The 16th Annual Korea-US Nano Forum @ UCSD
September 23-24, 2019

Implantable Neural Sensors for Brain-Machine Interface

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Introduction

Brain Computer Interfaces in Neural Engineering Point of View

Augmenting Functional Abilities of Human

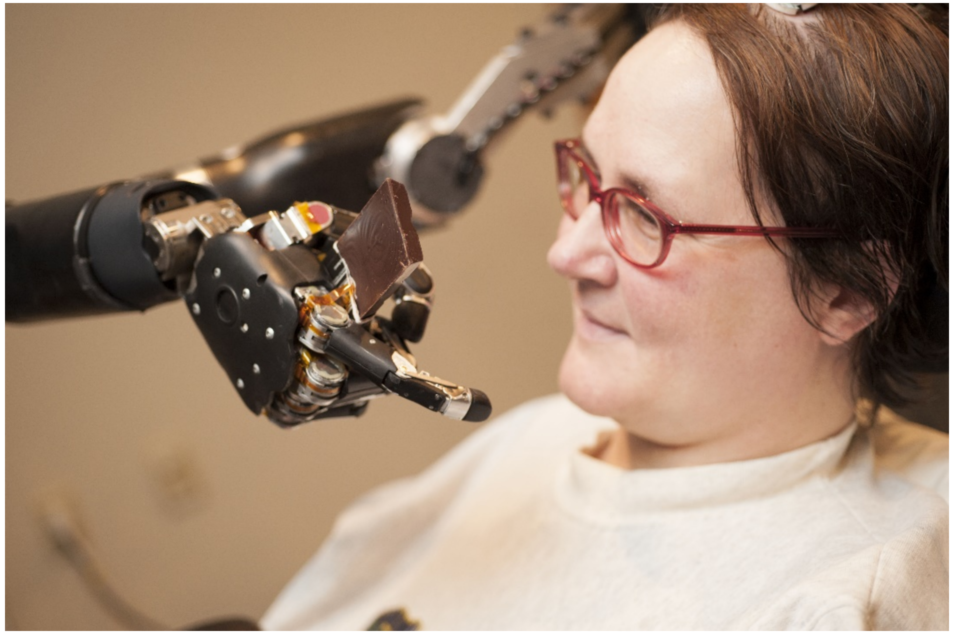
Ghost in the Shell (2017)

We may not be heading the direction in the movies, but they show endless possibilities *through imagination*

Introduction

Maybe not only through imagination, but also through ***scientific and technological advancements***

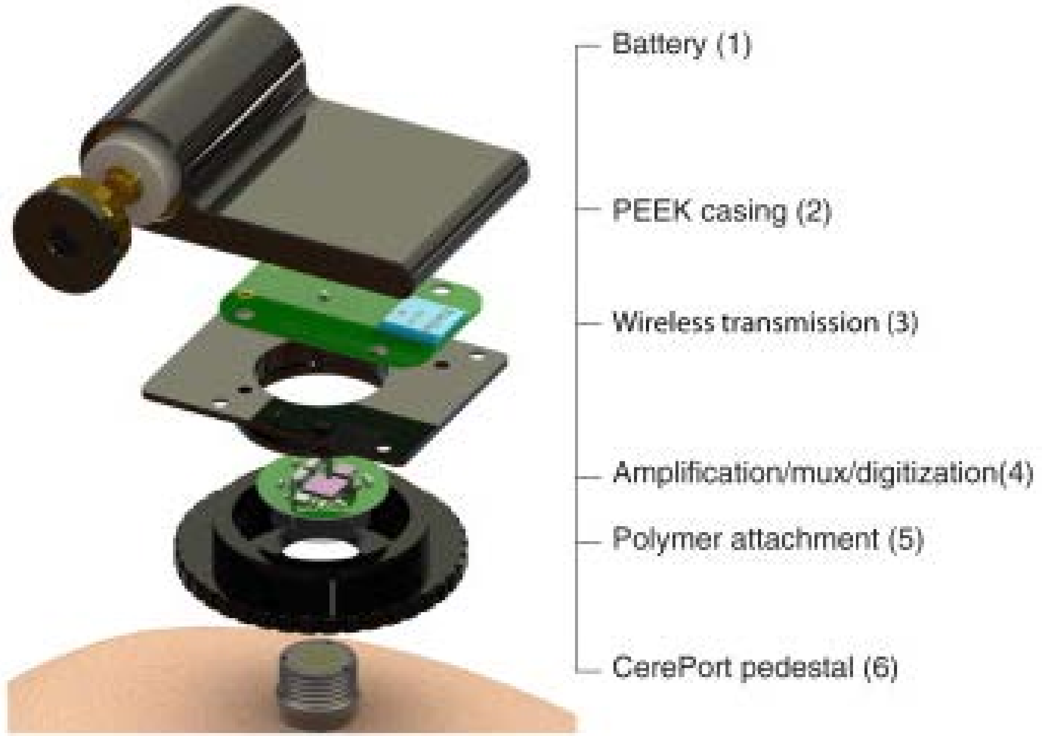
Hochberg et al, *Nature* (2012)

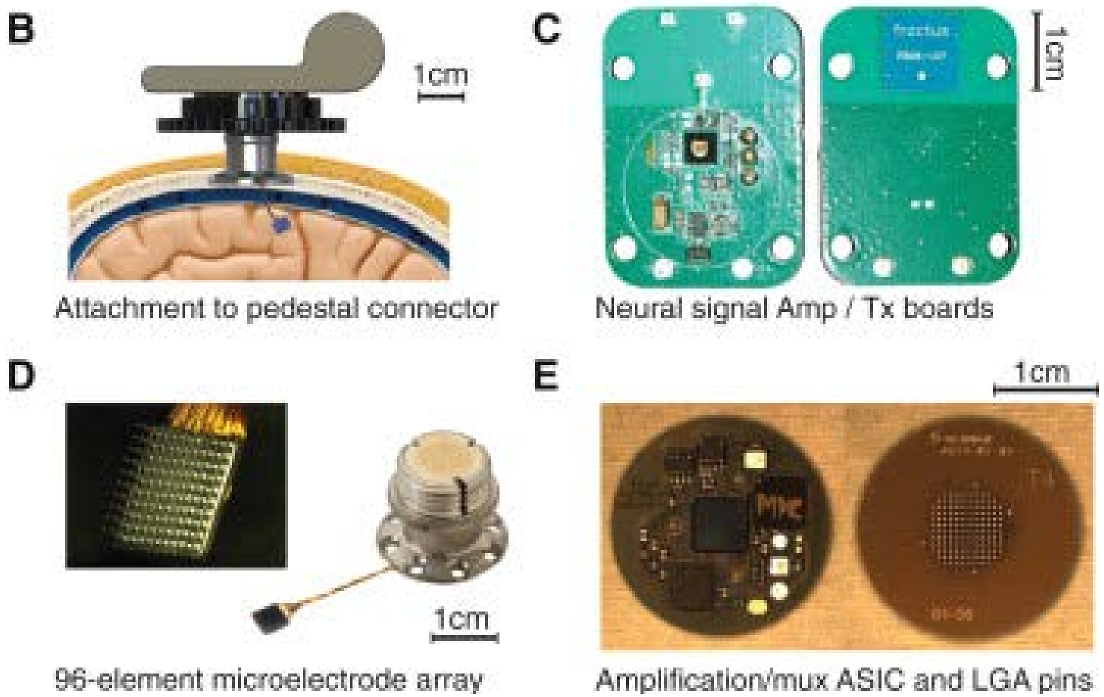


Schwartz et al, *Lancet* (2012)

Possibilities of augmenting human (motor) functions have been shown in prosthetic devices for the people with disabilities – any issue with the present devices/BCI hardware?

Wireless Neural Sensors

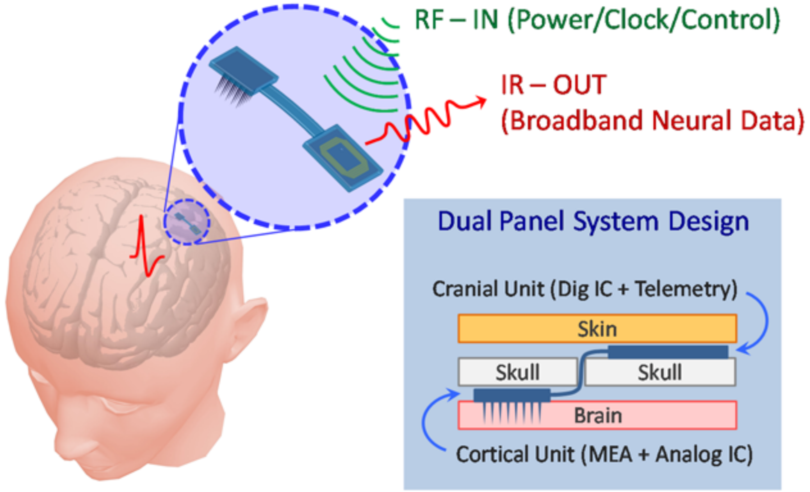


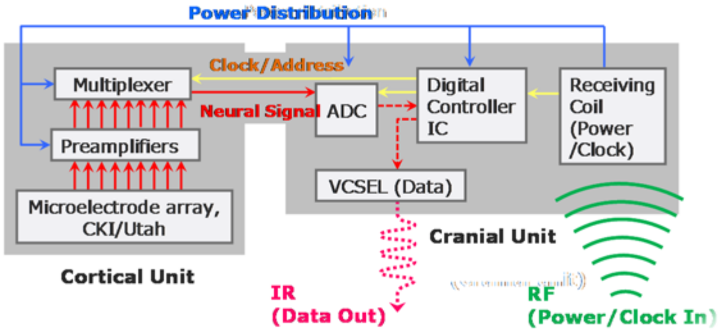


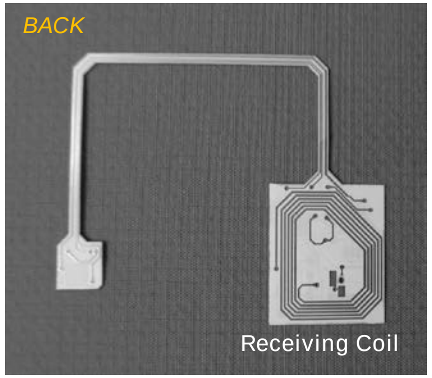
Full spectrum electrophysiology recordings during free behavior (in non-human primates, currently transition to human patients)

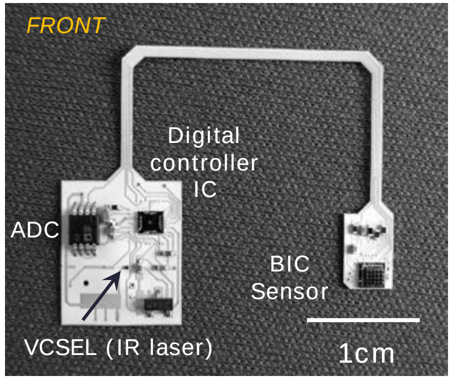
Yin et al, *Neuron* (2014)

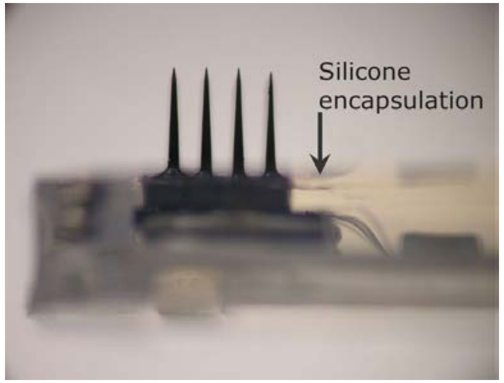
Fully Implantable Neural Sensors

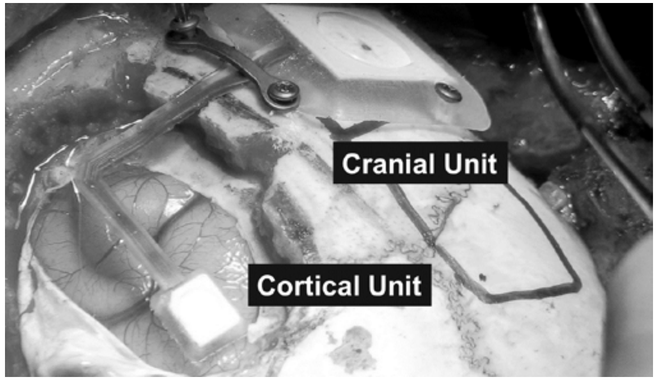


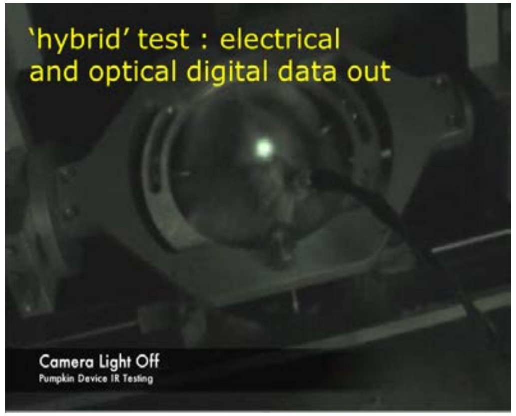






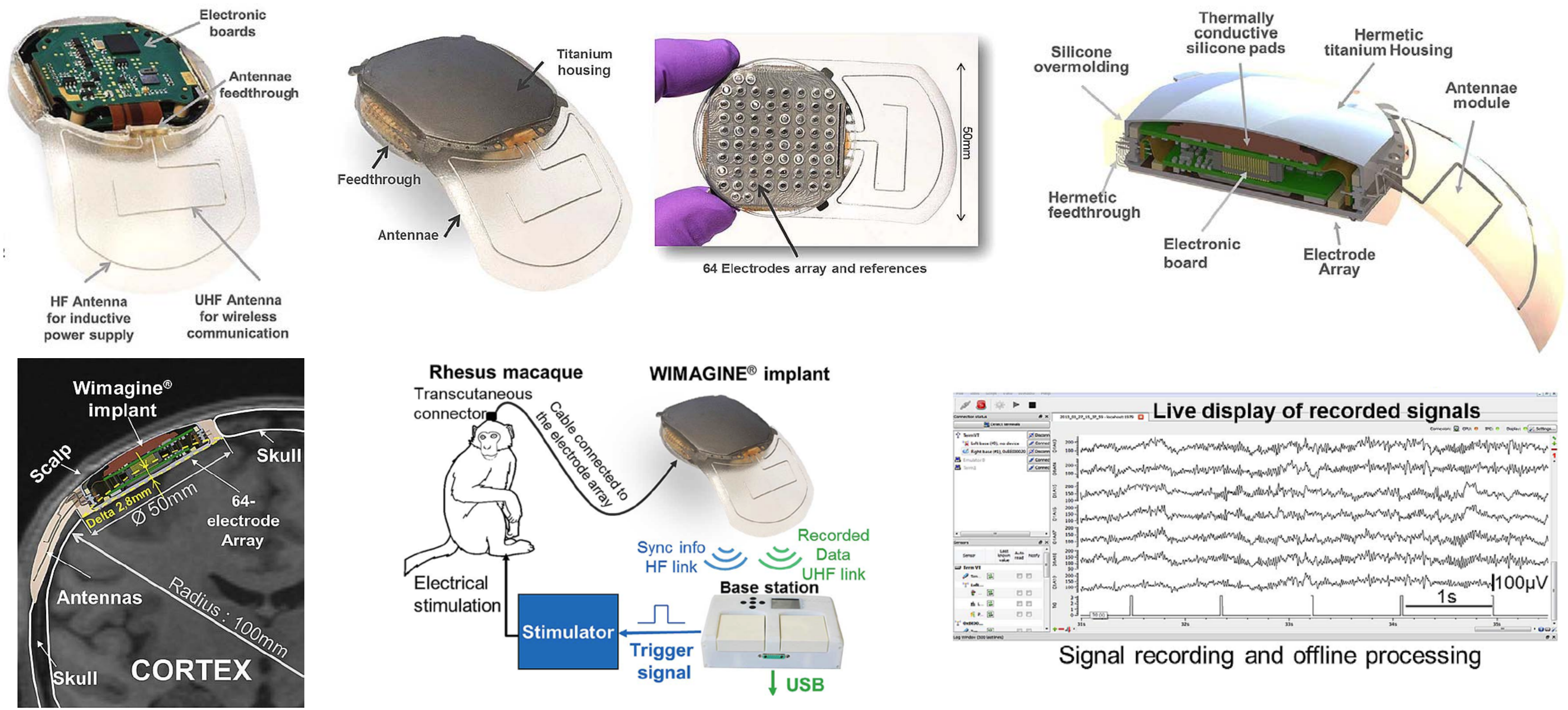






Song et al, *IEEE TNSRE* (2009)

Fully Implantable Neural Sensors



Mestais et al, *IEEE TNSRE* (2014)

Centralized vs. Distributed Neural Sensors

Centralized neural sensors (conventional approach)

- Developed through well-established medical implant platform (pacemaker, DBS, etc.)
- Relatively loose power requirement due to availability of high-power delivery schemes
- Encapsulation options: highly reliable Titanium hermetic sealing available
- Fully implantable system without external radio (at least no head-mount interface)
- Issues with *Scalability and Flexibility*

Centralized vs. Distributed Neural Sensors

Distributed neural sensors (high risk and “hopefully” high return approach)

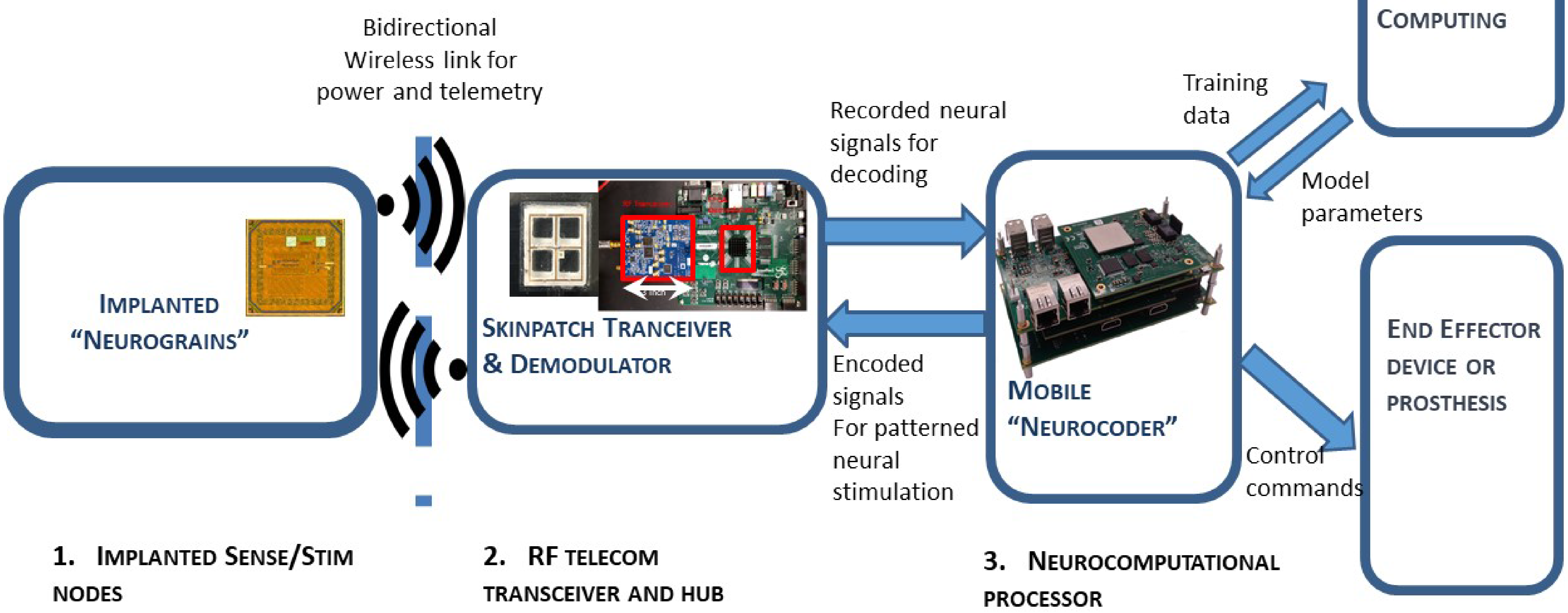
- Developed on the basis of system on chip (SoC) technology
- *Scalable* multi-channel network implemented via RF communication protocols
- Physically uncorrelated/non-regular individual channels enable *highly flexible* implementation
- Extremely tight power requirement (depending on the size)
- Limited encapsulation options (polymer, ceramic)
- Requires external units (e.g. head-mount radio transceiver)

Design Features of "Neurograins" *– 1.5 Years of Prelim Work*

- *Submillimeter sensor/stim nodes: Neurograins*
- Distributed system (currently epicortical)
- Very large number of nodes: 1,000 ~ 10,000
- Wireless power and telemetry
- Networking
- Adaptive selection from sub-population of sensors
- Plan for further scaling and miniaturization of intracortical implantable neurograins

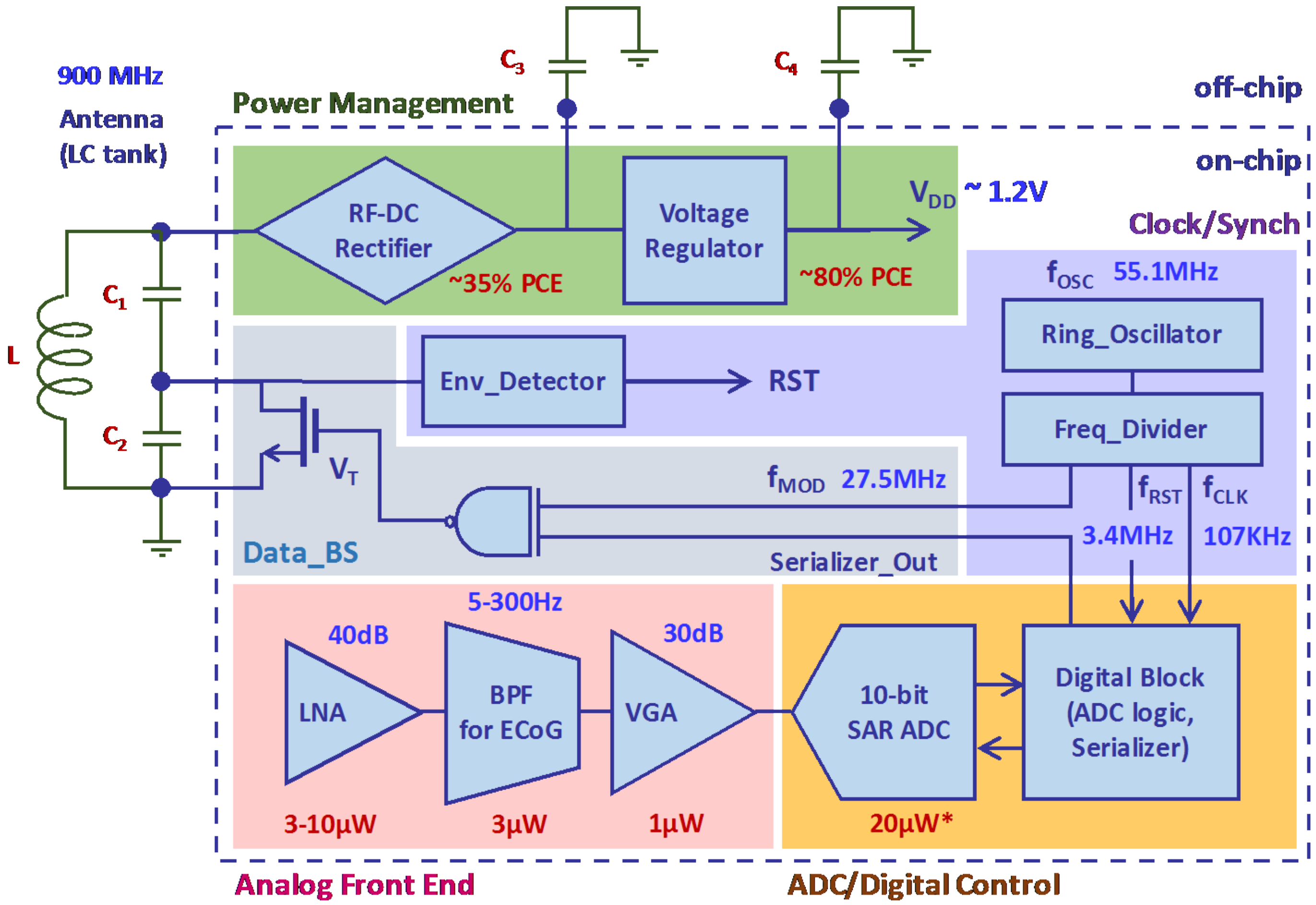
System Level Overview

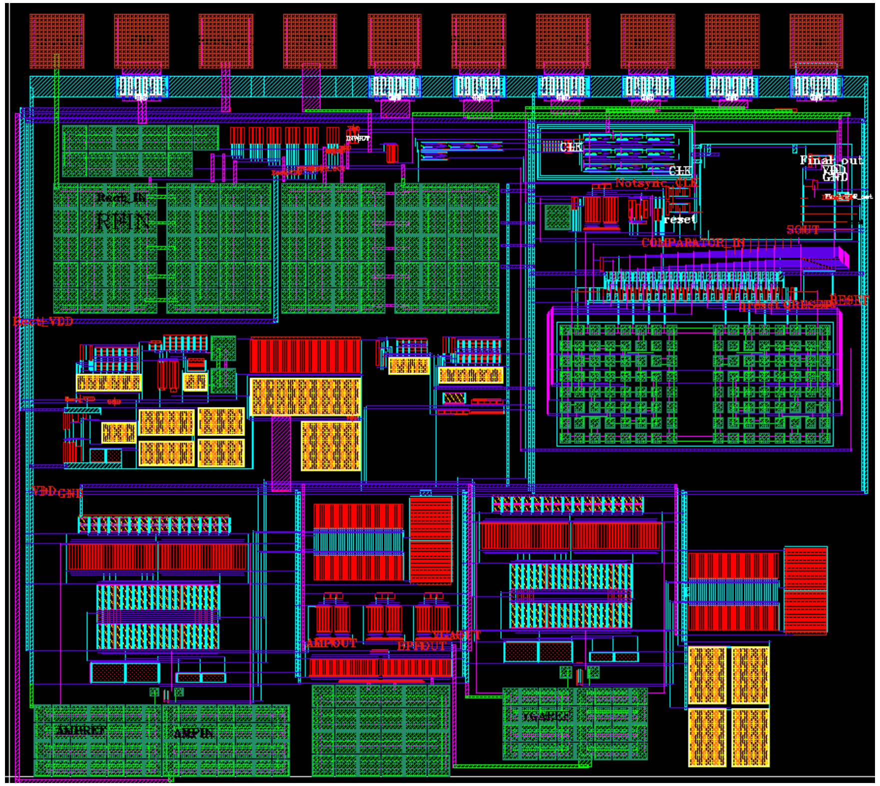
Neurograin System



Neurograin Microelectronics – Ultra Low Power, Ultra Compac t

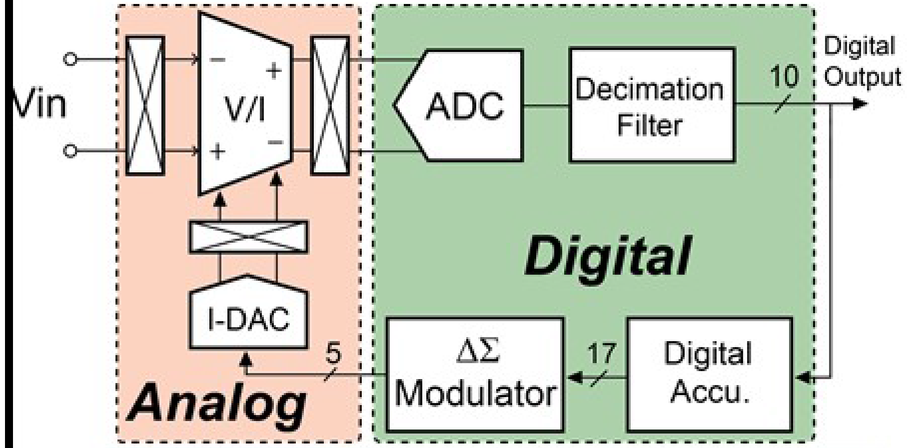
General Architecture of Neurograin SoC (Sensor)





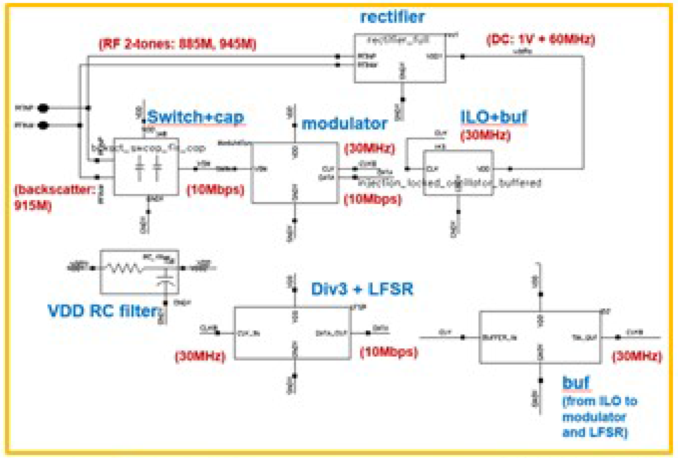
Neurograin Microelectronics (in Collaboration with UCSD)

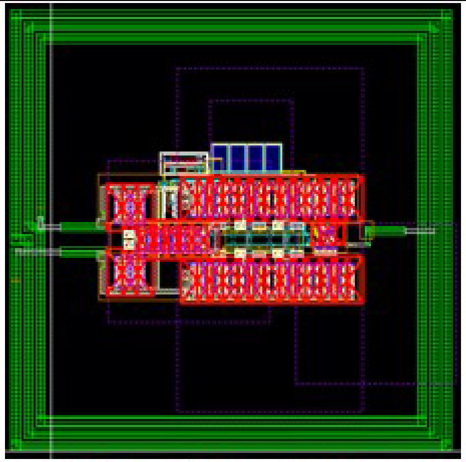
DC- coupled Analog Front End

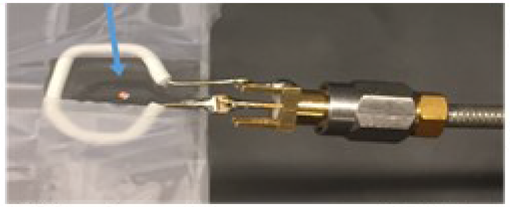


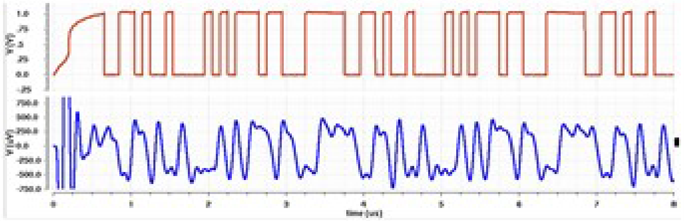
Power	3.18μW
Area	**0.01 mm²**
Input Impedance	700MΩ
Offset Cancellation	+/- 50mV
Bandwidth	0.1Hz to 500Hz
Noise	1.6μV

Ultra low-noise low power signal amplification

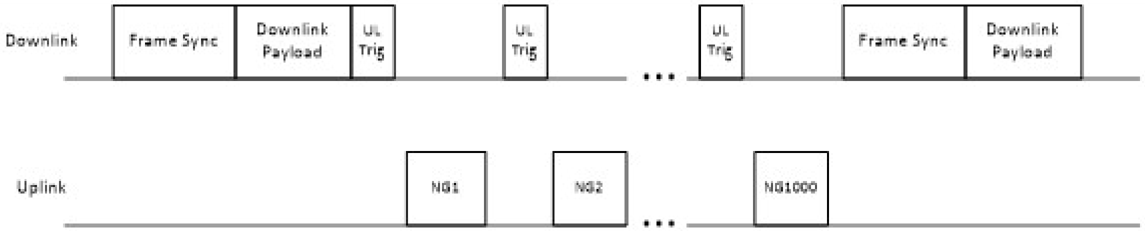








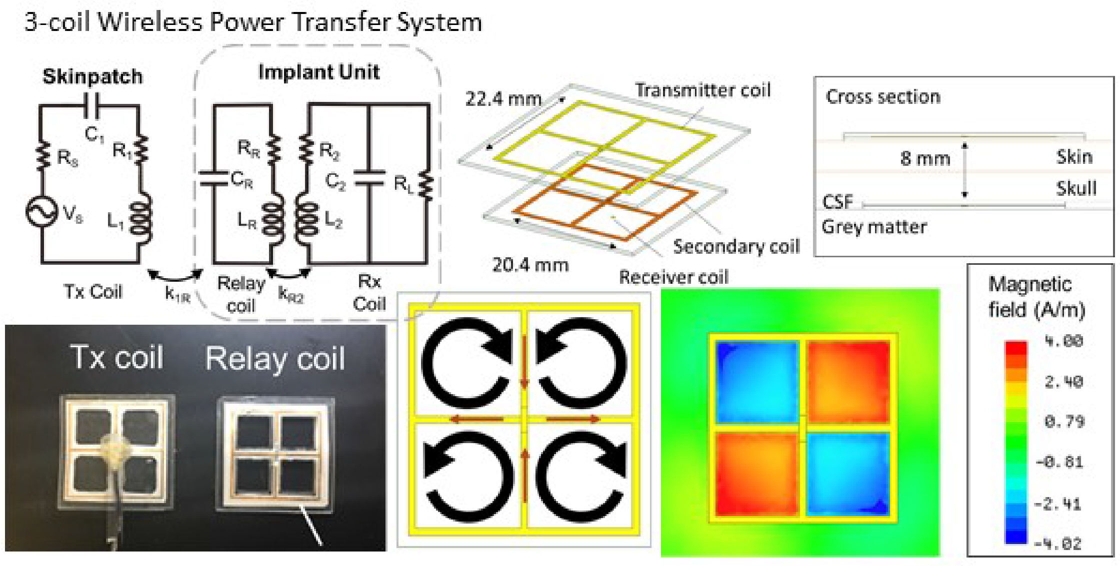
Wireless Power and Telemetry



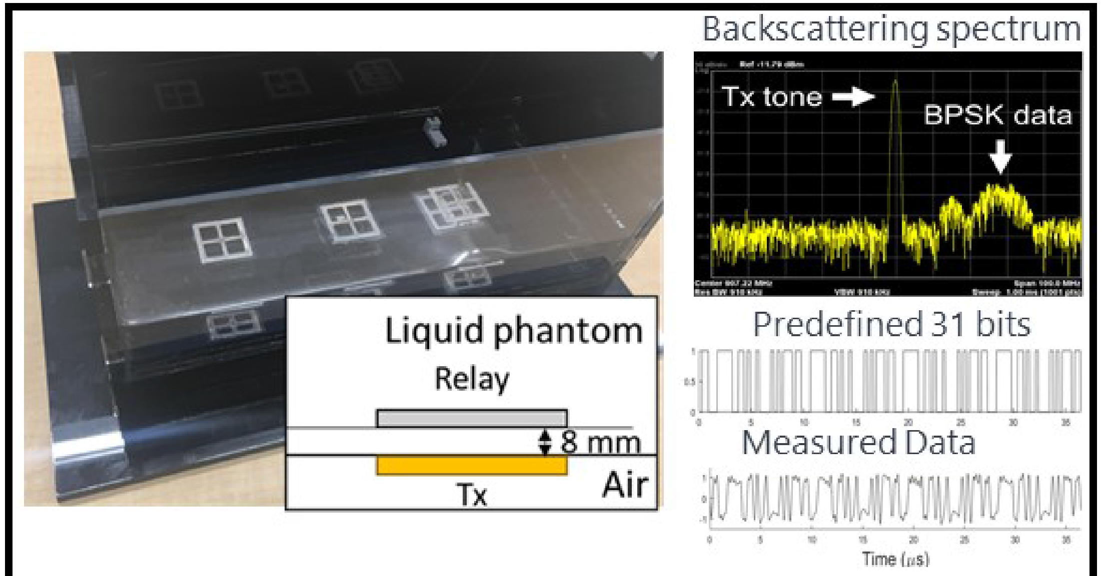
Time-division Multiple Access (TDMA) Networking Protocol

** Stim chip not featured

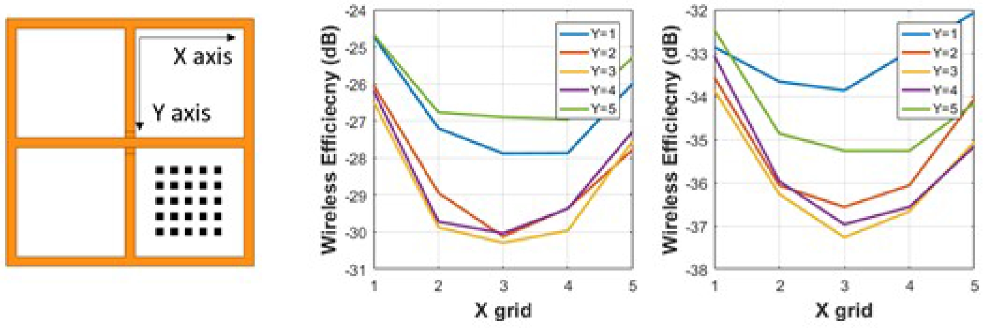
Wireless Power and Telemetry



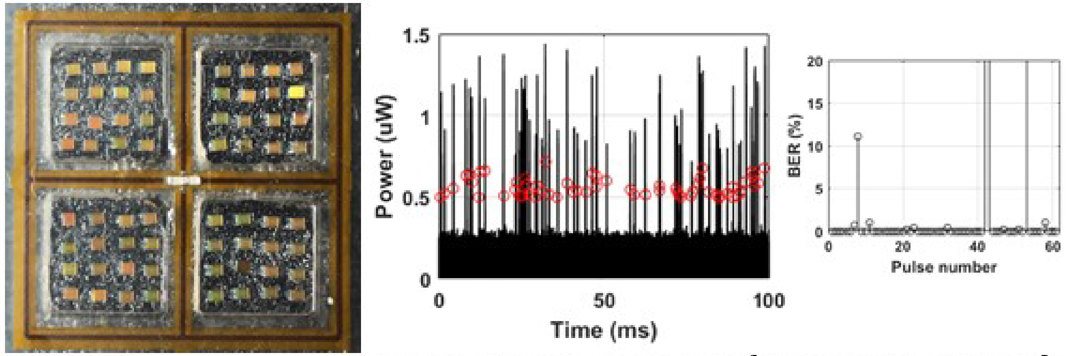
Optimized Near-field electromagnetic energy transfer



Benchtop “tissue phantom” test bench

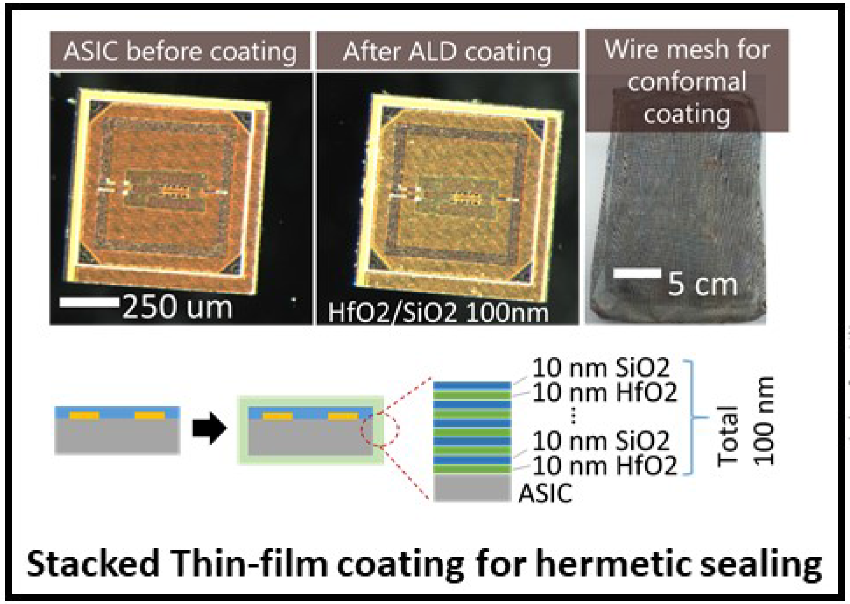


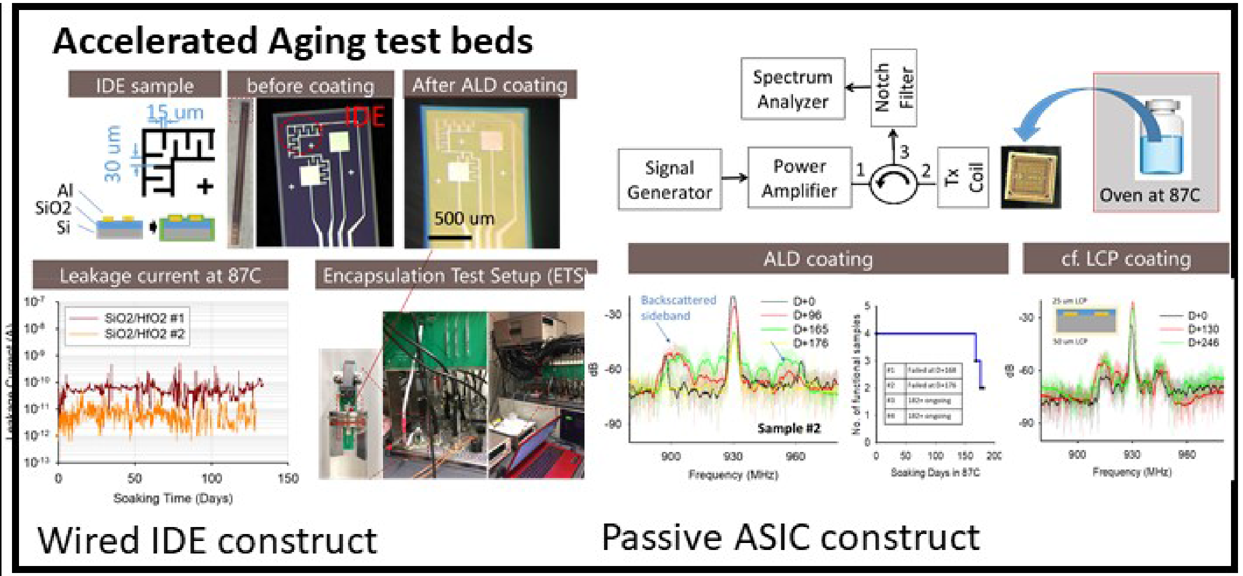
Spatial Variation in Wireless Power Transfer Efficiency

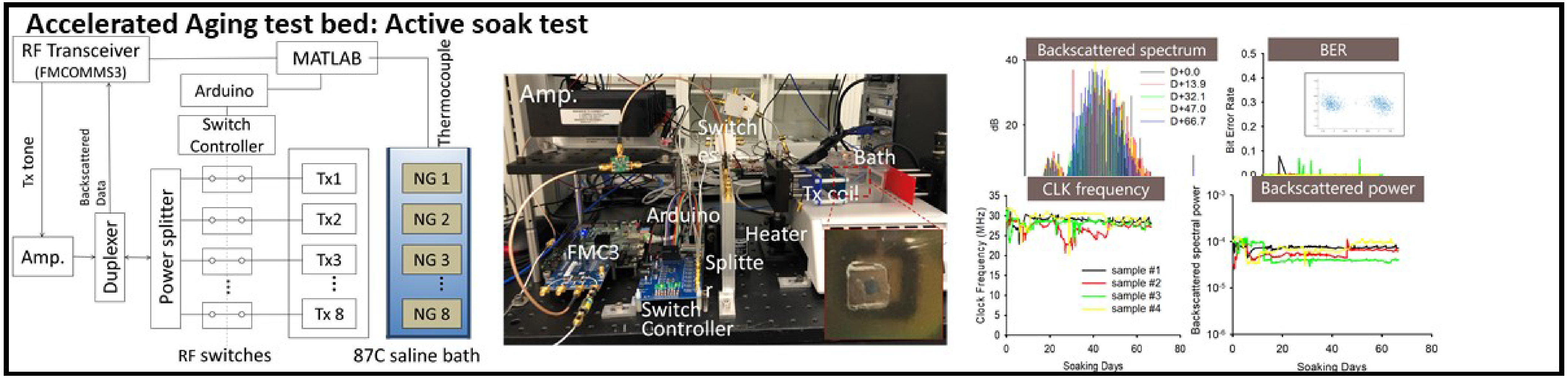


Primitive Network with data recovery (64 neurograins)

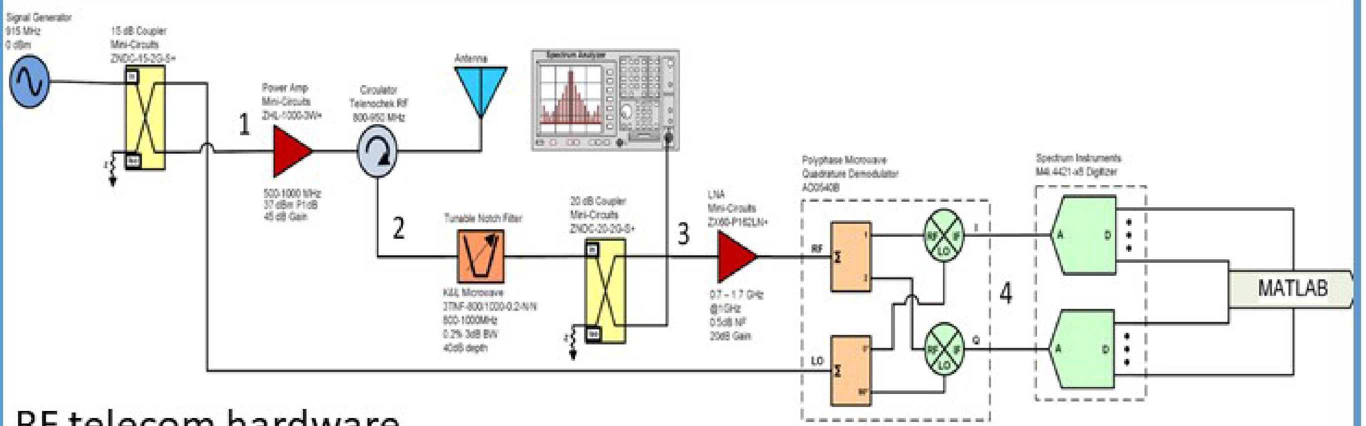
Packaging and Encapsulation



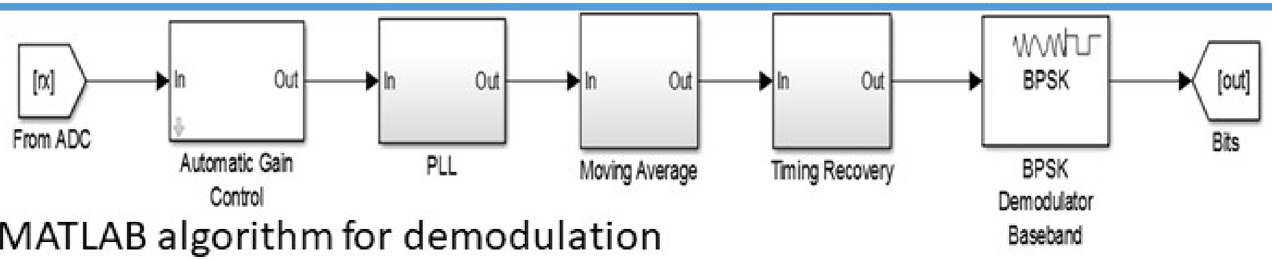




RF Telecommunication (in Collaboration with Brown/Qualcomm)

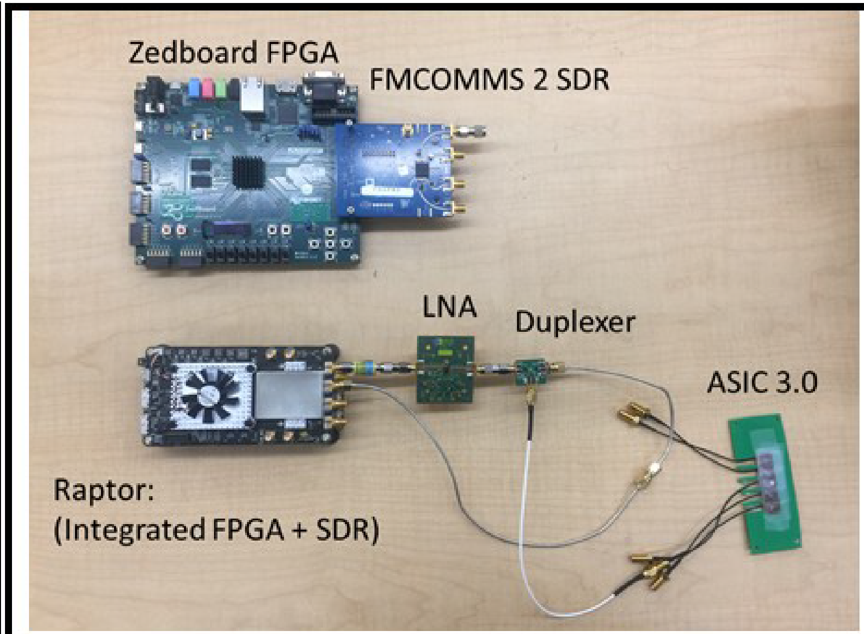


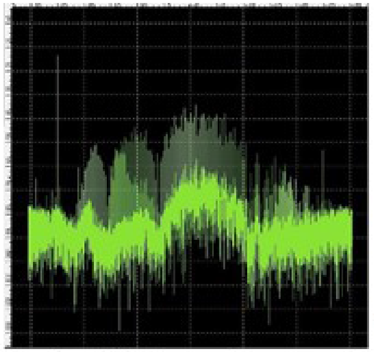
RF telecom hardware

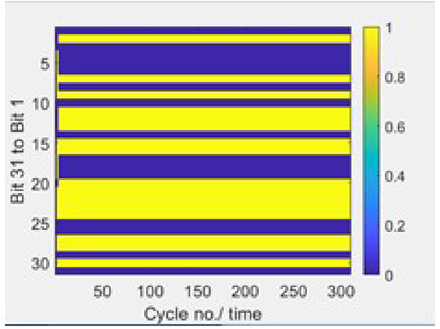


MATLAB algorithm for demodulation

Bench top Data Recovery and RF demodulation

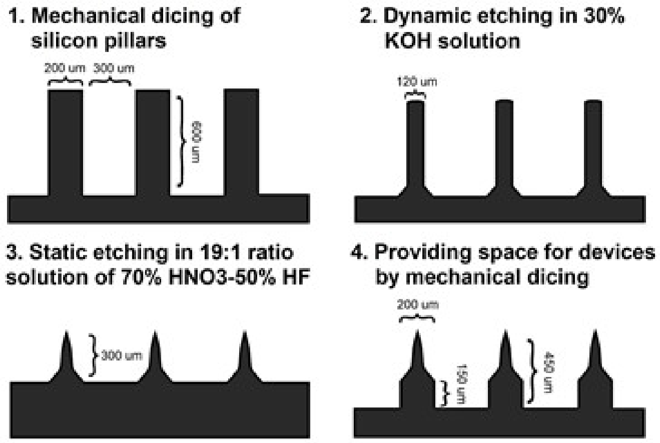


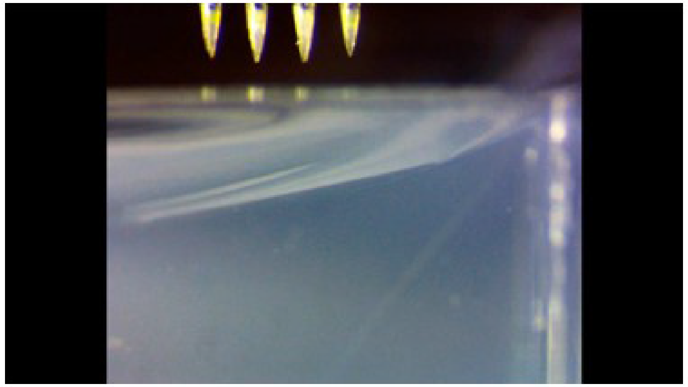




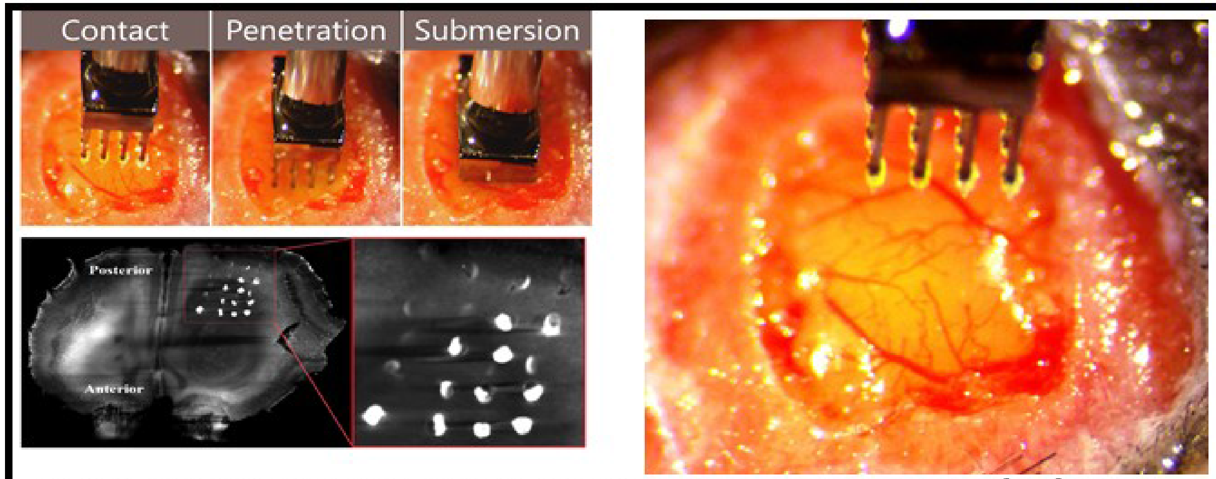
Portable Implementations with Software Defined Radio and FPGA back-ends

High Throughput Implantation



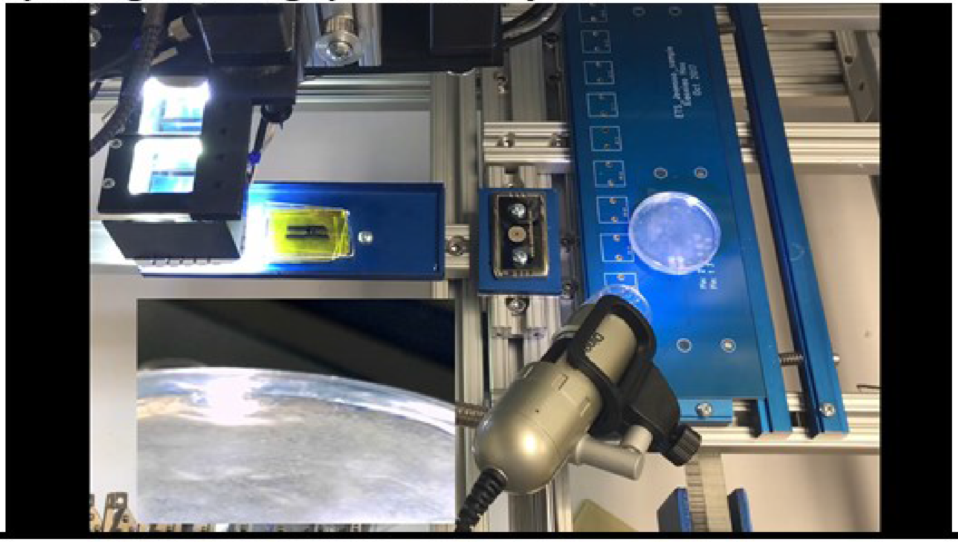


Fabrication of Insertion device with bio-dissolvable polymeric constructs

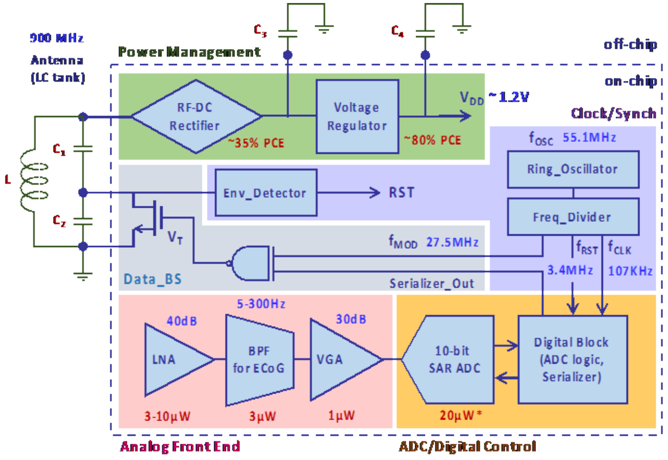


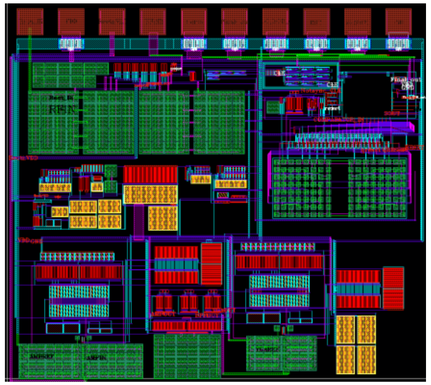
Insertion and Evaluation with Light sheet Microscopy (w/ CLARITY)

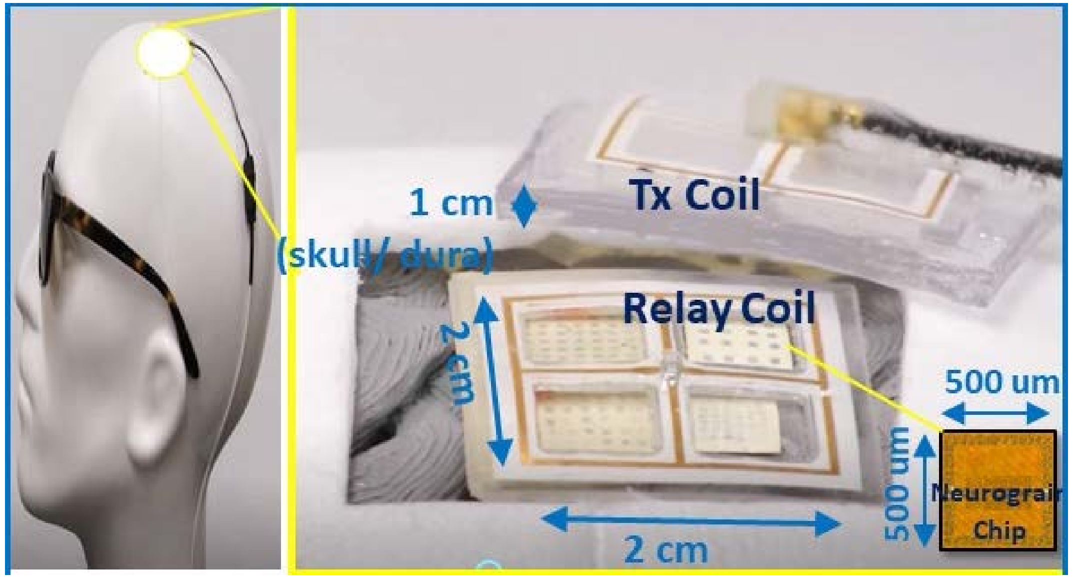
Sample High-throughput delivery



Summary of Current Neurograin System







- Developed first generation of sub-mm microelectronic chiplets for wireless recording and stimulation
- Validated IC performance at benchtop
- Developed and validated hermetic packaging approaches for microscale implants
- Developed RF telecom approaches and implementation on portable platform
- Explored high throughput implantation techniques for future generations of intracortical implantable neurograins
- Plan for further scaling and miniaturization of intracortical implantable neurograins

Thank you for your attention!

Collaborations: Brown University (Nurmikko, Larson), UCSD (Aspeck, Mercier, Leung)

Acknowledgements: J. Jang, C. Lee (SNU), J. Lee, J. Jeong, F. Laiwalla (Brown)

Support: NRF (Brain Research Program/Basic Research Program)