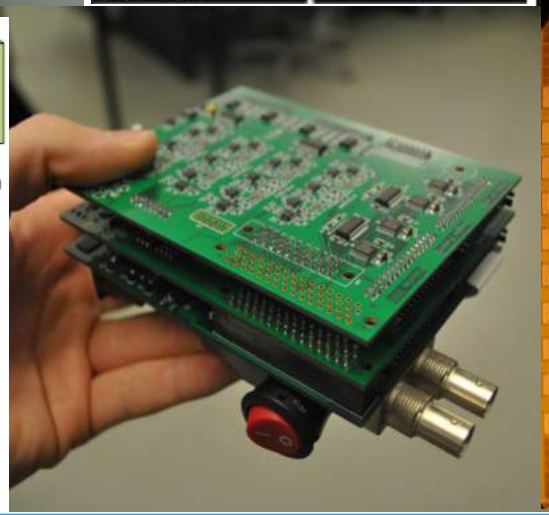


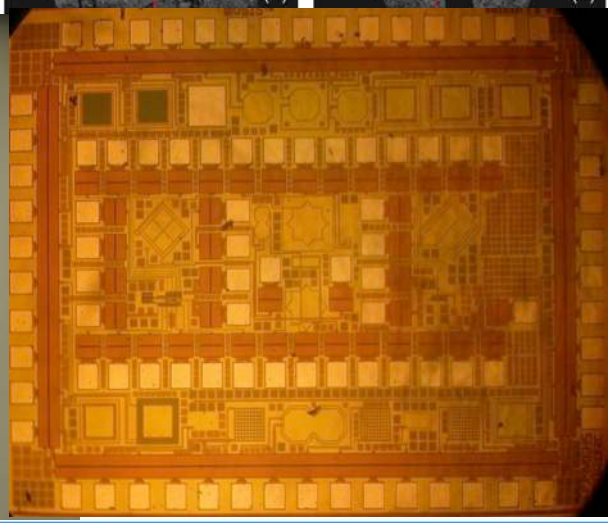




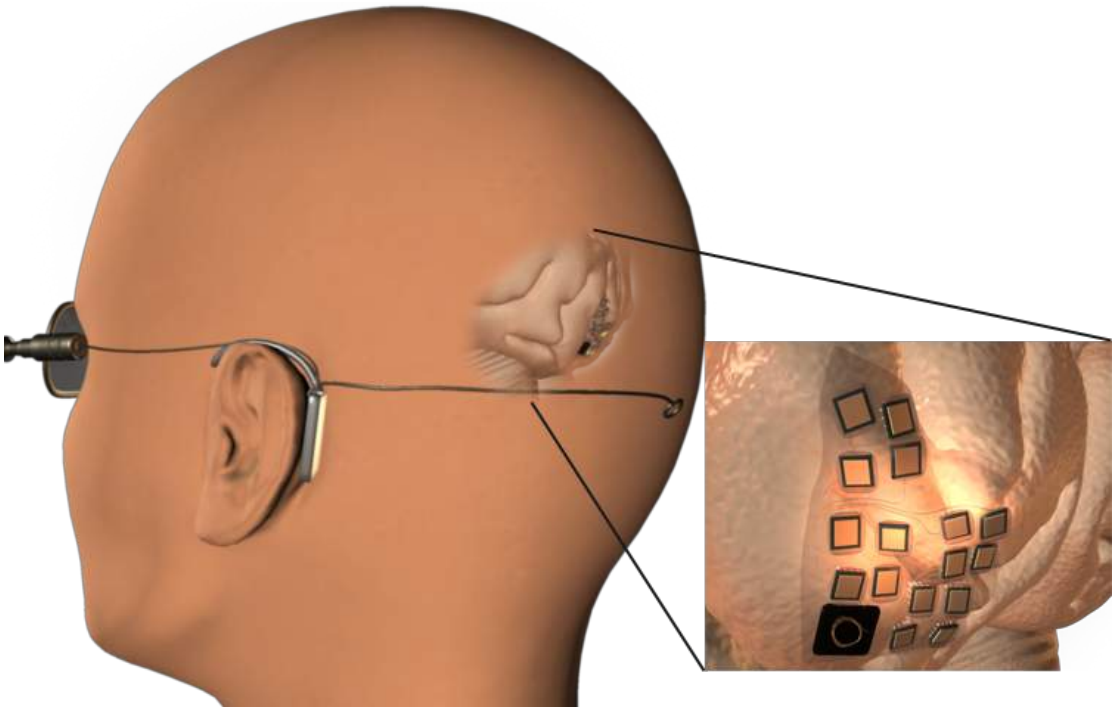


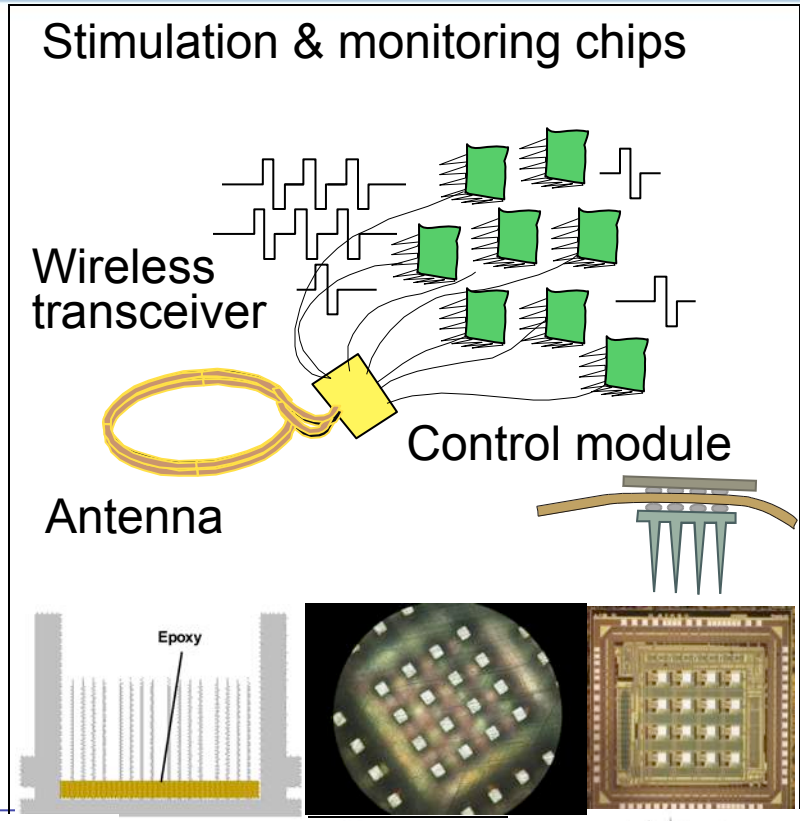


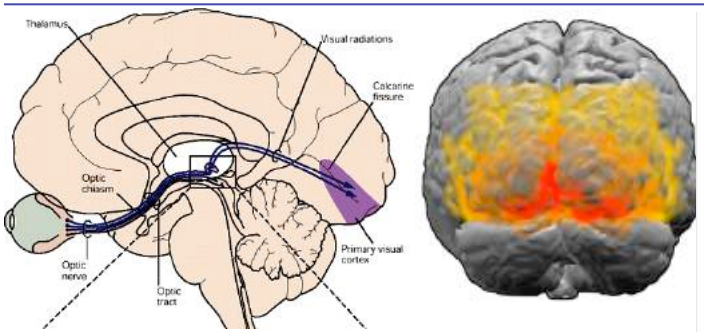


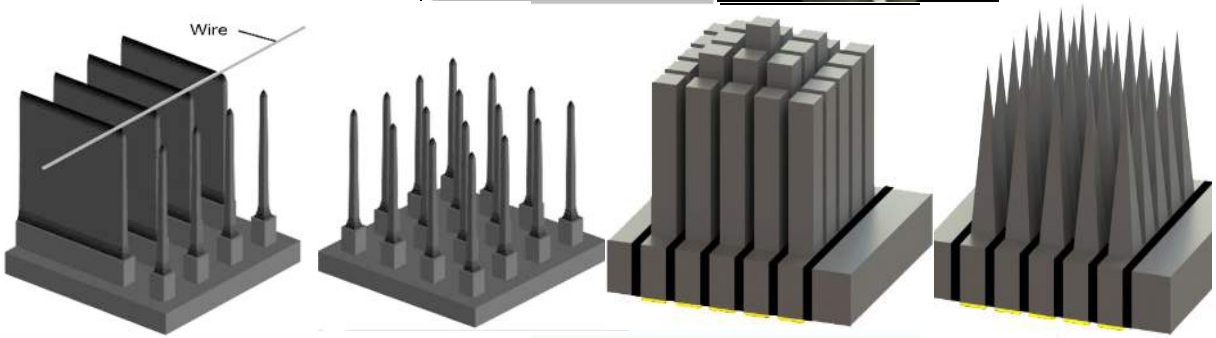


Intracortical Neurostimulation : Recover Vision

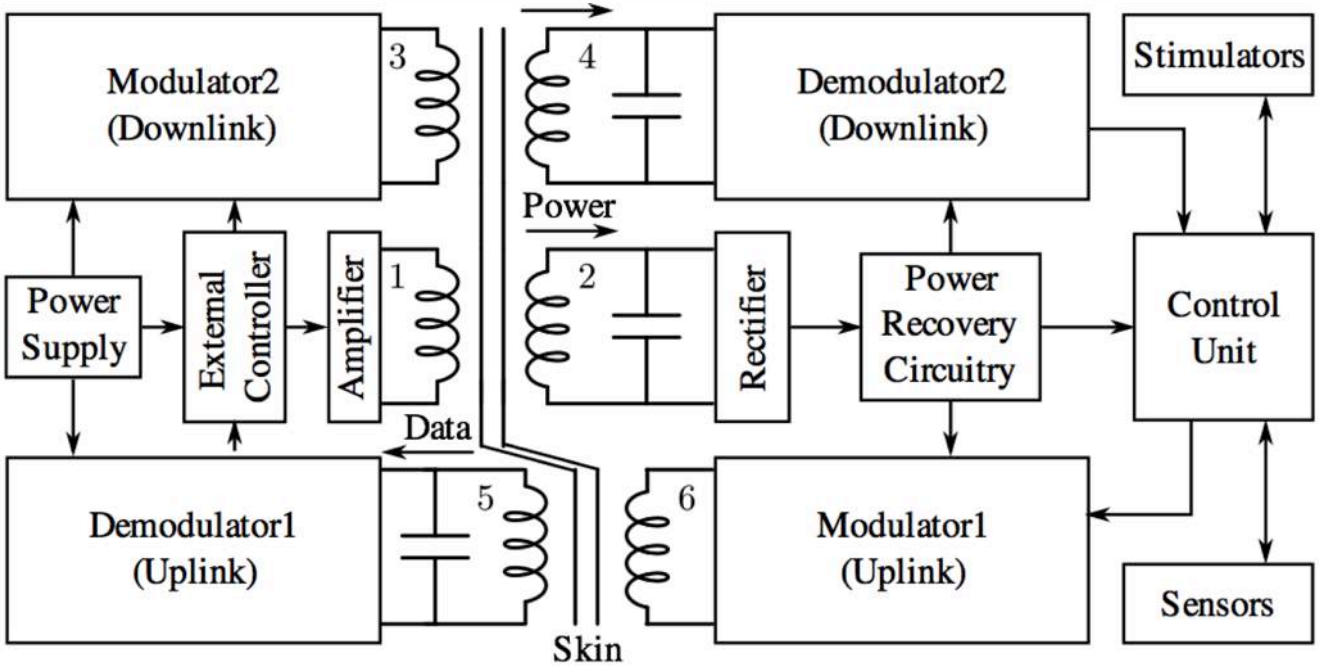


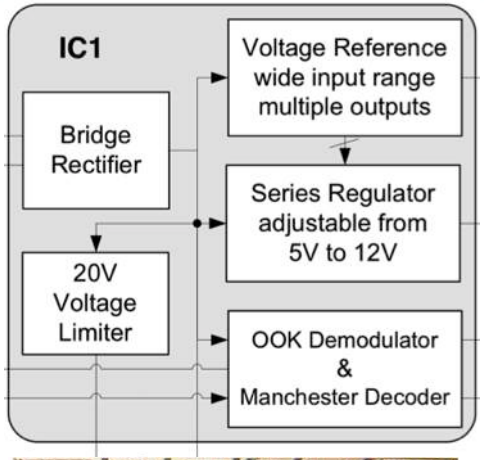


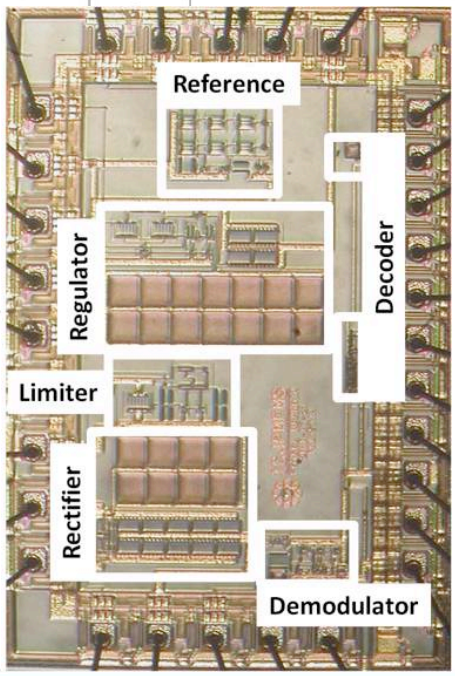




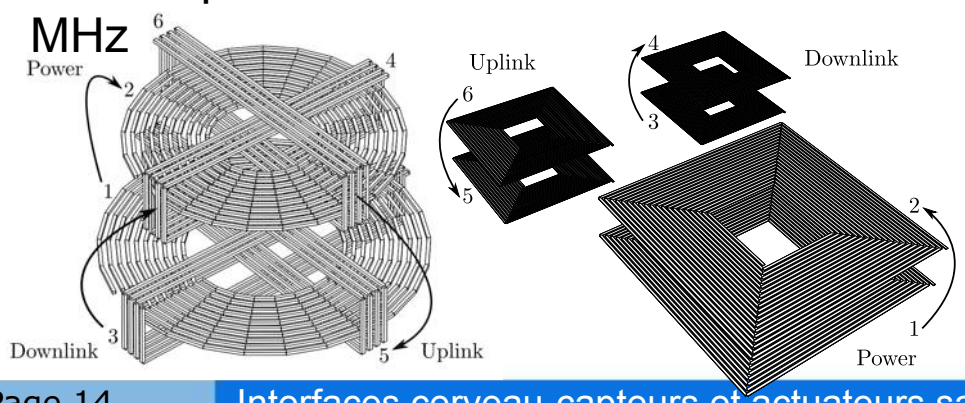
Inductive Power & Data Links : Higher Performance

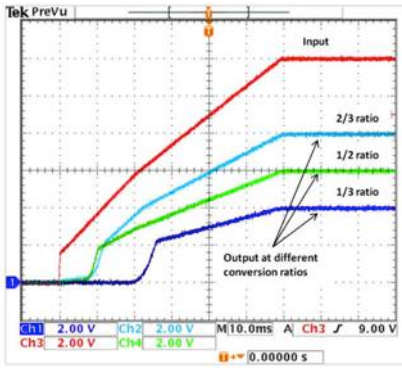






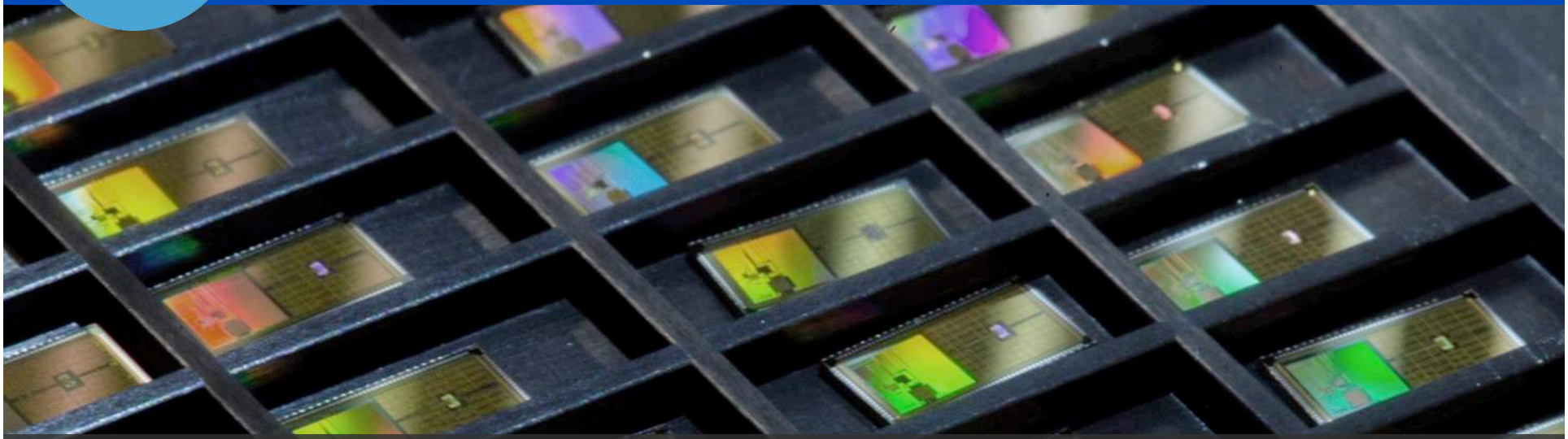
Power link = 1 MHz;
Down/Up links = 13.65 /6.5 MHz





Center for Wearable Sensors

UC San Diego
Jacobs School of Engineering

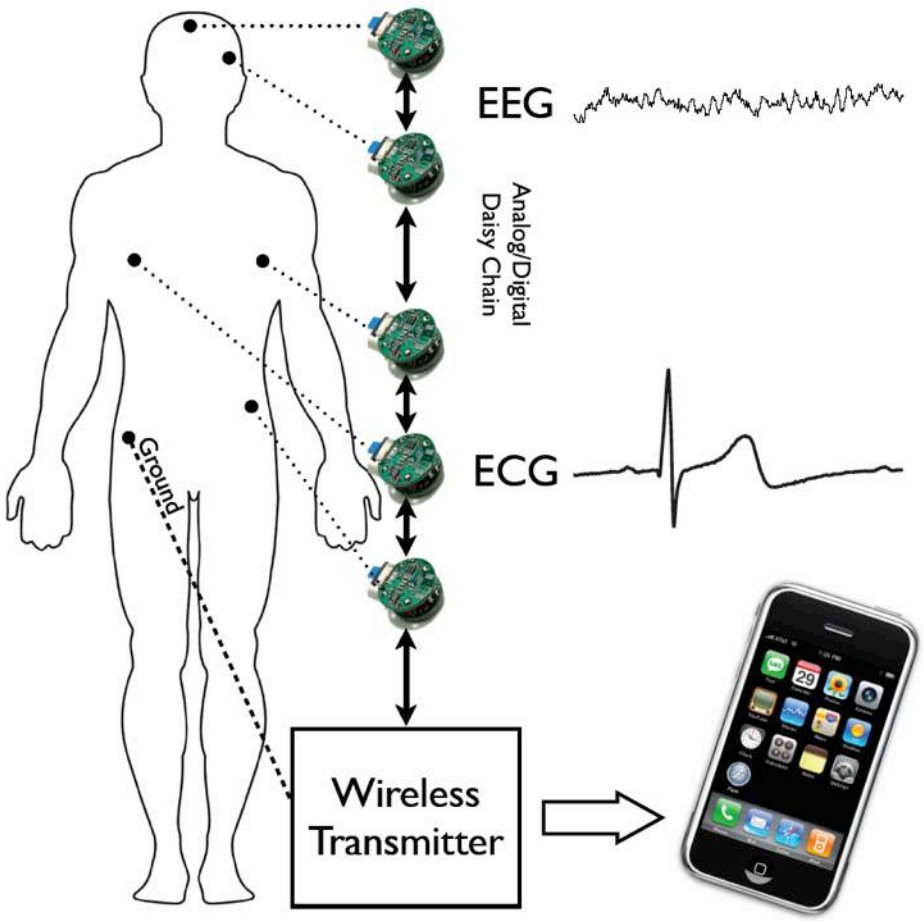


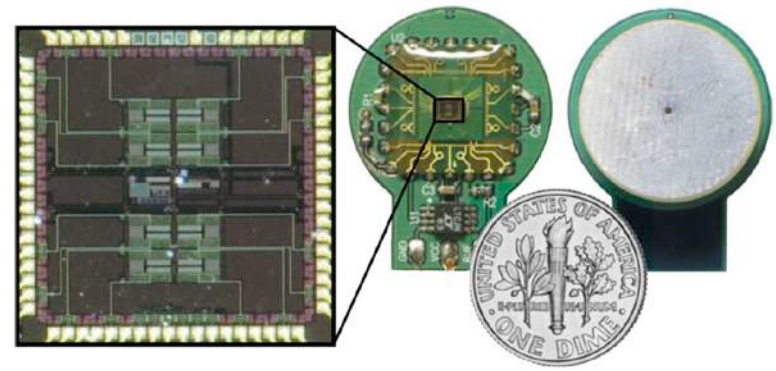
Unobtrusive Brain-Machine-Body Interfaces

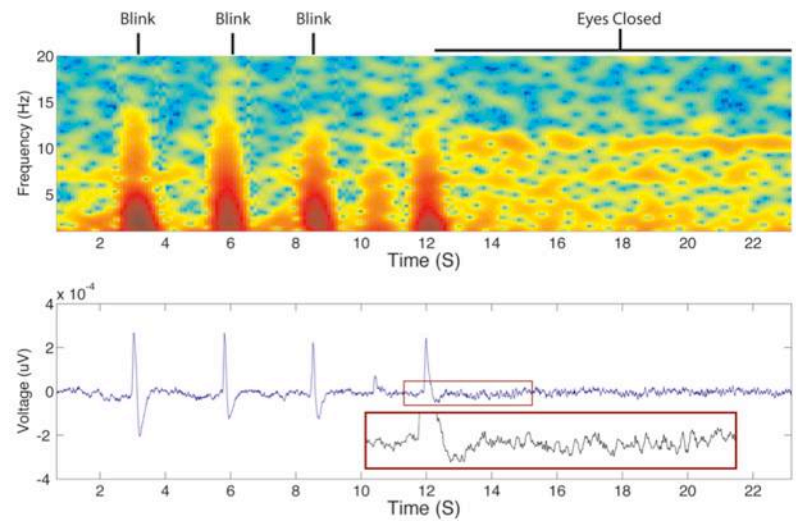
Gert Cauwenberghs
Integrated Systems Neuroengineering Laboratory
http://isn.ucsd.edu

Wireless Non-Contact Biopotential Sensors

Mike Yu Chi and Gert Cauwenberghs, 2010



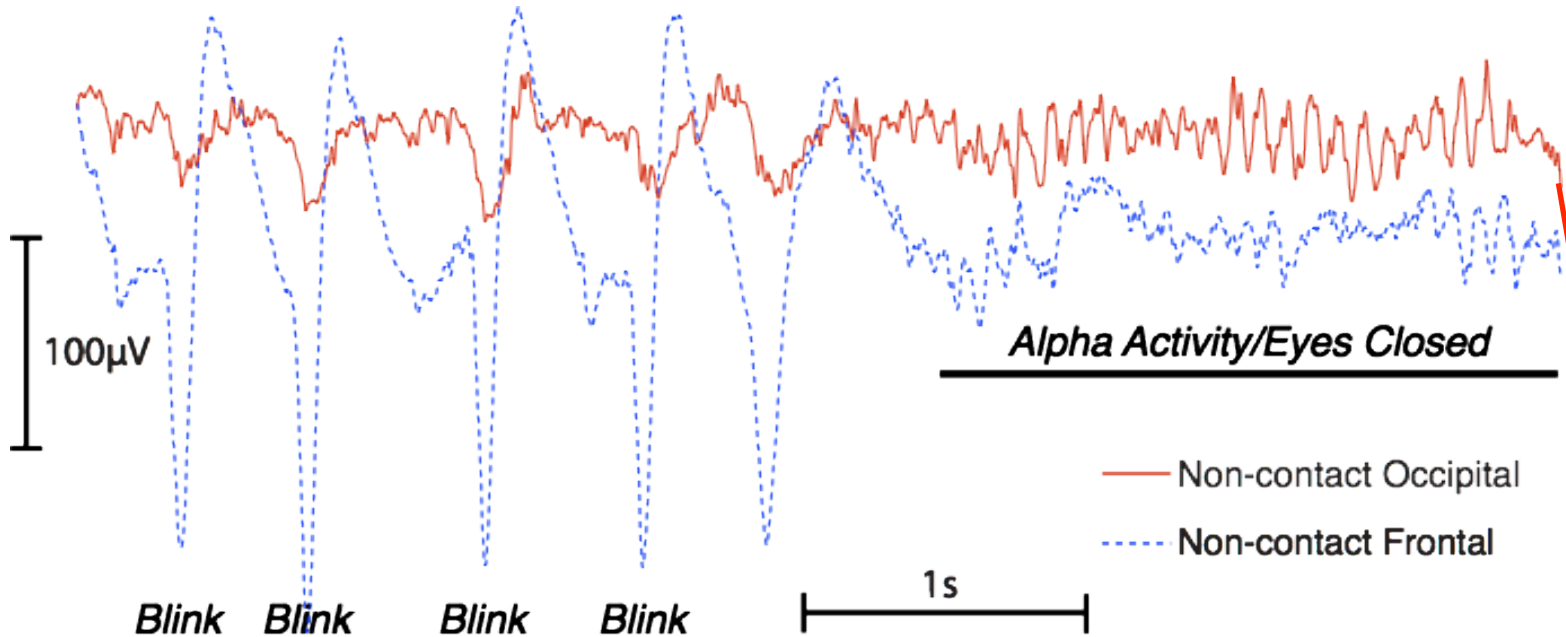




EEG alpha and eye blink activity recorded on the occipital lobe over haired skull

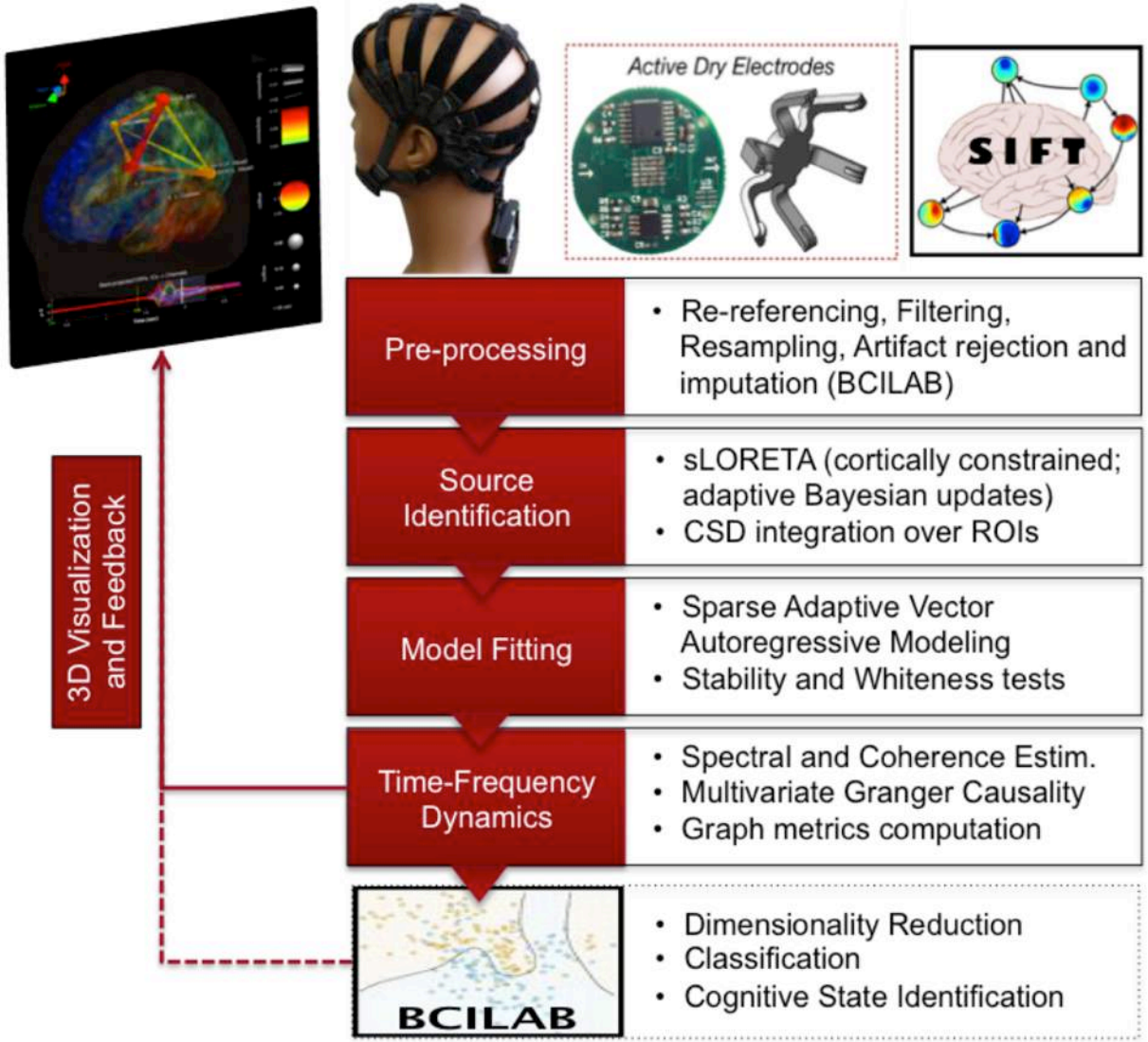
Non-Contact EEG Recording over Haired Scalp

Y. M. Chi, E. Kang, J. Kang, J. Fang and G. Cauwenberghs, 2010



- **Easy access to hair-covered areas of the head without gels or slap-contact**
- **EEG data available only from the posterior**
  - P300 (Brain-computer control, memory recognition)
  - SSVP (Brain-computer control)

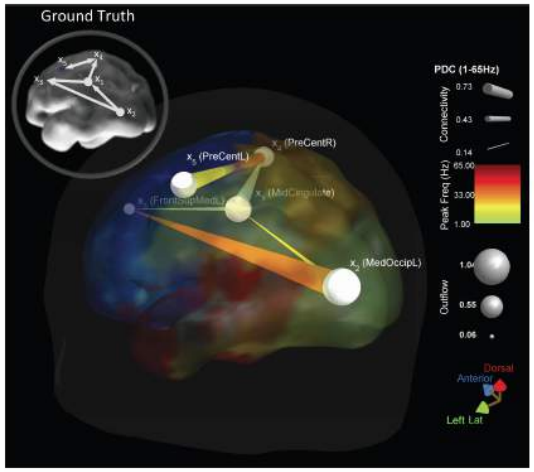
Real-Time Estimation and 3D Visualization of Source Dynamics and Connectivity Using Wearable EEG



Mullen, T., Kothe, C., Chi, Y. M., Ojeda, A., Kerth, T., Makeig, S., Cauwenberghs, G., Jung, T-P., *EMBC & Asilomar BCI*, 2013

Mobile Dry EEG Brain-Body Activity Imaging

Cognionics 64-channel wireless dry EEG system
http://[illegible]s.com



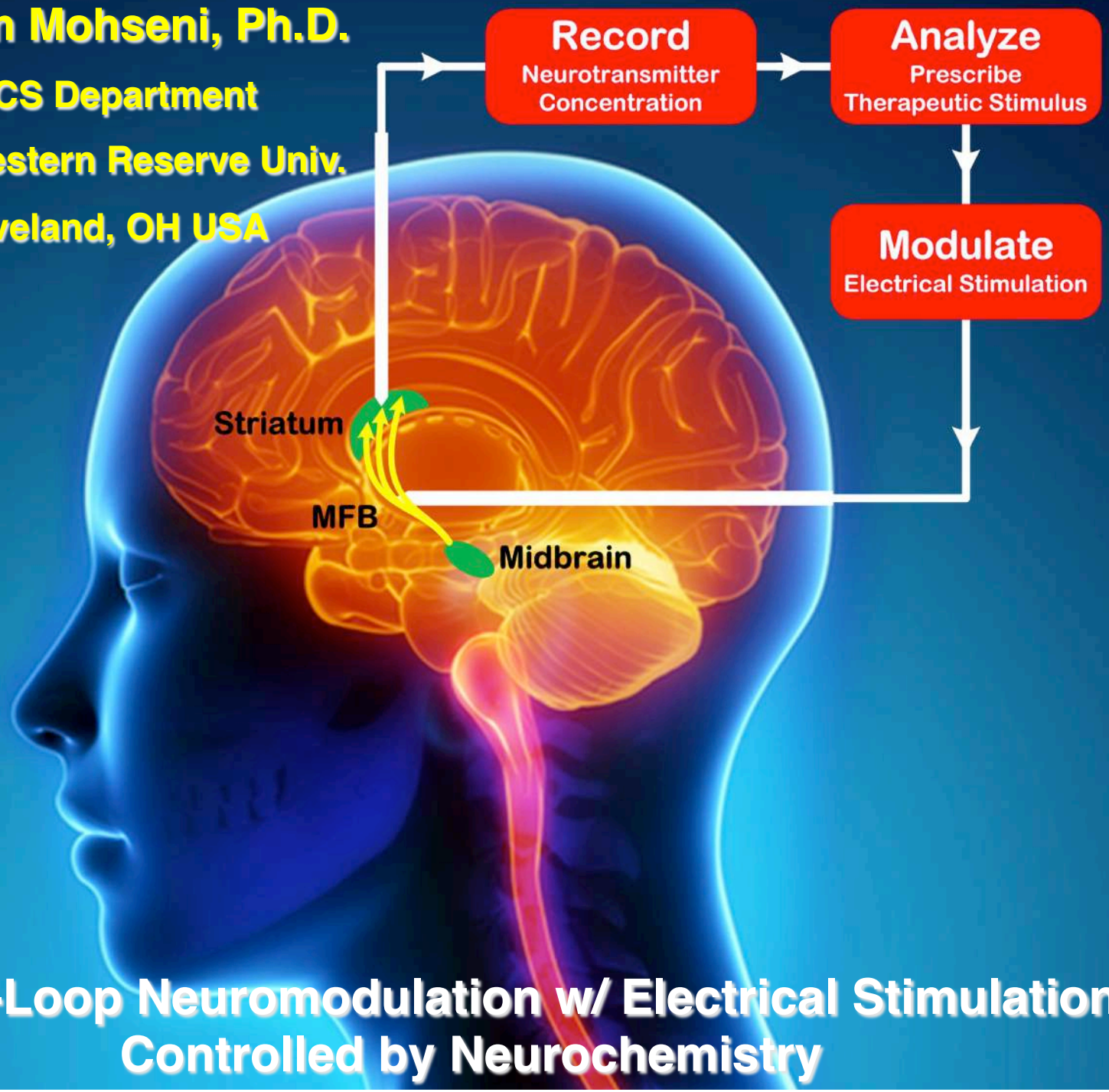
UCSD SCCN SIFT and ASR
http://sccn.ucsd.edu/wiki/SIFT

Mobile dry EEG ASR and SIFT video demonstration

Integrated Circuits Interfacing with the Brain

- Neural recording and neural stimulation
  - Both invasive and non-invasive
  - Recording: electrical, chemical, and optical
  - Stimulation: optical stimulation/optogenetics, current/charge-mode
- Closed-loop neural interfaces
  - Responsive neurostimulators (epilepsy), neurotransmitters control
- Neuronal modeling
  - Silicon neurons, spiking neural networks
- Other related topics (not discussed)
  - Wireless communications (transcutaneous)
  - Wireless powering (inductive, ultrasound)
  - Signal/information processing
  - In vivo applications (animal studies, clinical, wellness)

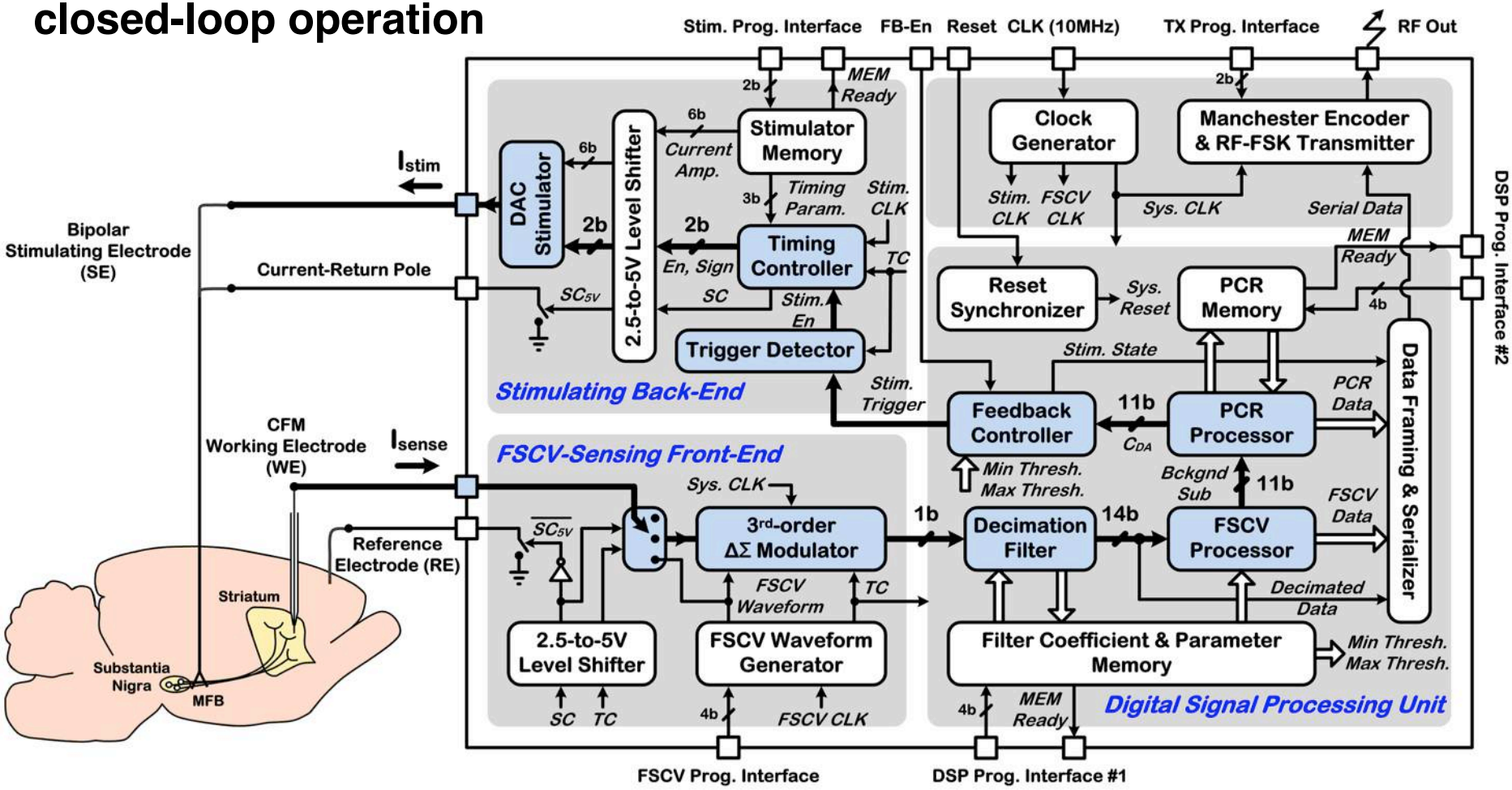
Pedram Mohseni, Ph.D.
EECS Department
Case Western Reserve Univ.
Cleveland, OH USA



Closed-Loop Neuromodulation w/ Electrical Stimulation Controlled by Neurochemistry

Neurochemostat System-on-Chip (SoC)

- **Dopamine sensing w/ fast-scan cyclic voltammetry (FSCV), real-time interferent removal, and feedback-controlled electrical stimulation for closed-loop operation**



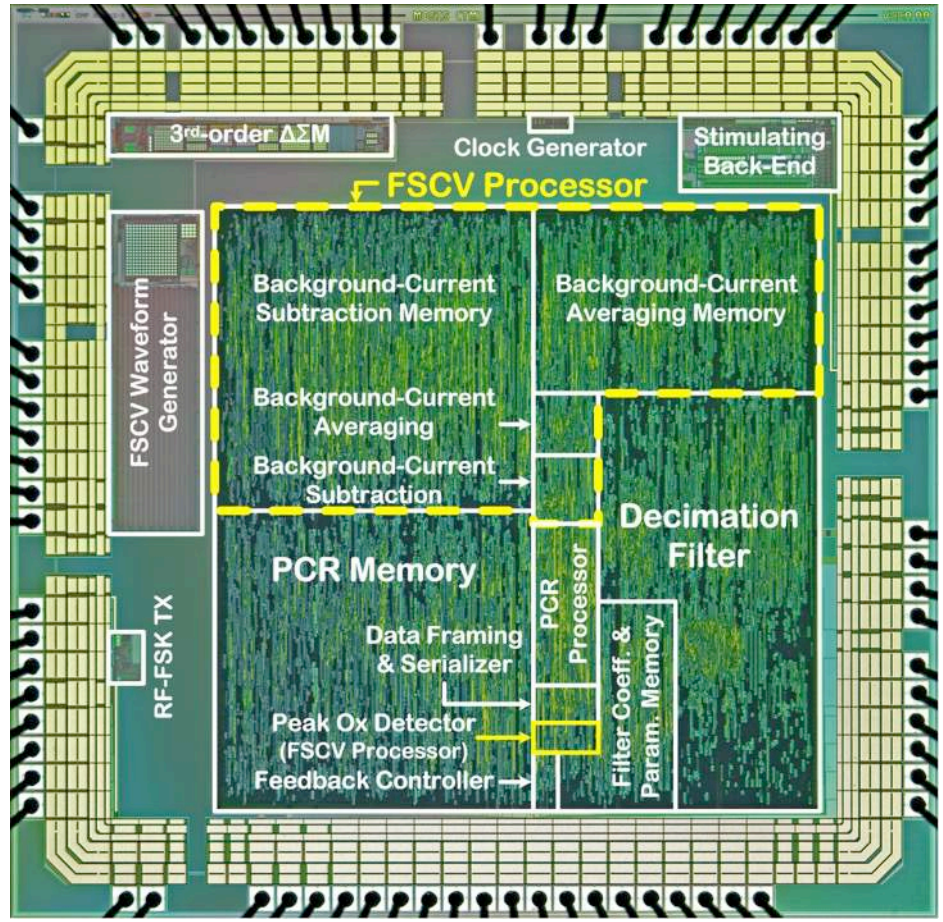
Neurochemostat SoC

Integrated Functionality

- FSCV sensing
- FSCV waveform generation
- FSCV signal processing
- Chemometrics
- Feedback-controlled stimulation
- Embedded timing management
- RF-FSK TX @ ~433 MHz

Power Supply

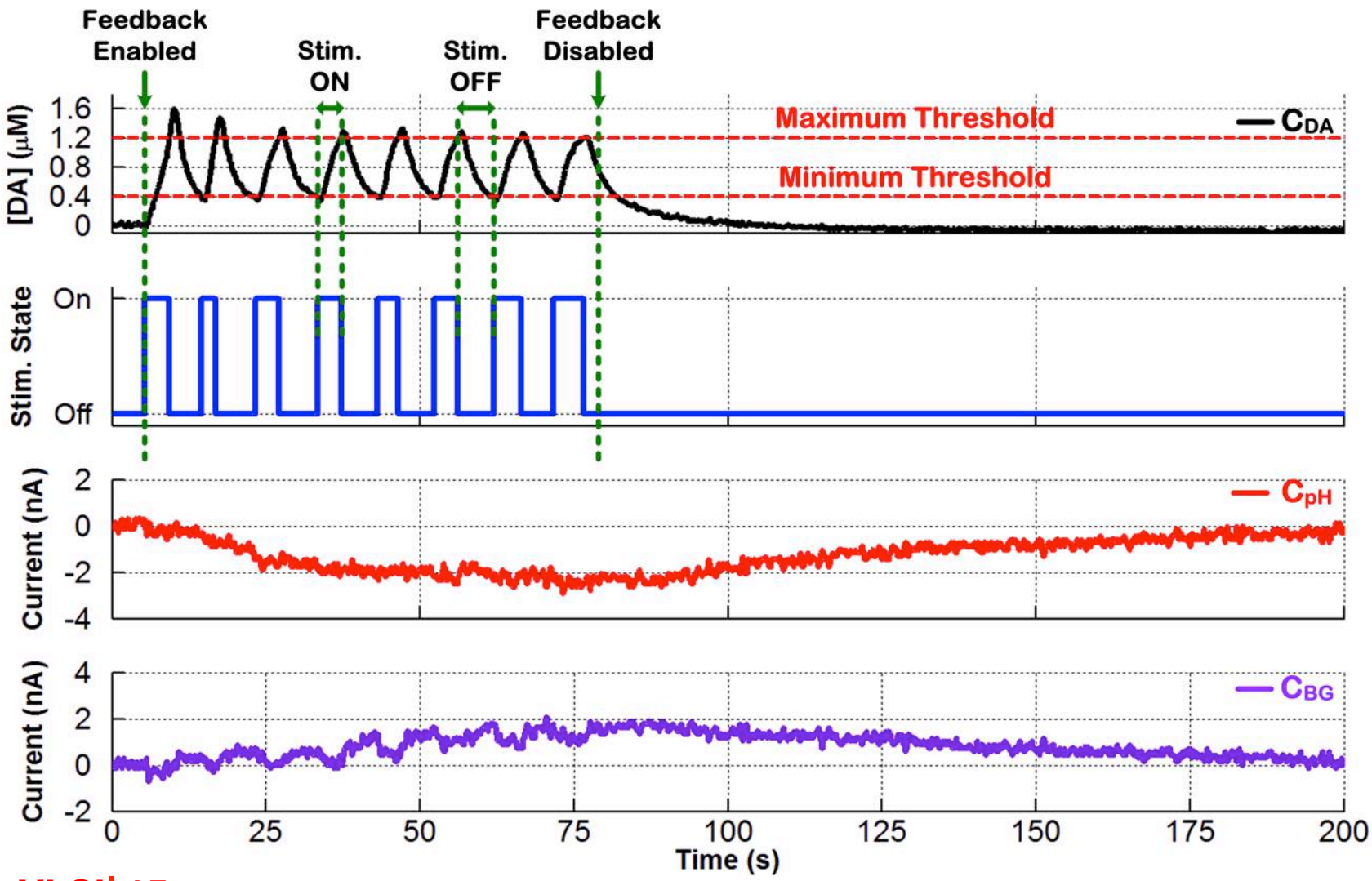
- Recording = 2.5 V
- Processing = 2.5 V
- Stimulation = 5 V



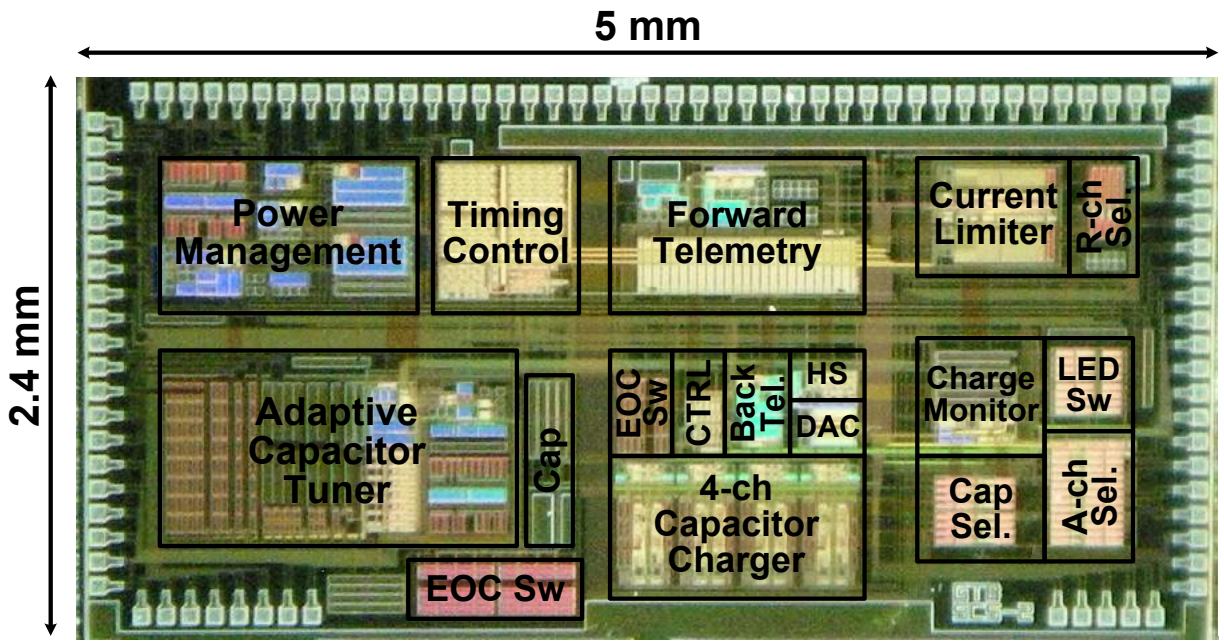
- AMS 0.35 μm 2P/4M CMOS
- Die size = 3.3 mm × 3.2 mm

Dopamine Regulation in Rat Brain

- **Closed-loop dopamine regulation *in vivo* after real-time differentiation from pH change and electrode current drift as common interferents**



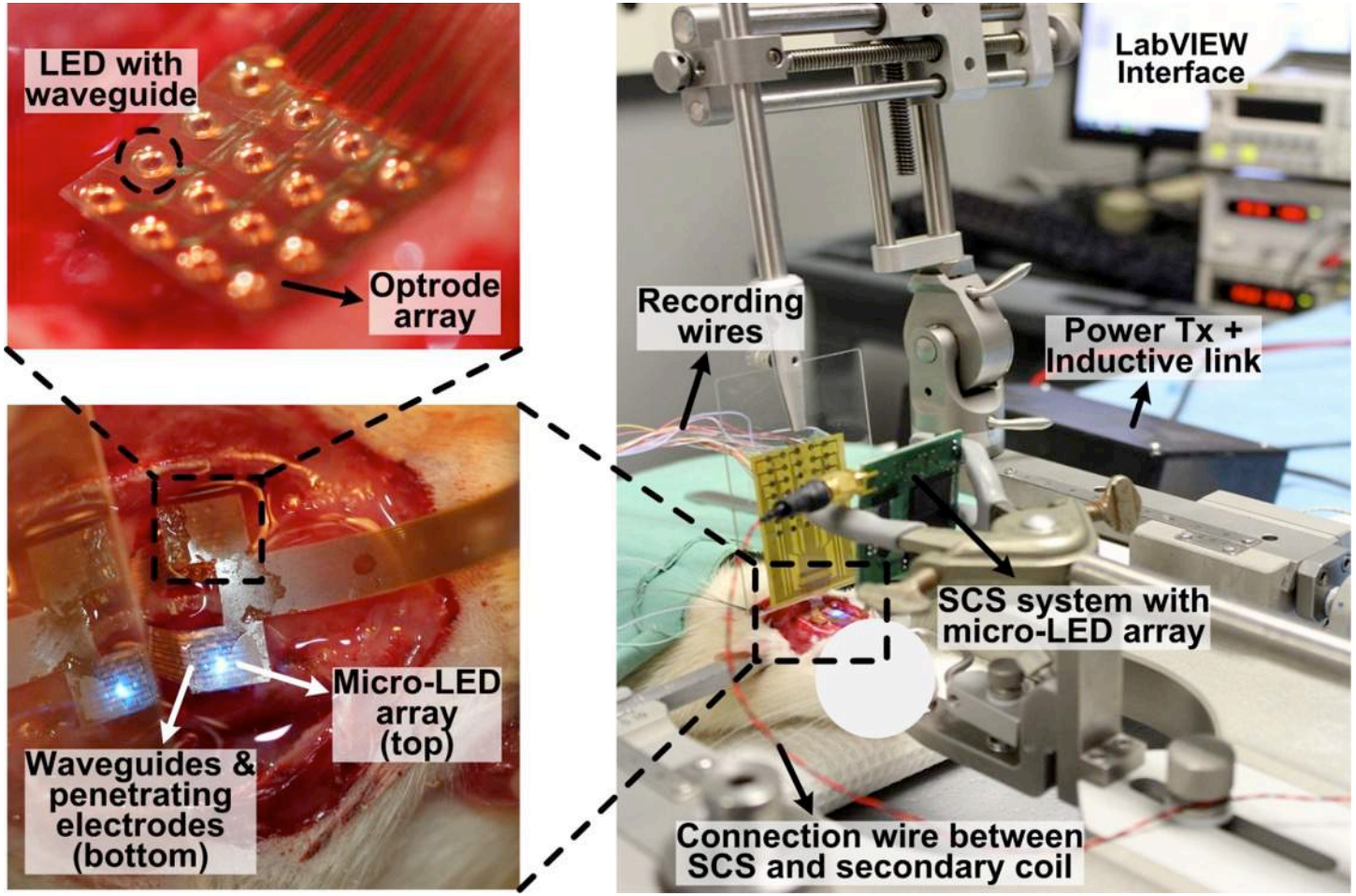
GeorgiaTech: Maysam Ghovanloo
Energy-efficient Neuro-Stimulators for Optogenetics



GT-Bionics Lab

School of Electrical and Computer Engineering

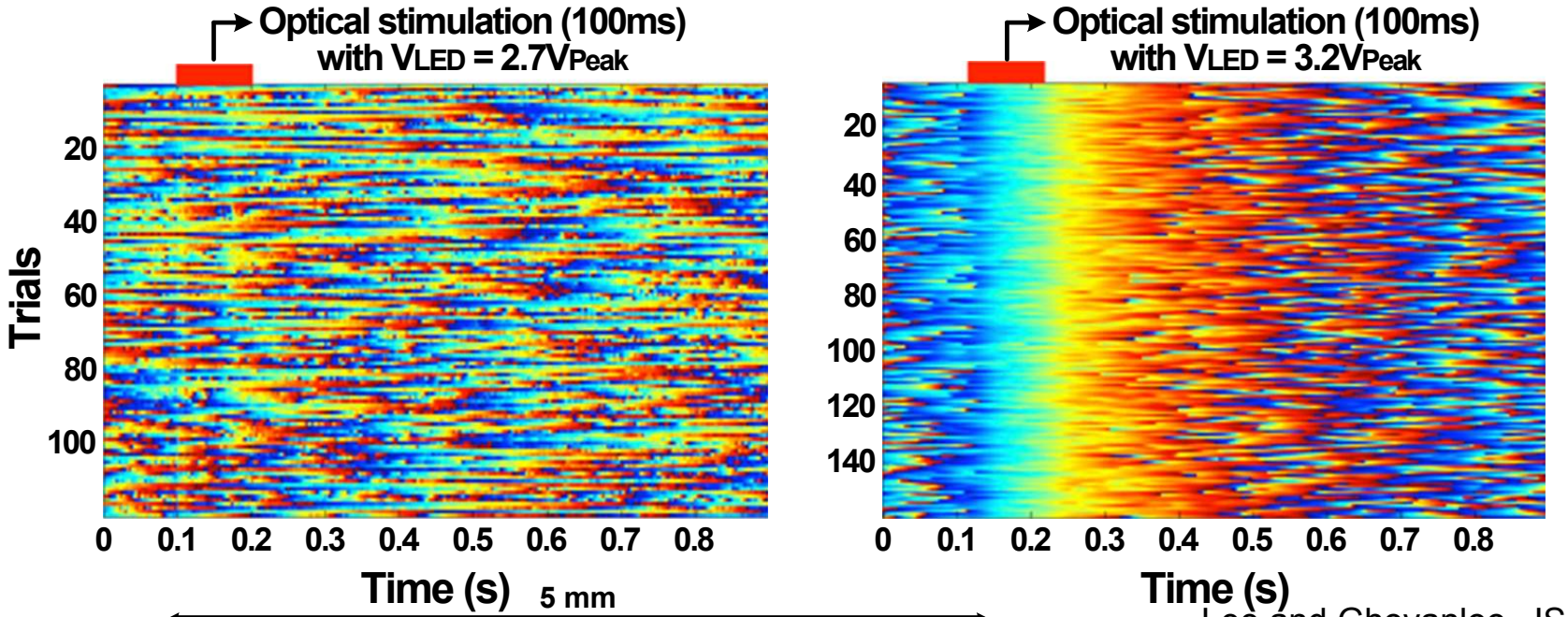
Maysam Ghovanloo, GeorgiaTech
Energy-efficient Neuro-Stimulators for Optogenetics



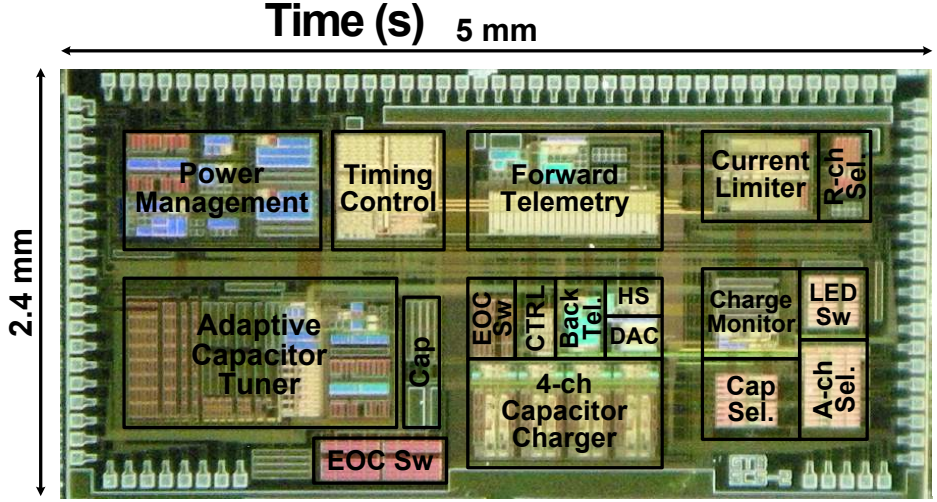
- Optical stimulation to visual cortex in the brain of anesthetized viral-transfected rats + local field potential (LFP) recording.

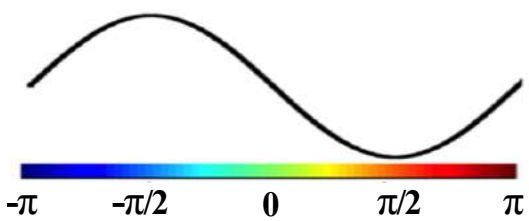
Lee and Ghovanloo, JSSC'15

Instantaneous LFP Phase



Lee and Ghovanloo, JSSC'15

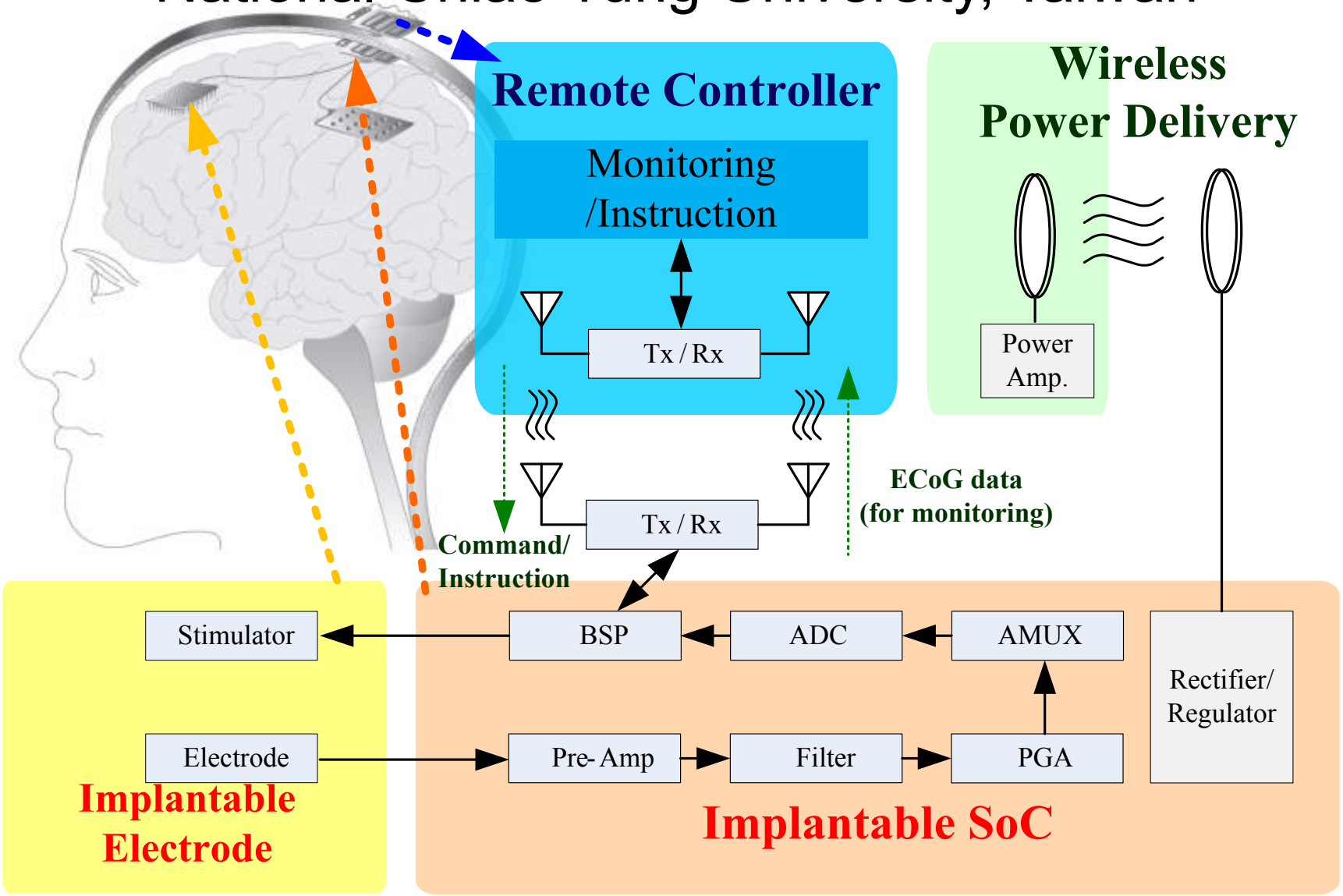




- Instantaneous phase of light-induced LFP at 1~25Hz
- No phase consistency w/ V_{LED} = 2.7V_{Peak}, while clear phase synchronization during optical stimulation w/ V_{LED} = 3.2V_{Peak}.

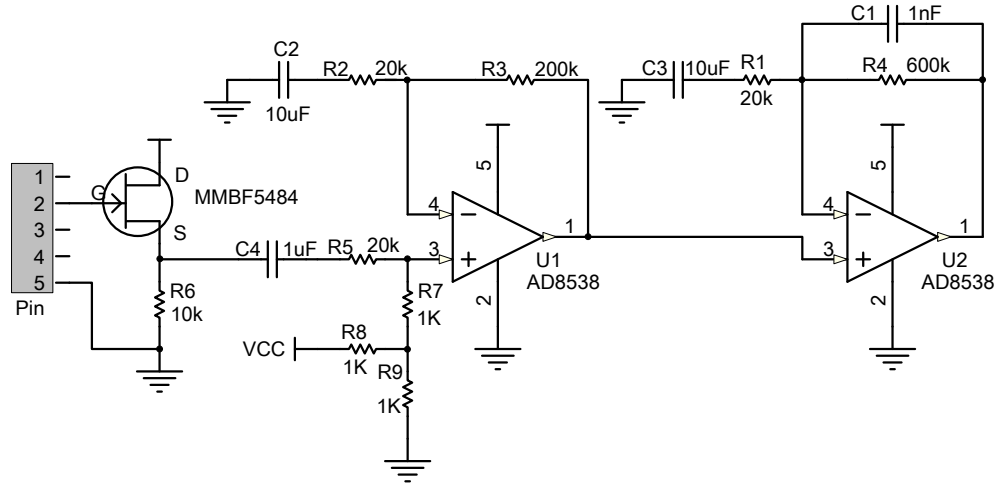
Closed Loop Seizure Detection and Suppression

Herming Chiueh
National Chiao Tung University, Taiwan

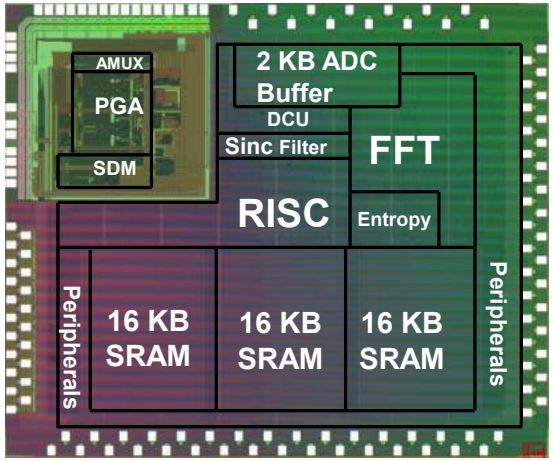


Animal Test of Seizure Detection

Long-Evans rats with spontaneous absence seizure

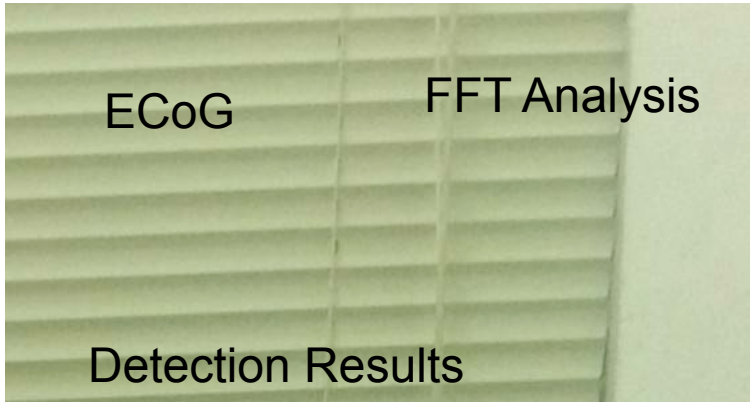


Pre-amplifier with 3,000x gain

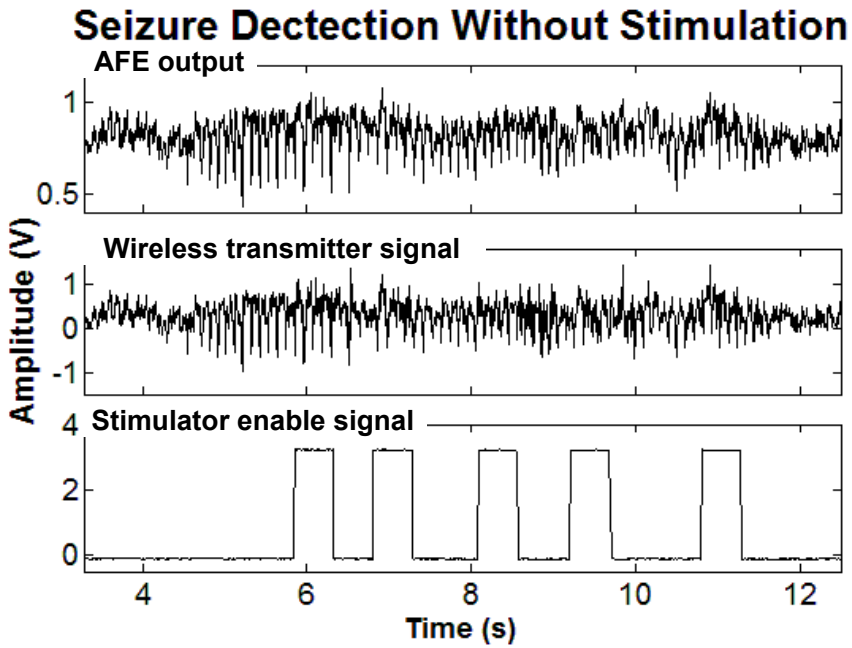


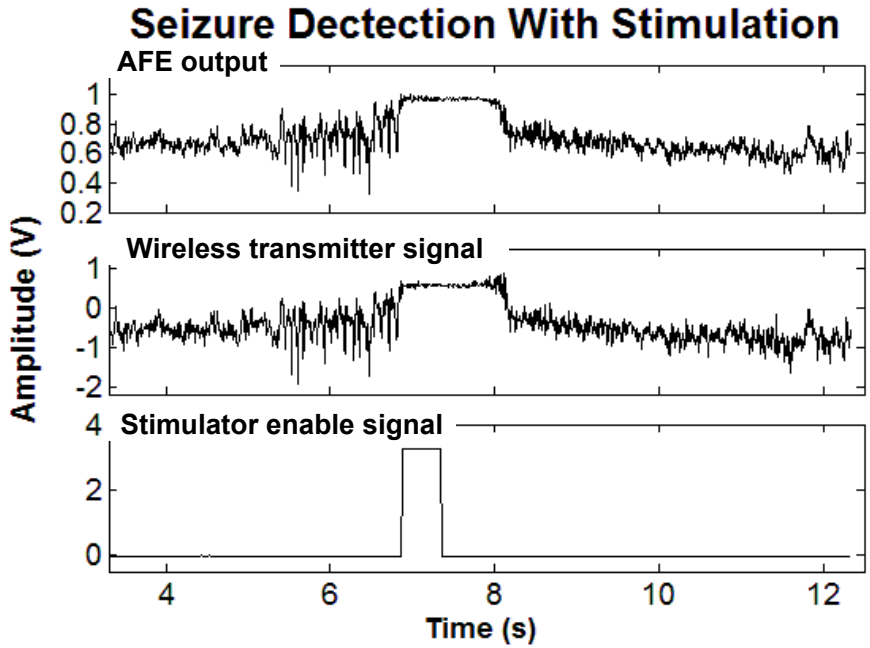
This Work

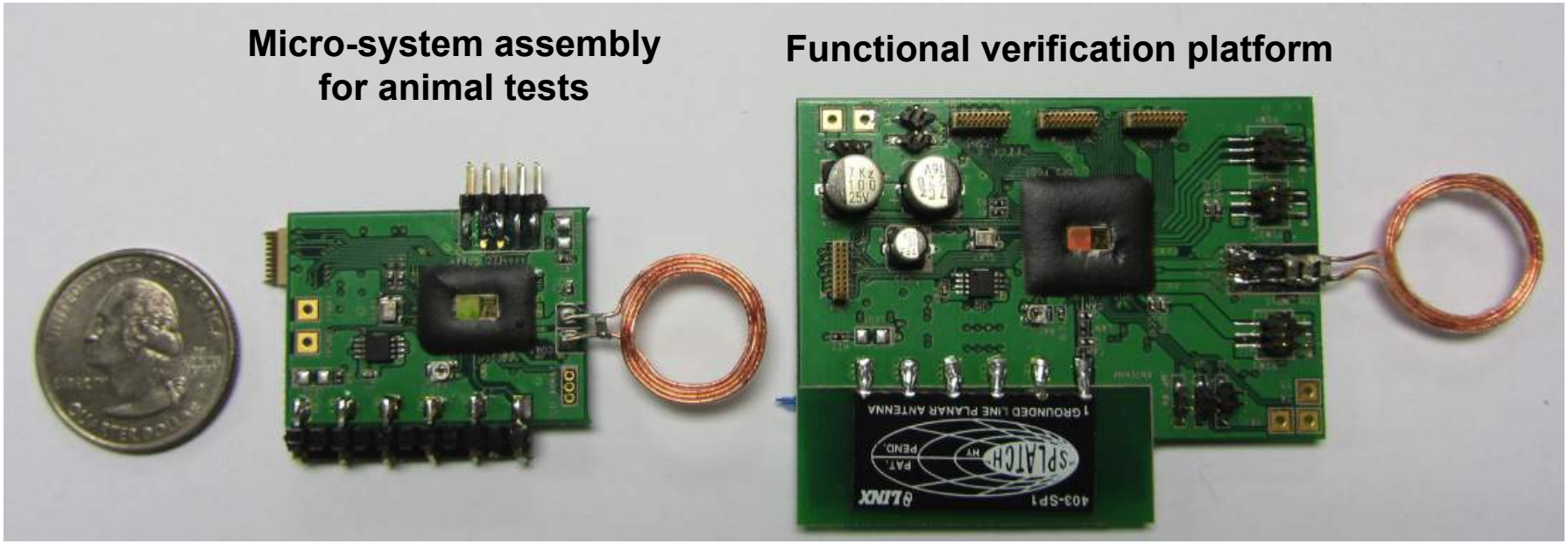
USB



Spike-wave discharge shown on LabVIEW-based GUI (200S/sec)


Seizure Dectection Without Stimulation
AFE output
Wireless transmitter signal
Stimulator enable signal
Amplitude (V)
Time (s)


Seizure Dectection With Stimulation
AFE output
Wireless transmitter signal
Stimulator enable signal
Amplitude (V)
Time (s)

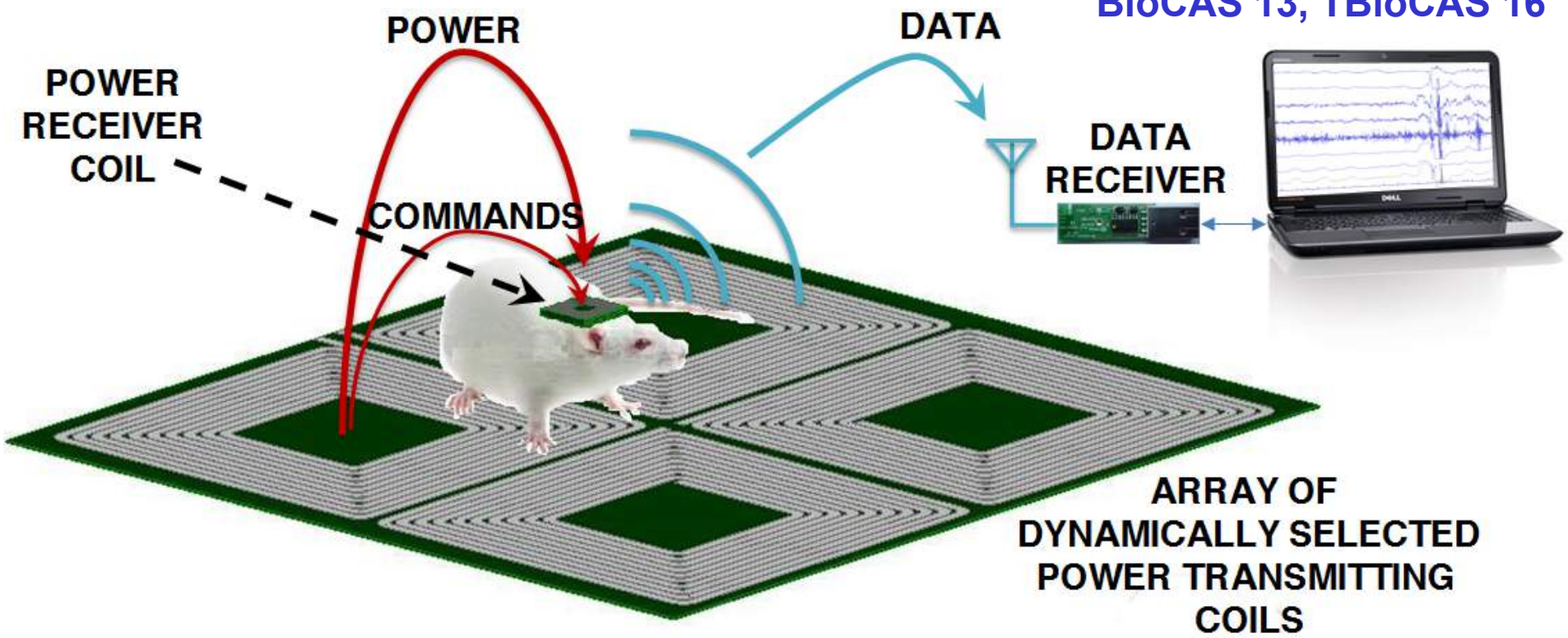

Micro-system assembly
for animal tests
Functional verification platform

Wireless Closed-Loop Neurostimulators for the Treatment of Intractable Epilepsy

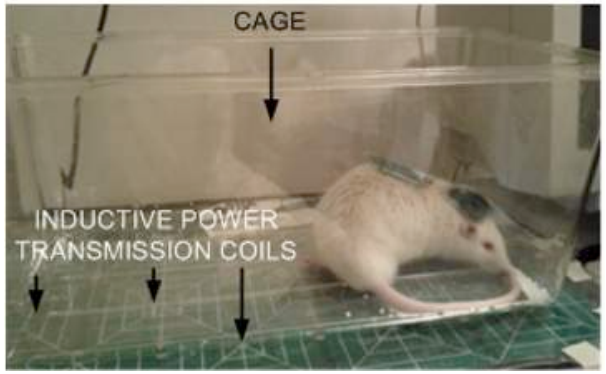
Roman Genov, Tariq Salam,
Hossein Kassiri, Nima Soltani, Jose Luis Perez Velazquez
Department of Electrical and Computer Engineering,
Hospital for Sick Children
University of Toronto
roman@eecg.utoronto.ca

Roman Genov University of Toronto
Closed-loop Neurostimulators for Epilepsy

BioCAS 13, TBioCAS 16



- Closed-loop neurostimulator
  - For drug-resistant epilepsy
  - Seizures predicted and aborted
- Wireless data
- Inductive powering



Toronto Integrated Neural Interfaces (TINI)

ESSCIRC 14

ESSCIRC 12 JSSC 16

ESSCIRC 11 JSSC 13

CICC 11

JSSC 13

ISCAS 09

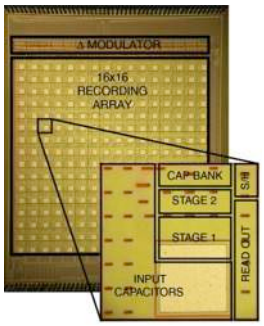
TBioCAS 13

ISSCC 07

TBIOCAS 10

JSSC 09

0.35µm

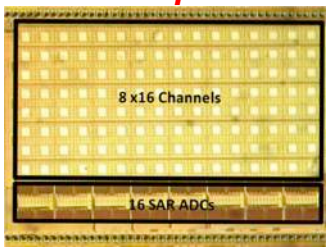


2007

256 recording channels

On-chip gold electrodes

0.35µm



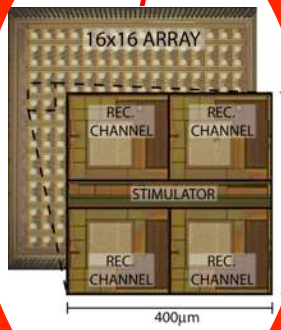
2009

128 recording channels

Column parallel 8-bit SAR ADC

128 voltage stimulation channels

0.35µm



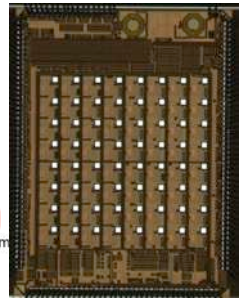
2010

256 recording & stimulation channels

In-channel 8-bit single slope ADC

64 current stimulation channels

0.13µm



2011

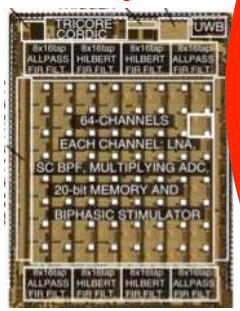
64 recording channels

In-channel 8-bit SAR ADC

64 FIR filters

FSK Wireless TX

0.13µm



2012

64 recording & 64 stimulation channels

UWB Wireless TX

Seizure detection & control

Phase synchrony features

0.13µm

2014

64 recording & 64 stimulation channels

DC-coupled front end

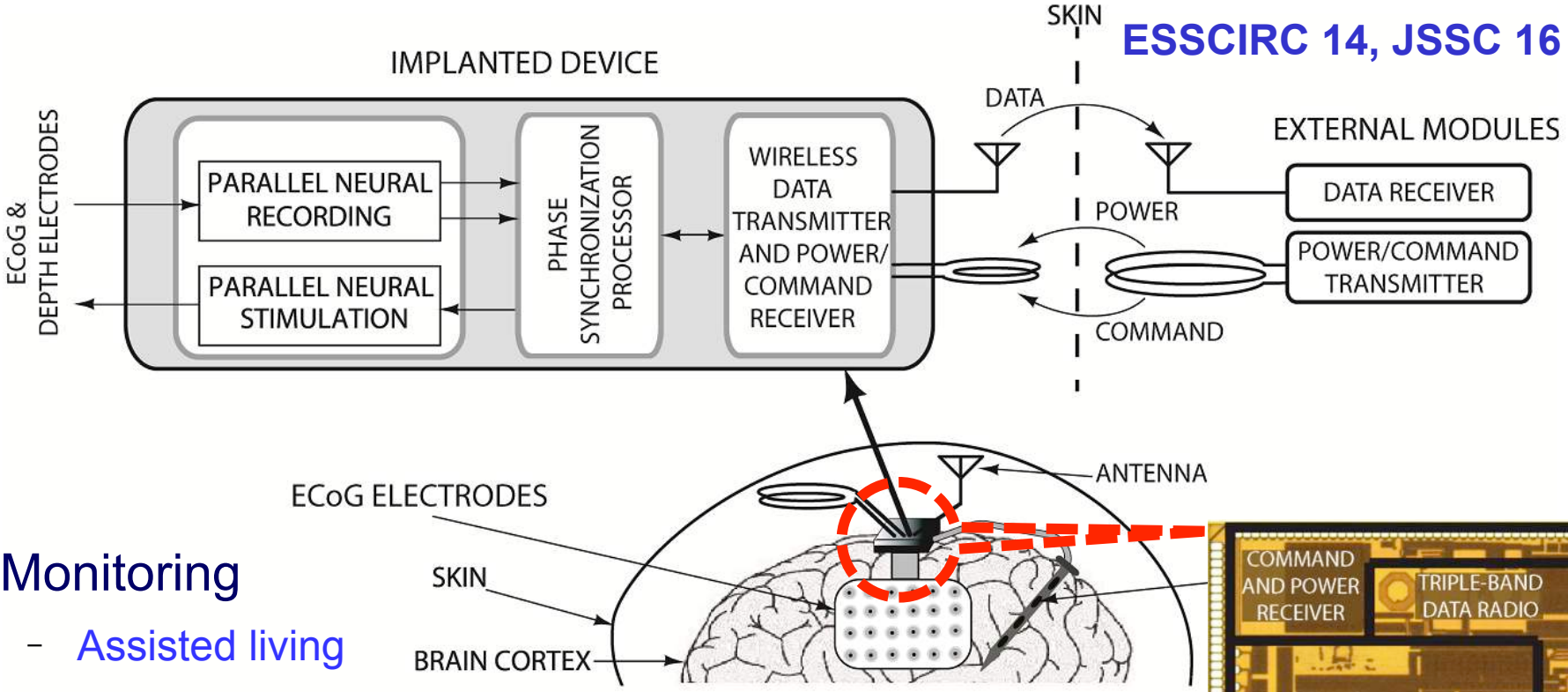
Triple-band TX

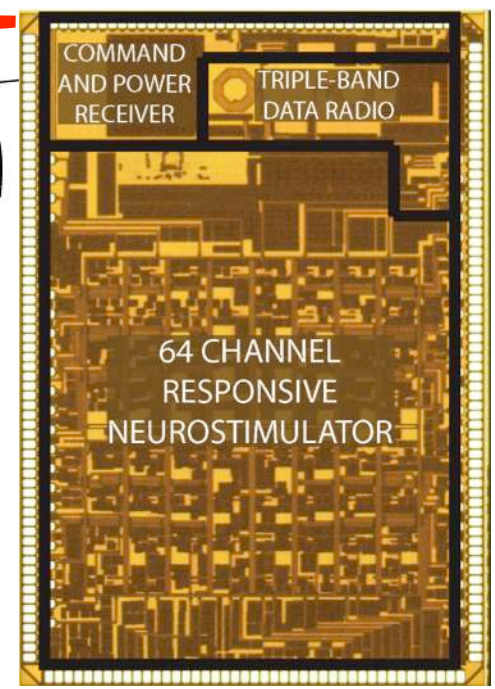
Seizure detection & control

Phase synchrony features

Closed-Loop Neurostimulation

ESSCIRC 14, JSSC 16

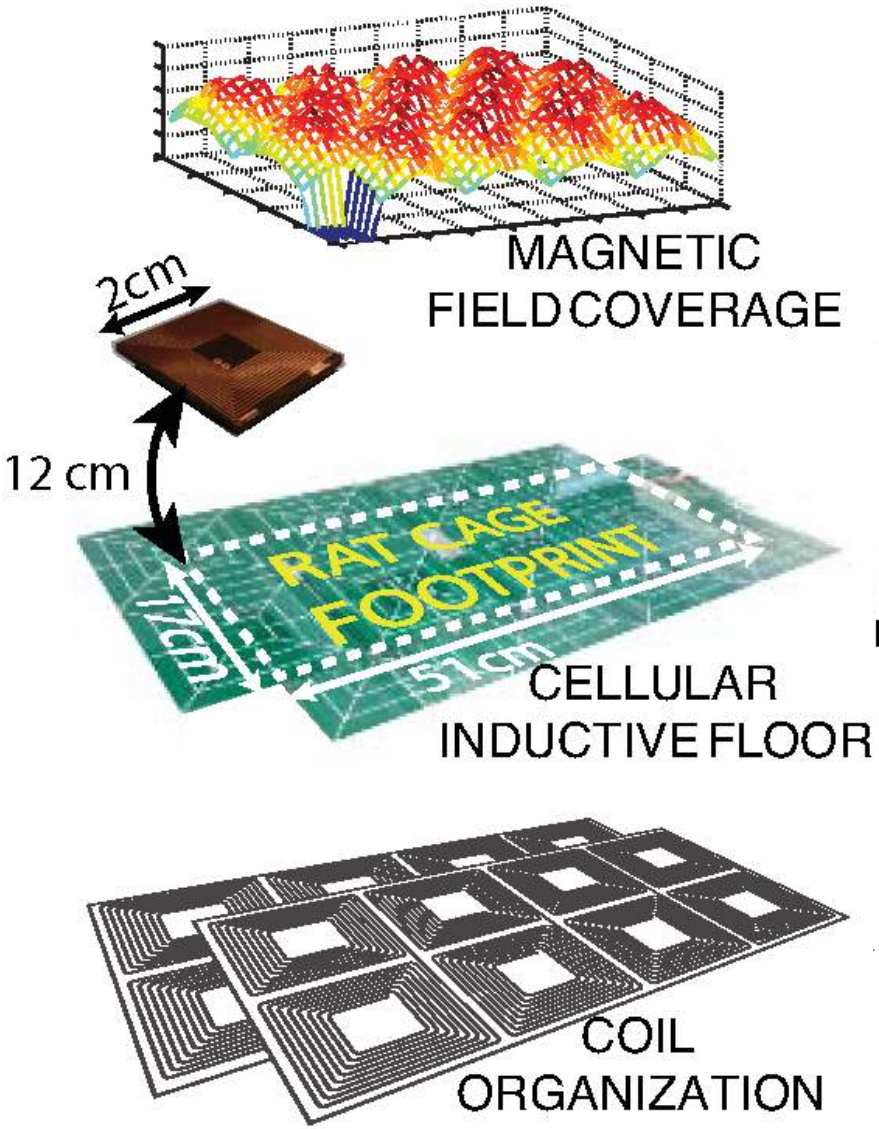


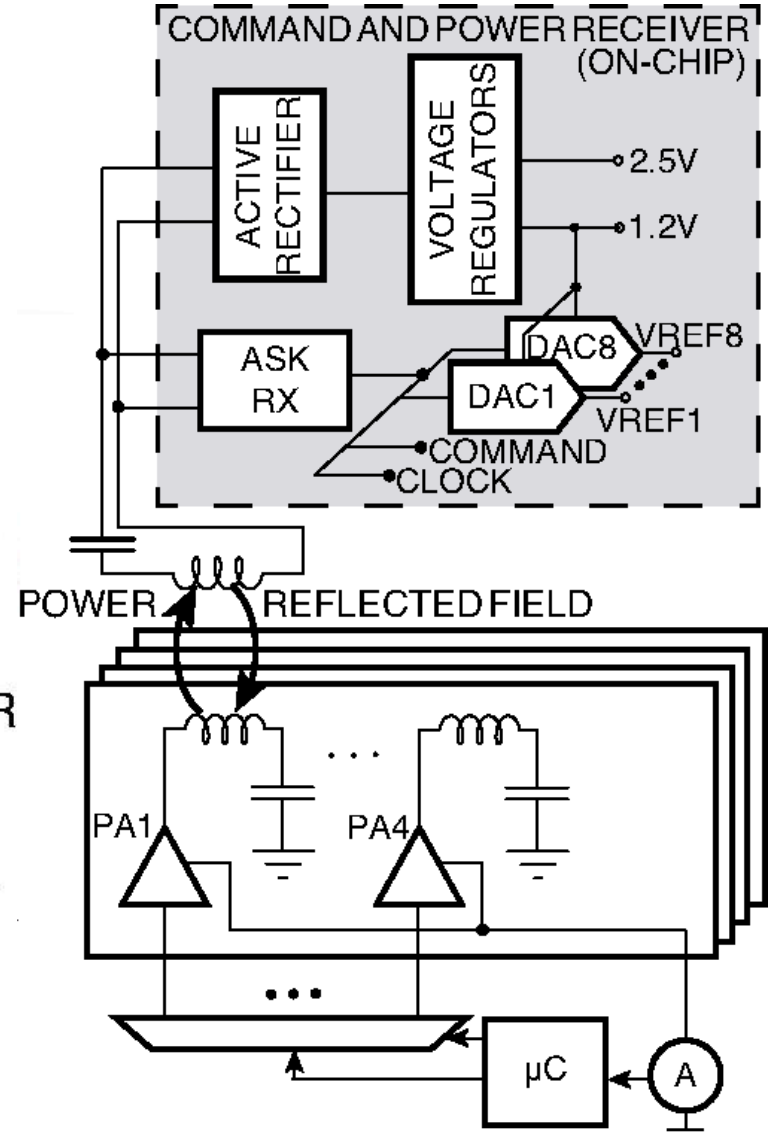


- Monitoring
  - Assisted living
    - e.g., in ALS
- Diagnostics
  - Wireless monitoring
    - e.g., preoperative epileptic seizure localization
- Treatment
  - *Automated (closed-loop) control*
    - e.g., *intractable epilepsy* → seizure abortion

Cellular Inductive Powering

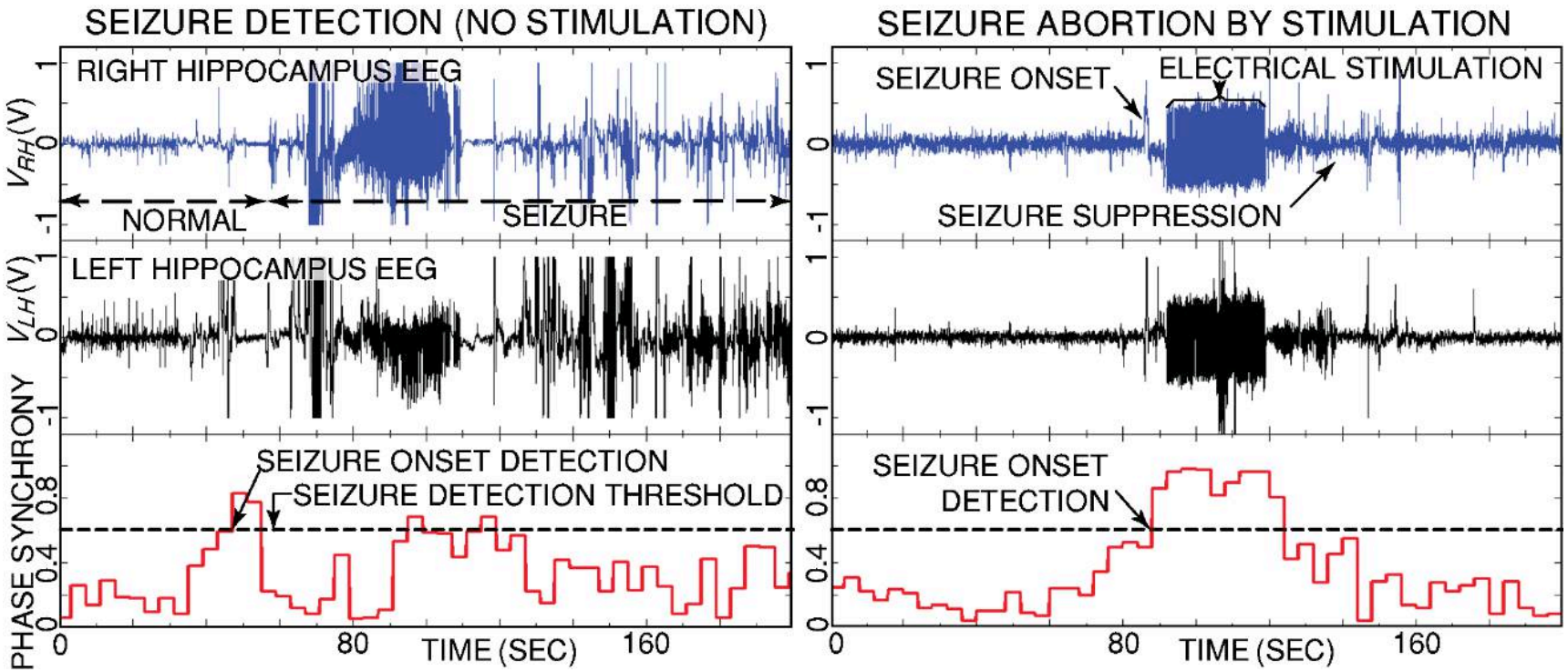
BioCAS 13, TBioCAS 16





Seizure Control Example

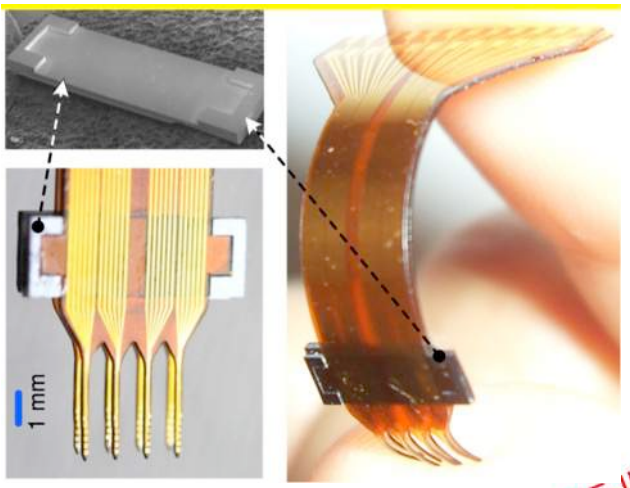
with Tariq Salam and J L Perez Velazquez, Epilepsia 2015



- ~ 5 seizures per day
- 500 seizures
- Detection sensitivity = 89%
- False alarm = 0.24 per day

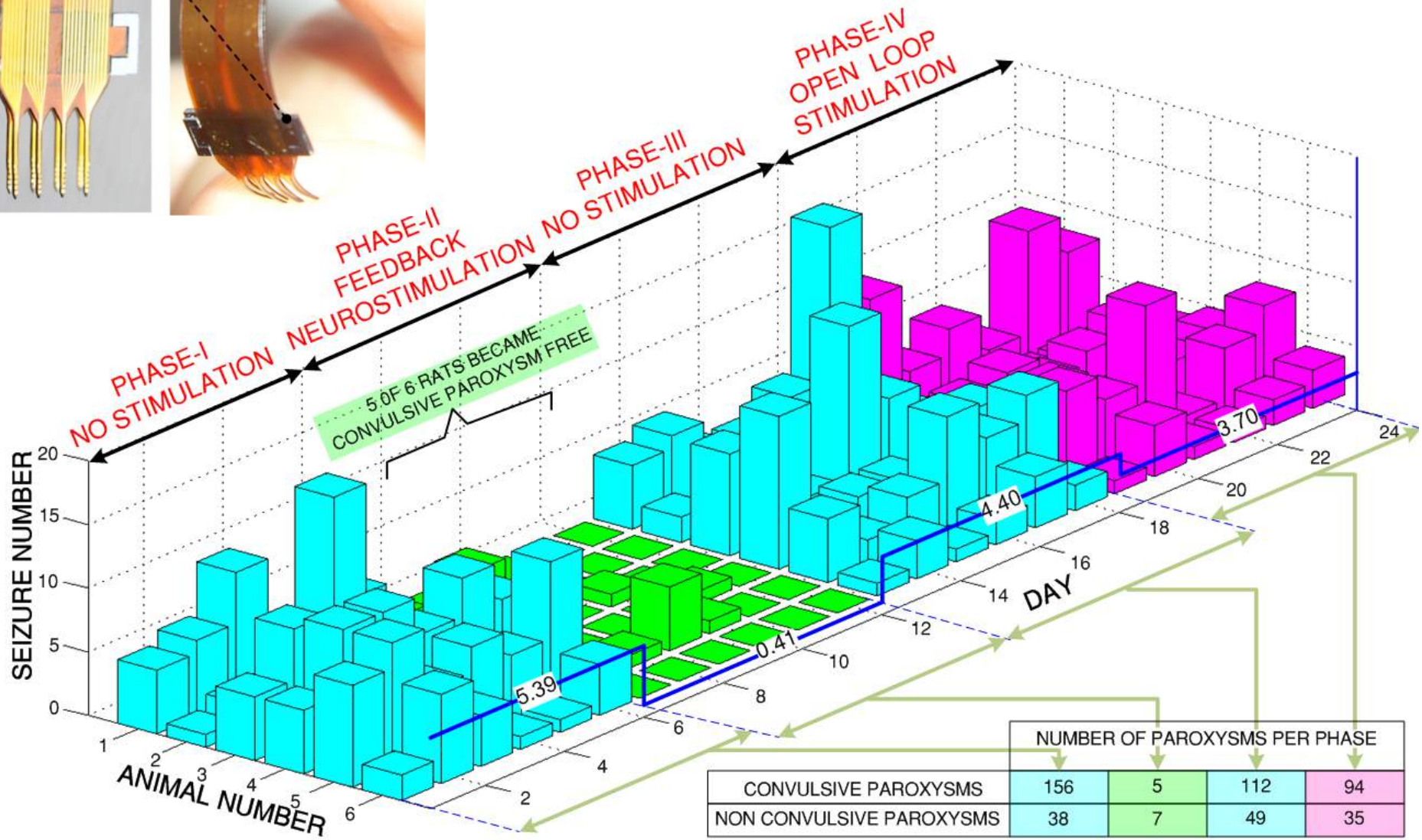
- 5 of 6 animals became seizure free
- No adverse effect
- **~93% seizure reduction**

3,500-hour Seizure Control Statistics



with T. Salam, J L Perez Velazquez, Epilepsia 2015
with S. Gabran and R. Mansour, TNSRE 2013-14

- 24/7 chronic video monitoring and treatment



	NUMBER OF PAROXYSMS PER PHASE			
CONVULSIVE PAROXYSMS	156	5	112	94
NON CONVULSIVE PAROXYSMS	38	7	49	35

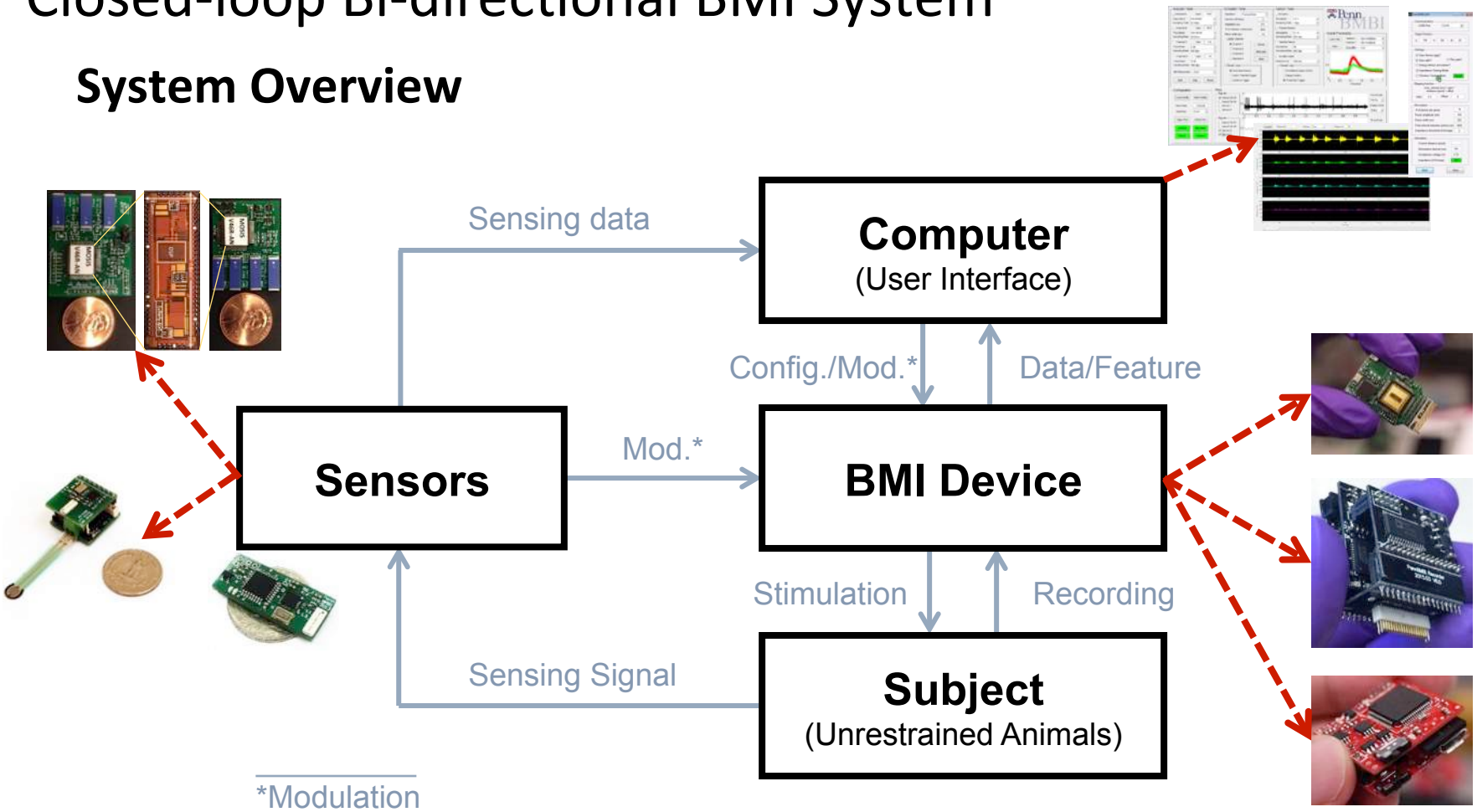
Penn Engineering and School of Medicine

Xilin Liu, Milin Zhang, Timothy Lucas, Drew Richardson and Jan Van der Spiegel

Penn Engineering

Jan Van der Spiegel University of Pennsylvania
Closed-loop Bi-directional BMI System

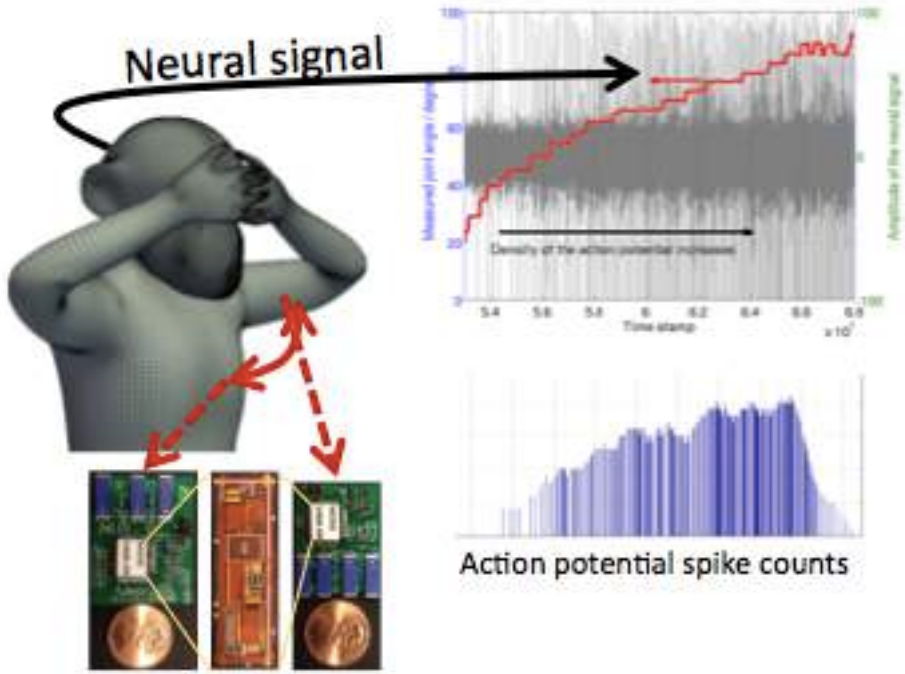
System Overview



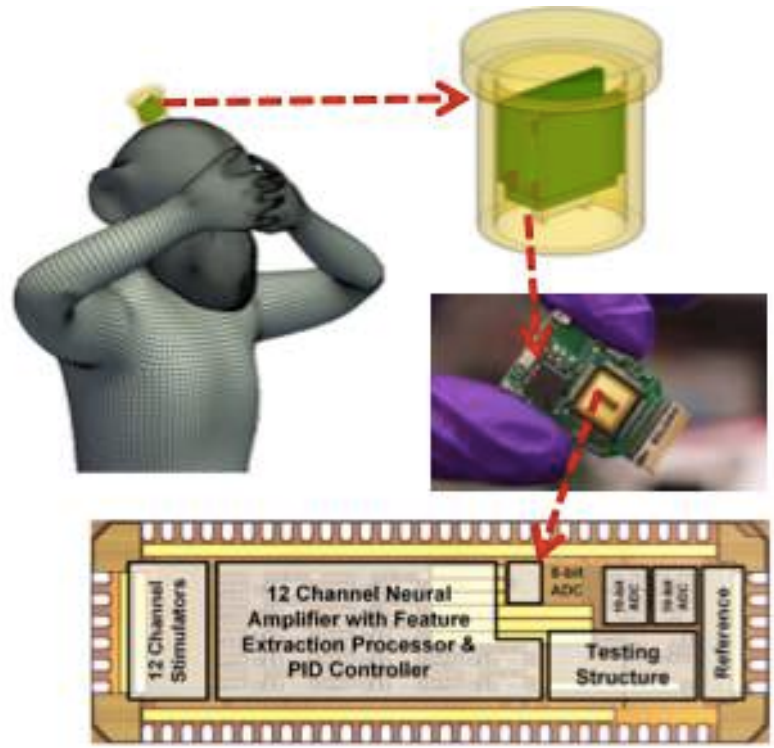
Penn Engineering

[Xilin Liu, et al., ISCAS 2014 and

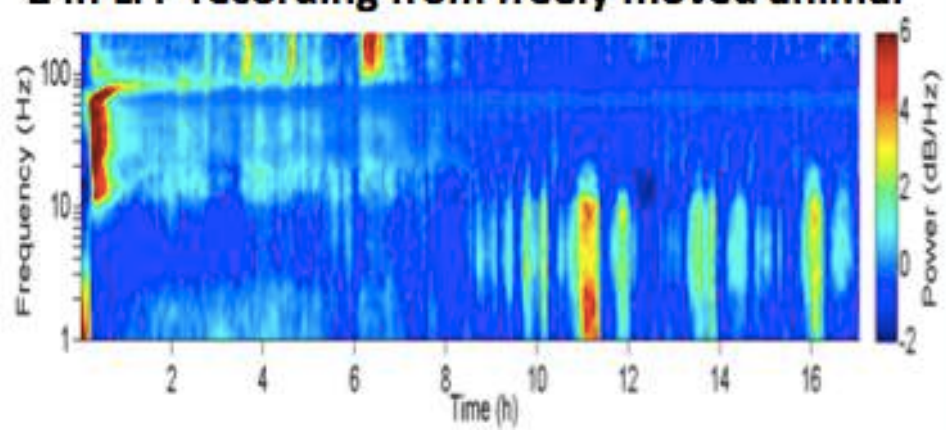
Wireless electrogoniometer



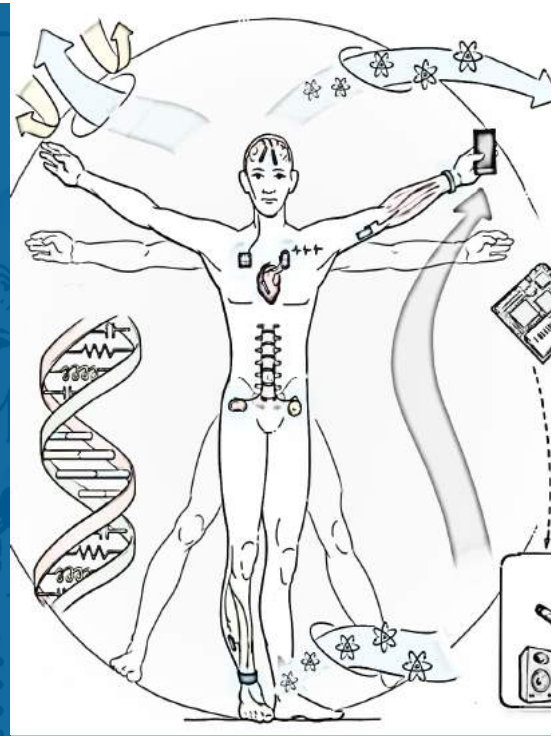
Bidirectional Neural Interface



24h LFP recording from freely moved animal



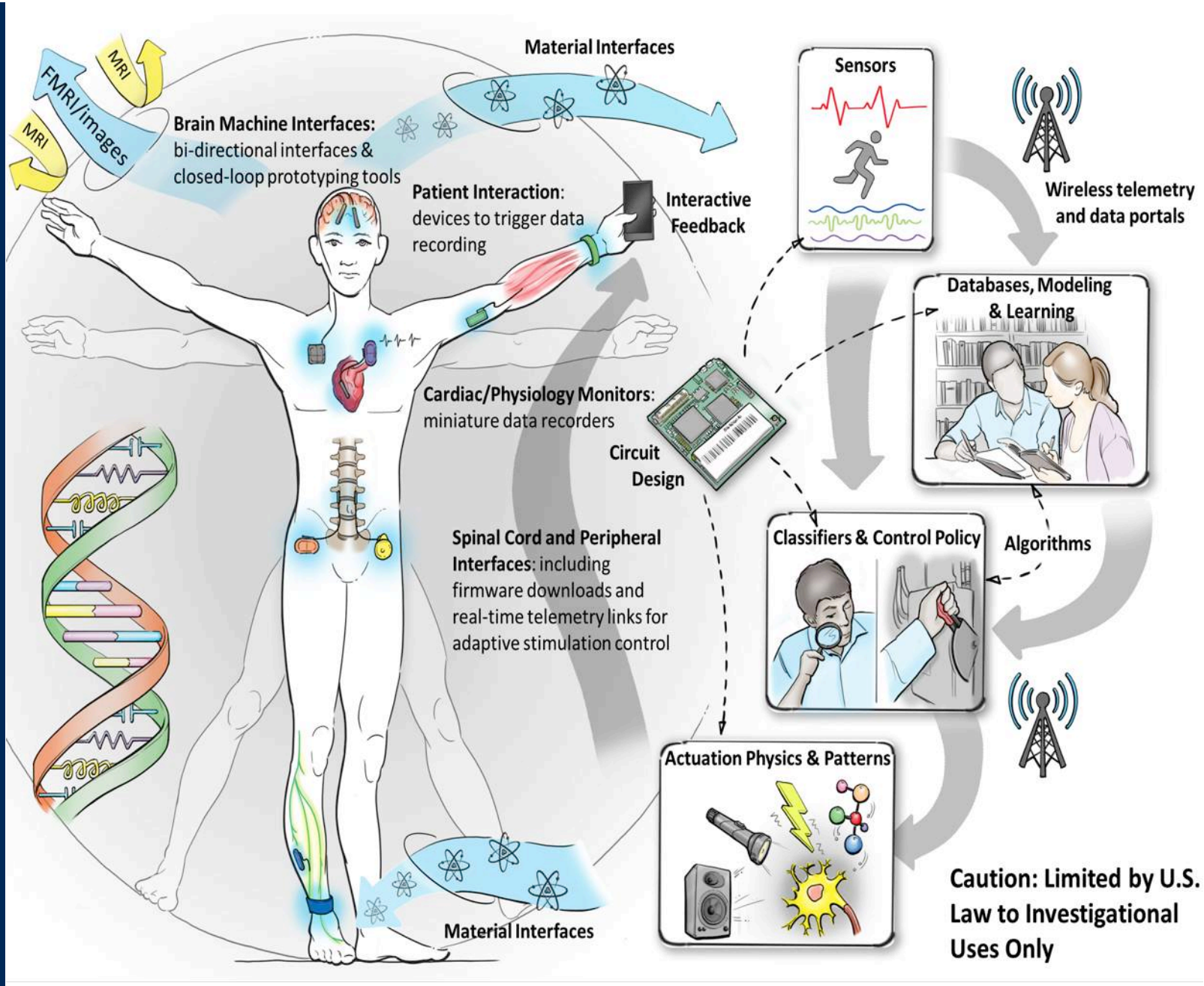
BOOTSTRAPPING CLINICAL NEUROSCIENCE CONSIDERATIONS FOR THE DESIGN AND DEPLOYMENT OF RESEARCH PAYLOADS



TIMOTHY DENISON, PH.D.
TECHNICAL FELLOW
SR. DIRECTOR OF CORE TECHNOLOGY
MEDTRONIC NEUROMODULATION

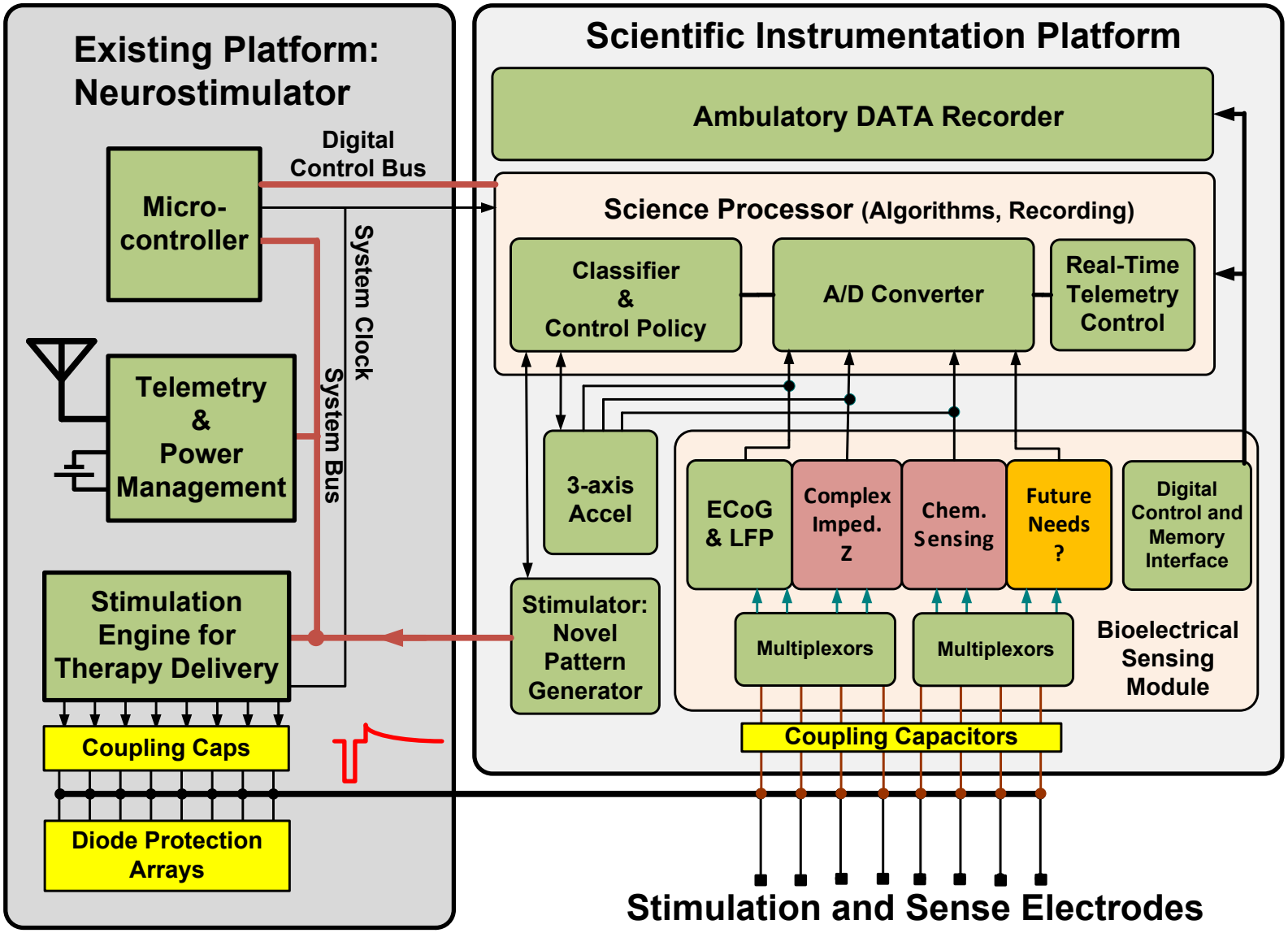
Medtronic
Further, Together

TOOL CONCEPTS IN SUPPORT OF THE BRAIN INITIATIVE



CONCEPT OF EMBEDDING "SCIENTIFIC PAYLOADS" IN A MEDICAL DEVICE

PROBE "TRANSFER FUNCTIONS" OF NEURAL NETWORKS AND APPLY TO ALGORITHMS

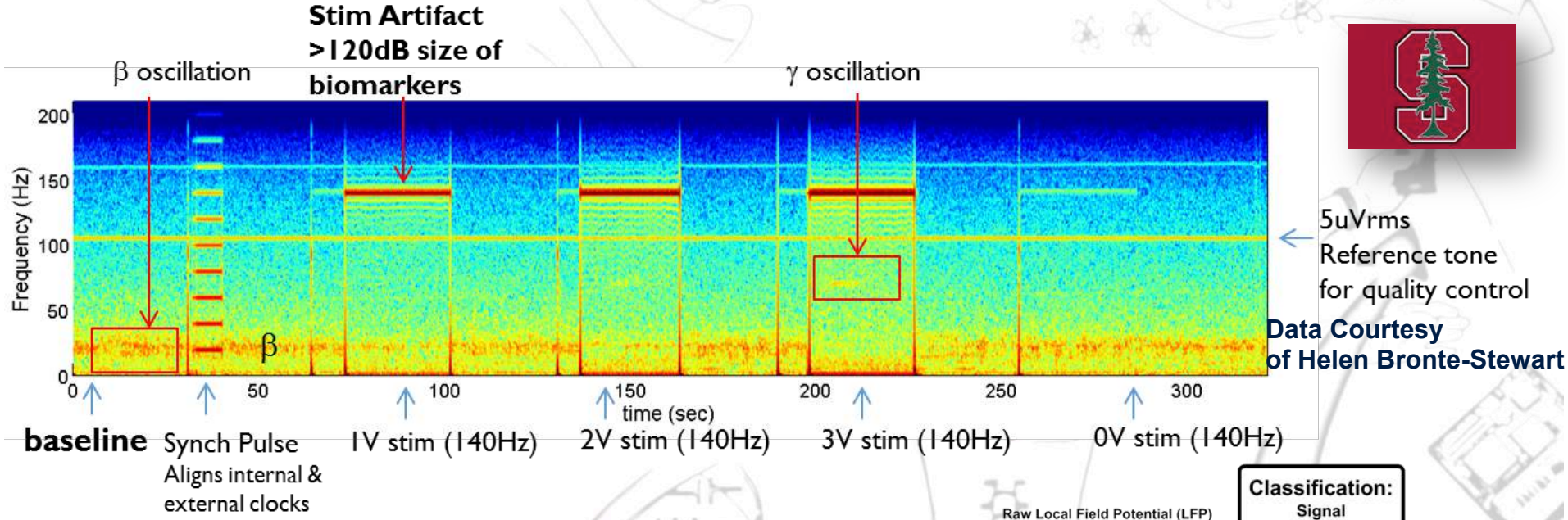


Stanslaski et al., IEEE Neural Engineering, 2011

Rouse et al, Journal of Neural Engineering, 2011

NEURAL CIRCUIT TRANSFER FUNCTION AND ALGORITHM EXAMPLE

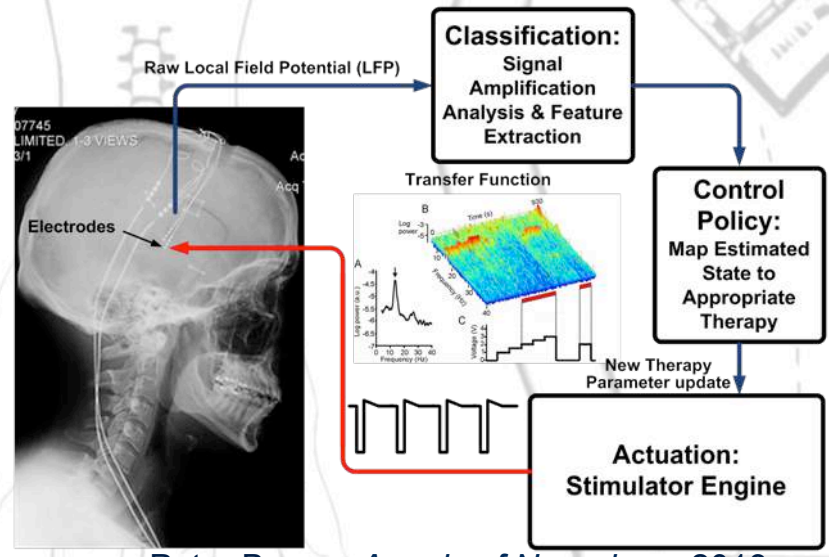
PARKINSON'S PATIENT'S RESPONSE TO ELEC. STIMULATION (CHRONIC W/ ACTIVA PC+S)



Data Courtesy of Helen Bronte-Stewart

INSTRUMENTATION PAYLOAD CONSIDERATIONS

- Sensing ~1uVrms signals during stimulation (~120dB)
- Ensuring signals are not saturating (robust algorithms)
- Synchronization of instruments (implanted/lab clocks)
- Clinician correlation with symptoms
  - Define the key biomarkers
  - Define transfer function
  - Map to a closed loop algorithm

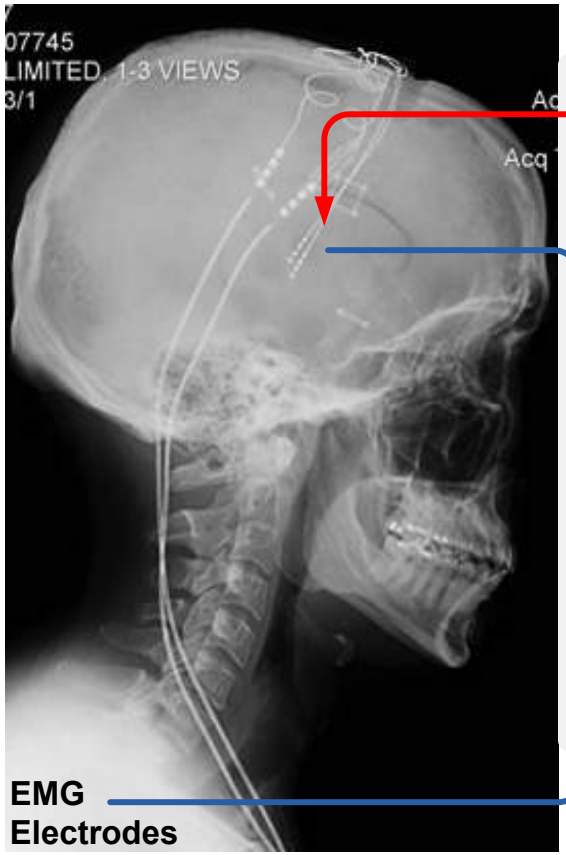


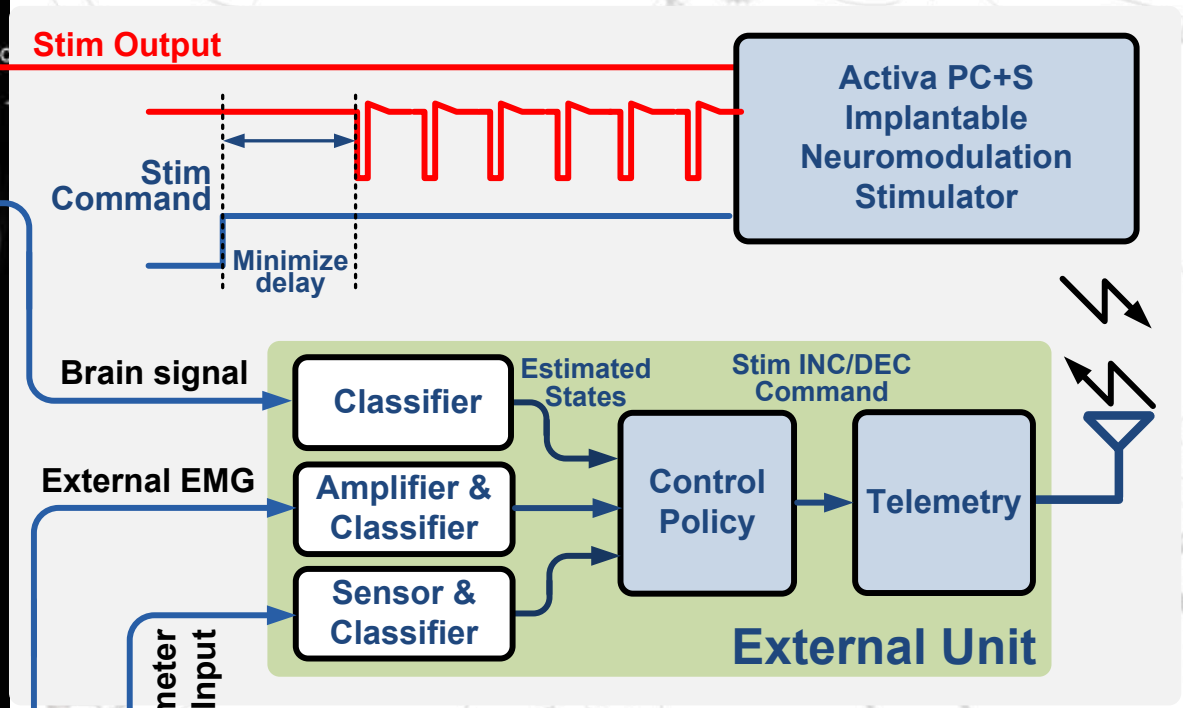
Peter Brown. *Annals of Neurology*. 2013.

Quinn et al, Beta Oscillations in Freely Moving Parkinson's Subjects Are Attenuated During Deep Brain Stimulation, Movement Disorders, 2015

NEED FOR TOOLS FOR ITERATIVE ALGORITHM DEVELOPMENT

COMPUTERS-IN-THE-LOOP/CLINIC → EMBEDDED ARCHITECTURES





frontiers in NEURAL CIRCUITS

METHODS ARTICLE
published: 22 January 2013
doi: 10.3389/fncir.2012.00117

A translational platform for prototyping closed-loop neuromodulation systems

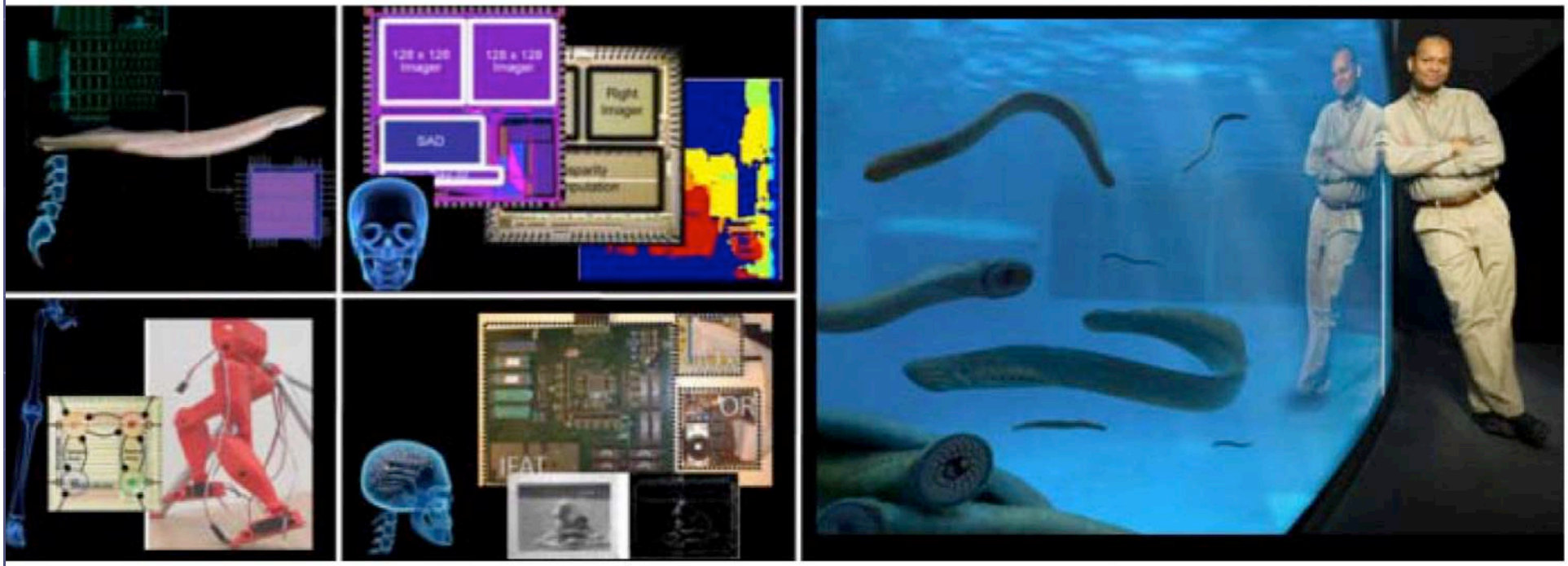
Pedram Afshar*, Ankit Khambhati, Scott Stanslaski, David Carlson, Randy Jensen, Dave Linde, Siddharth Dani, Maciej Lazarewicz, Peng Cong, Jon Giftakis, Paul Stypulkowski and Tim Denison*

Integrated Circuits Interfacing with the Brain

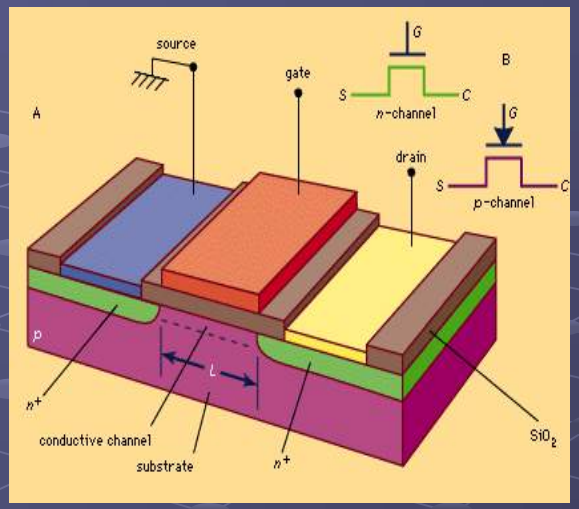
- Neural recording and neural stimulation
  - Both invasive and non-invasive
  - Recording: electrical, chemical, and optical
  - Stimulation: optical stimulation/optogenetics, current/charge-mode
- Closed-loop neural interfaces
  - Responsive neurostimulators (epilepsy), neurotransmitters control
- Neuronal modeling
  - Silicon neurons, spiking neural networks
- Other related topics (not discussed)
  - Wireless communications (transcutaneous)
  - Wireless powering (inductive, ultrasound)
  - Signal/information processing
  - In vivo applications (animal studies, clinical, wellness)

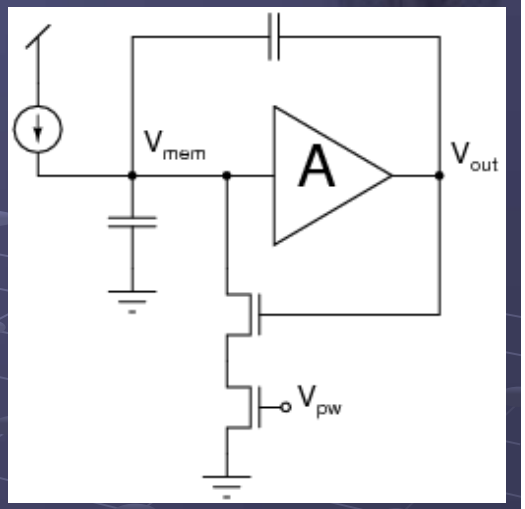
Silicon Models of Neurons

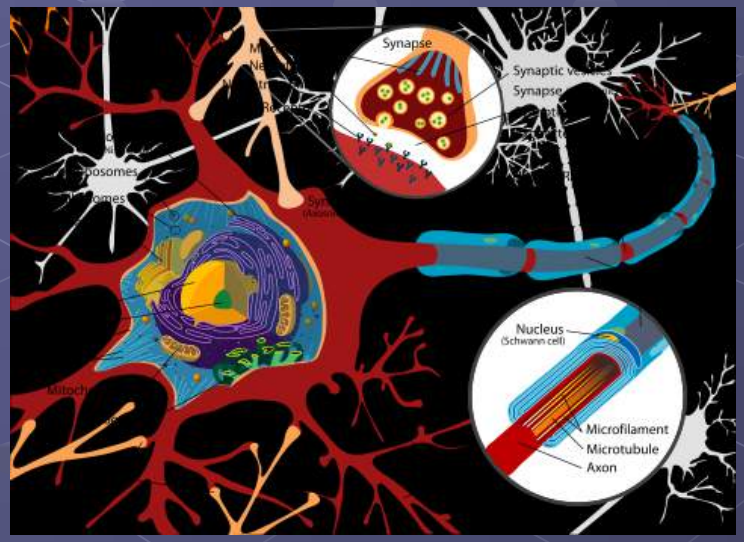
Ralph Etienne-Cummings
Dept. of Electrical and Computer Engineering and Computer Science
Johns Hopkins University

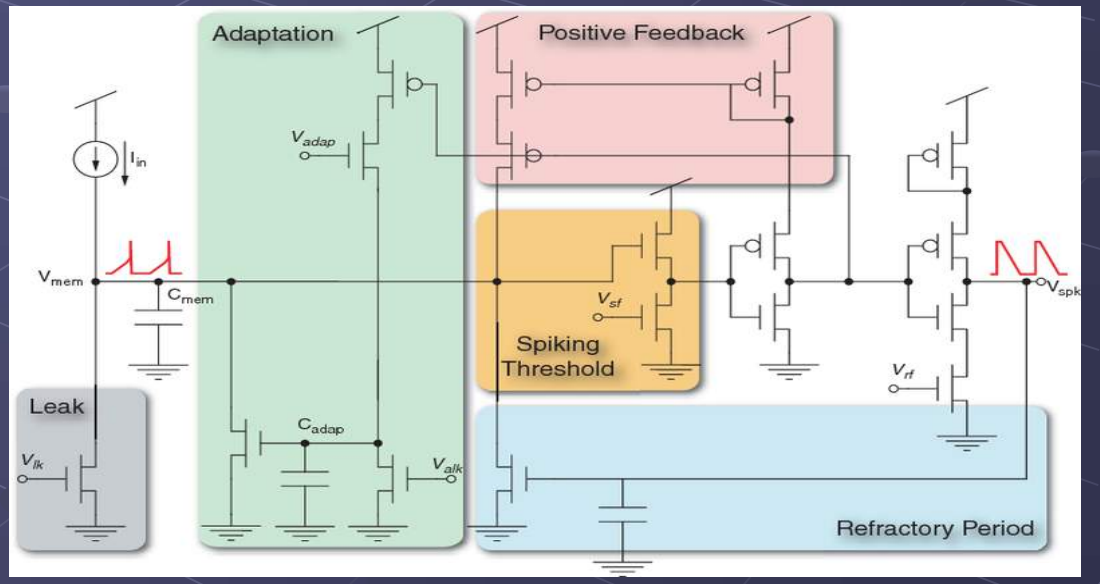


Neuron Models in Silicon









Paul Mueller, Carver Mead, *Neuromorphic Circuits*, 1986 - 1990

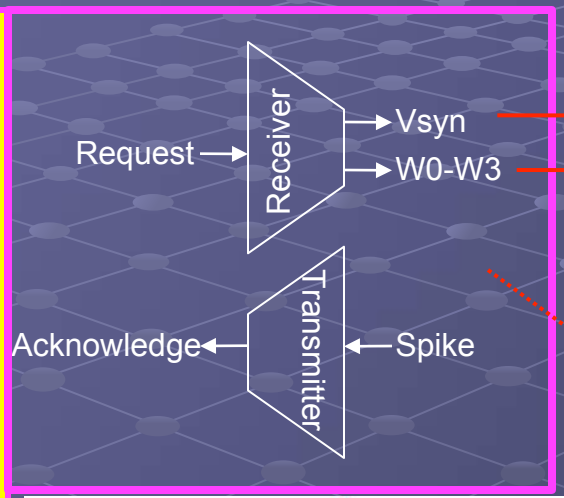
After wikipedia.com

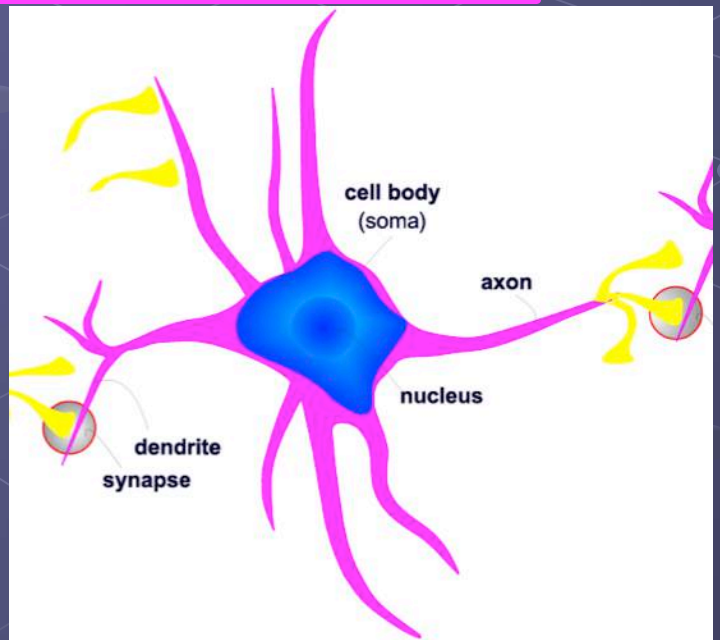
Ralph Etienne-Cummings Johns Hopkins University

Silicon Models of Neurons

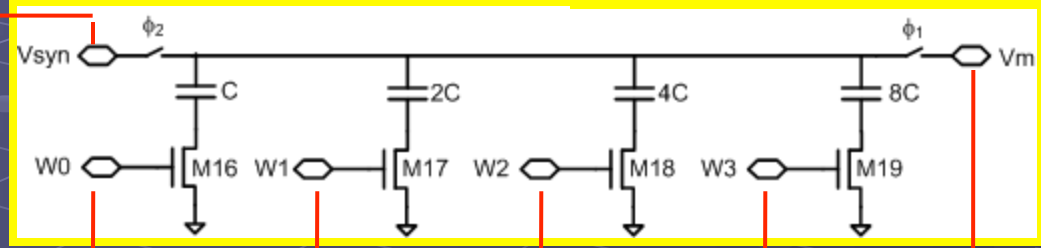
3D CMOS Design

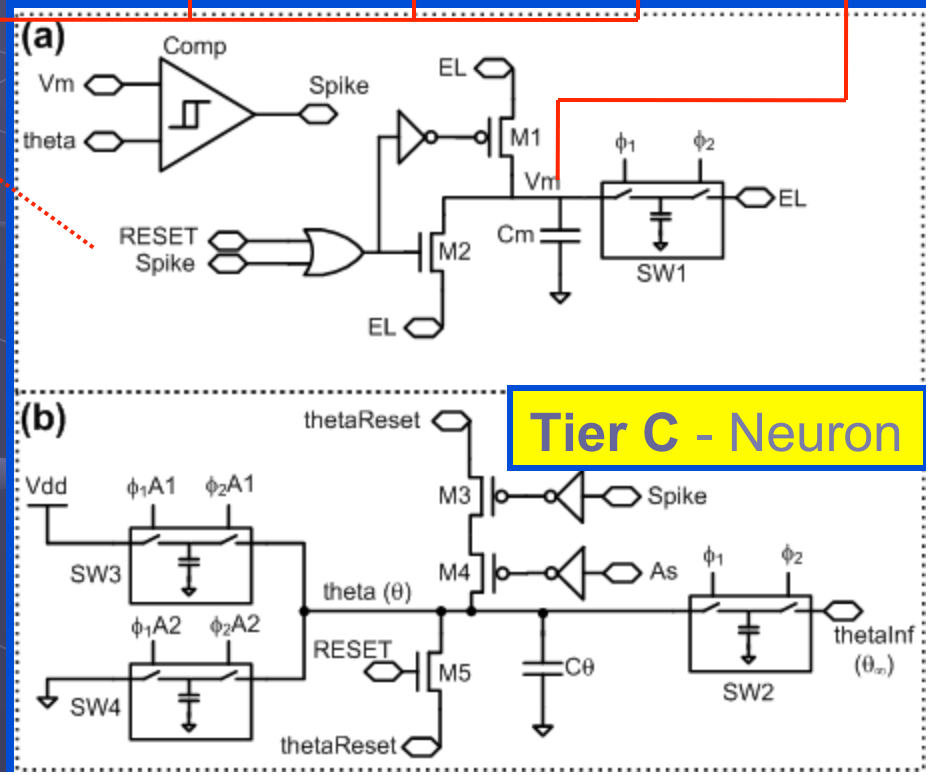
Tier A – Communication





Tier B – Synapse



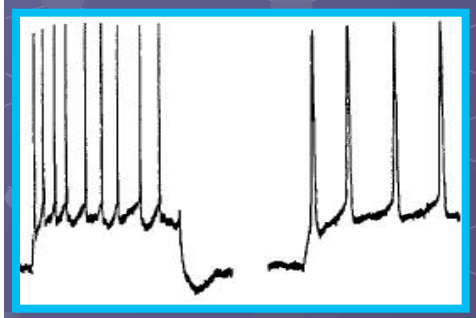
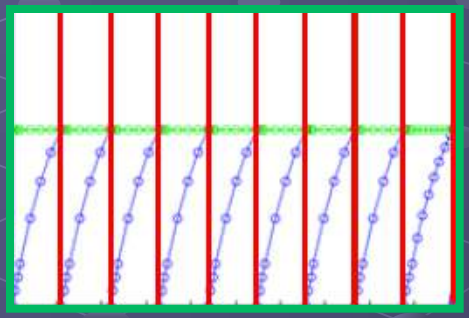
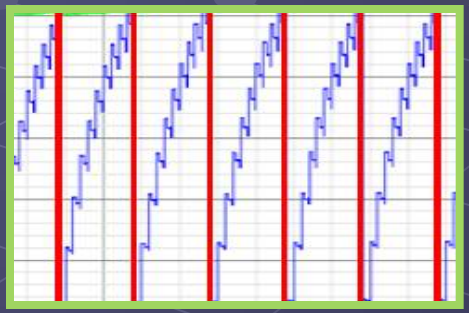
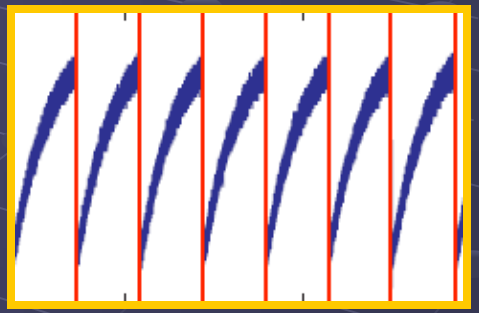


Tier C - Neuron

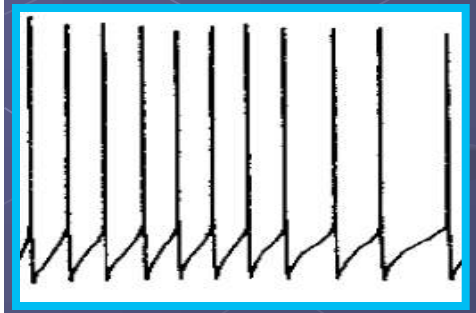
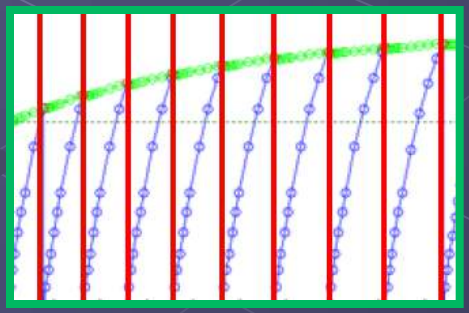
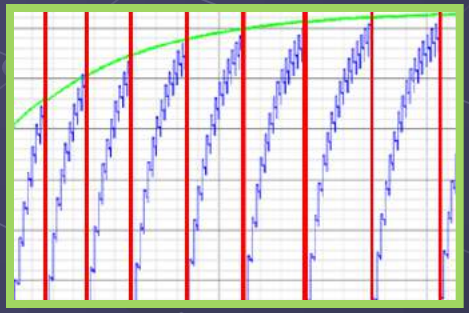
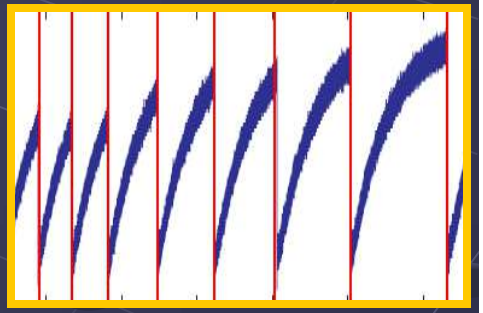
Neuron Design Stages

Neuron in Biology → MatLab Simulations → Cadence Simulations → Neuron on Chip

- Tonic Spiking

- Spike Frequency Adaptation

F. Folowosele et al., *IEEE TNN,* 2011

Integrated Circuits Interfacing with the Brain

- Neural recording and neural stimulation
  - Both invasive and non-invasive
  - Recording: electrical, chemical, and optical
  - Stimulation: optical stimulation/optogenetics, current/charge-mode
- Closed-loop neural interfaces
  - Responsive neurostimulators (epilepsy), neurotransmitters control
- Neuronal modeling
  - Silicon neurons, spiking neural networks
- Other related topics (not discussed)
  - Wireless communications (transcutaneous)
  - Wireless powering (inductive, ultrasound)
  - Signal/information processing
  - In vivo applications (animal studies, clinical, wellness)