CENTER *for* NEUROTECHNOLOGY

a National Science Foundation Engineering Research Center

A 158 pJ/bit 1.0 Mbps Bluetooth Low Energy (BLE) Compatible Backscatter Communication System for Wireless Sensing

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Outline

1. Motivation
2. BLE Backscatter Communication
3. NeuroDisc Design
4. Experimental Results
5. Conclusions & Future Work

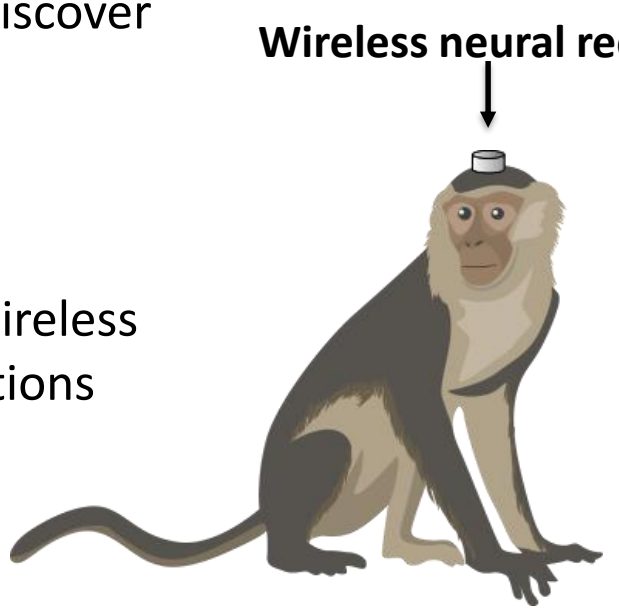
Motivation

UW Center for Neurotechnology's Vision

Advance treatment of neurological disorders

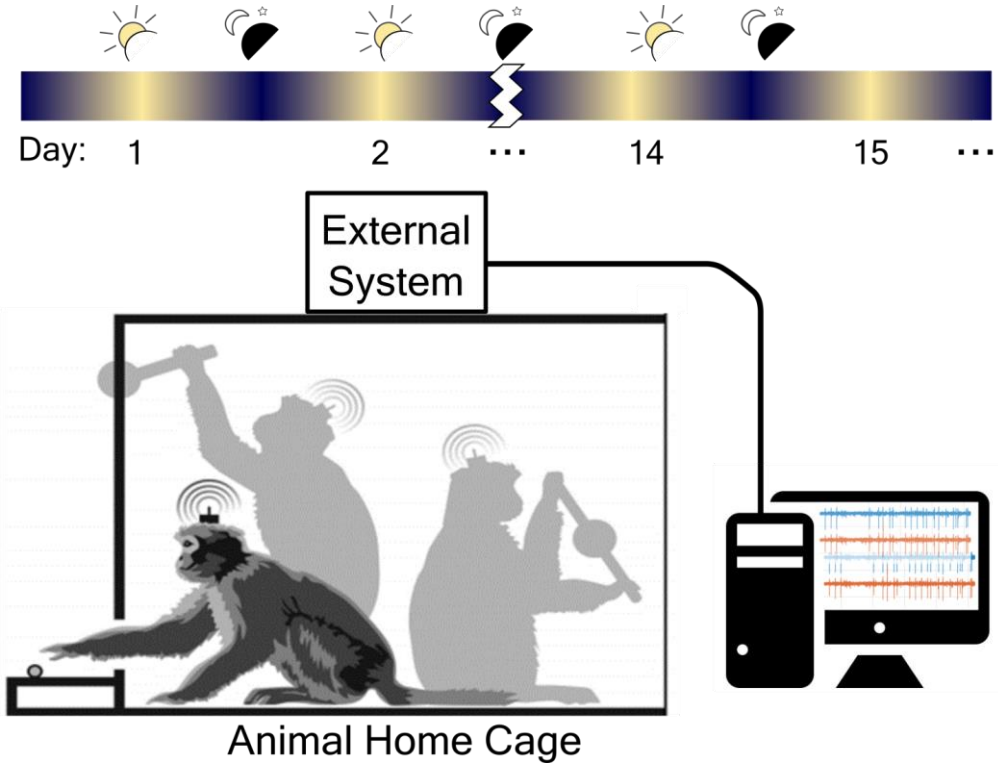
Develop wireless devices that enable long-duration (> 2 days) neural recording experiments to discover principles of neuroplasticity

High power consumption of conventional wireless hardware has restricted experiment durations



Motivation

How to efficiently uplink experimental data?



Requirements

Sensing: Sample neural signals (fsample = 500 Hz minimum)

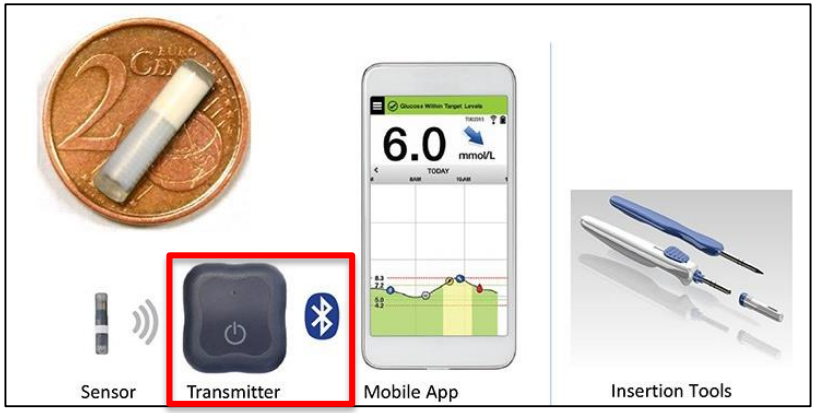
Wireless Energy Efficiency: Consume less energy than commercially available options

Reduced complexity: Compatible with commercially available receivers

Bluetooth Low Energy (BLE)

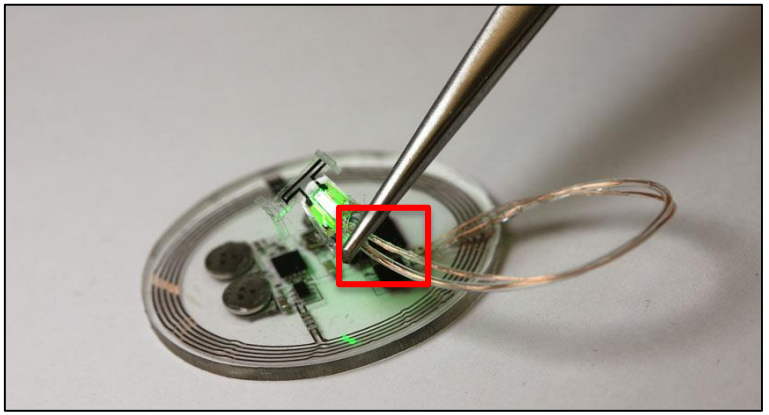
BLE is a ubiquitous and low-cost, but it consumes too much power

FDA-Approved Blood Glucose Monitor



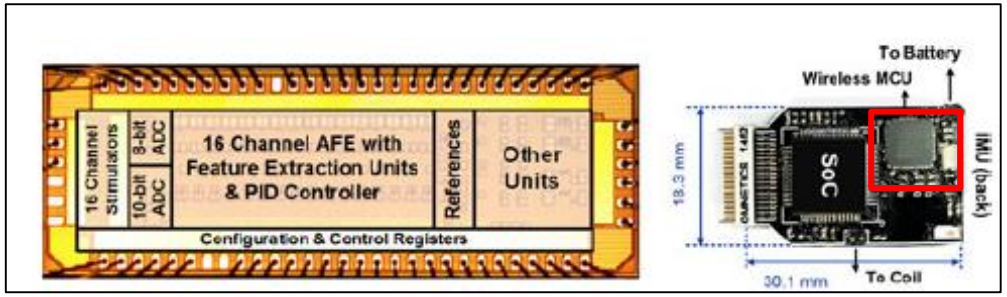
Senseonics 2018.

Implantable Optogenetic Stimulator for Rats



A.D. Mickle et al. "A wireless closed-loop system for optogenetic peripheral neuromodulation." Nature Letters. 2019.

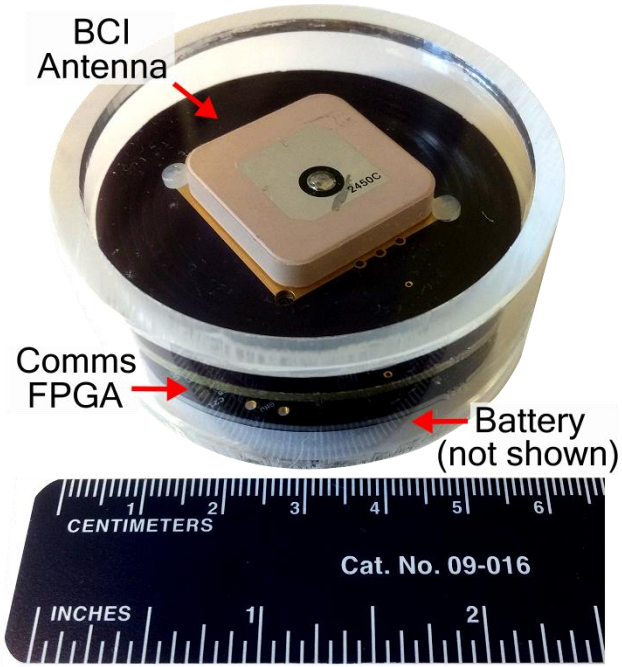
Bi-Directional Brain-Computer Interface



X. Liu et al. "Design of a closed-loop, bidirectional brain machine interface system with energy efficient neural feature extraction and PID control ." TBioCAS. 2017.

NeuroDisc+BLE Backscatter Uplink

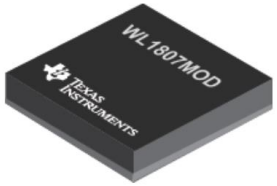
NeuroDisc uses an energy efficient alternative to commercial uplinks and is compatible with billions of BLE devices



BLE Backscatter (this work): 158 pJ/bit at 1 Mbps

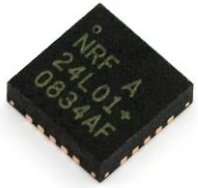
IEEE 802.11n Wi-Fi: 8 nJ/bit at 100 Mbps
Bluetooth Low Energy (BLE): 10 nJ/bit at 1 Mbps
Zigbee: 100 nJ/bit at 0.25 Mbps
SD card: 1.24 nJ/bit at 80 Mbps

WL1807MOD WiFi



TI.com

nRF24L01+ BLE



Sparkfun.com

J. F. Ensworth and M. S. Reynolds, "Every smart phone is a backscatter reader: Modulated backscatter compatibility with Bluetooth 4.0 low energy (BLE) devices," IEEE RFID Conference 2015.

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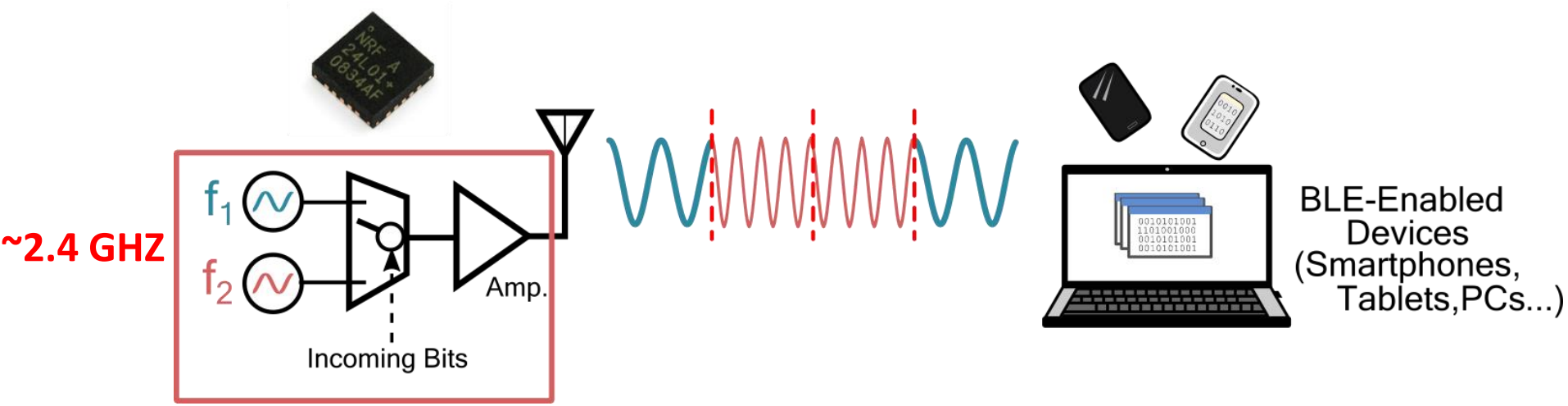
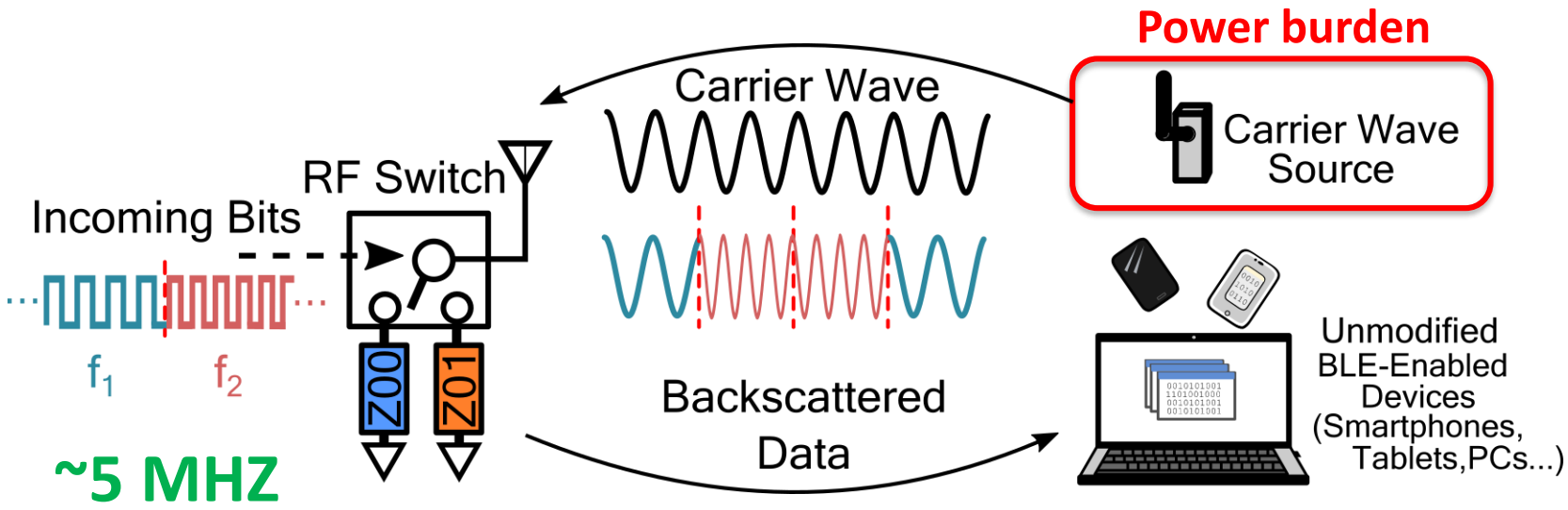
Conventional BLE Communication

RF carrier generation and RF amplification consume significant amounts of power



Power burden

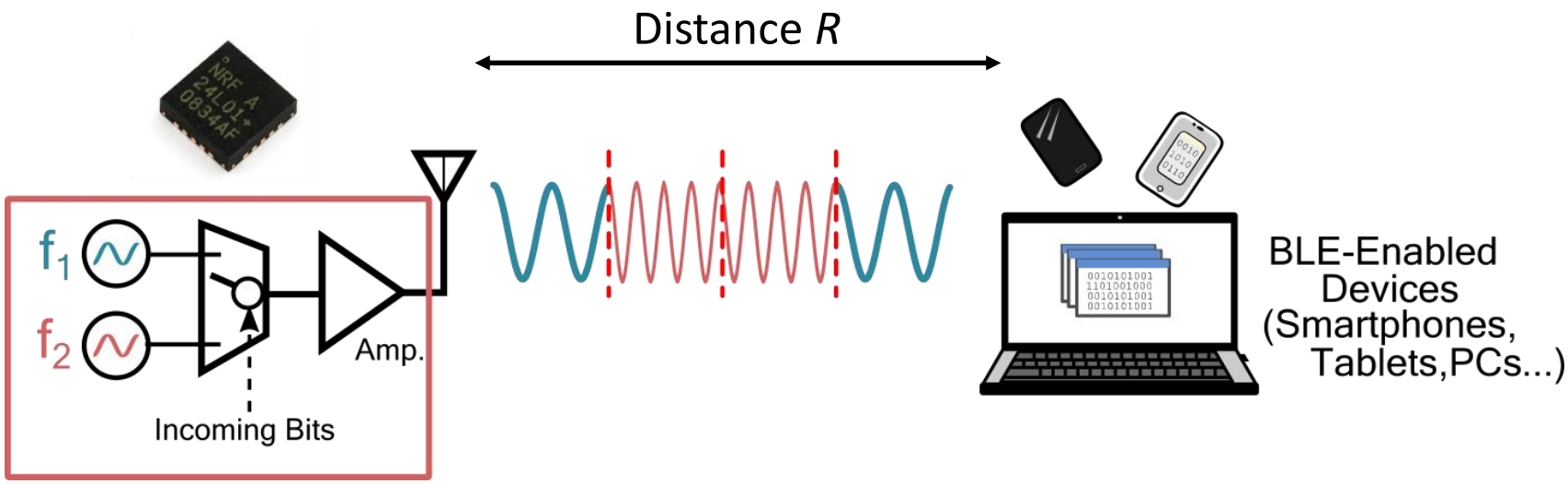
BLE Backscatter Communication



BLE Backscatter modulation saves energy by only switching at low MHz rates

BLE Backscatter Communication

The drawback to backscatter communication is a less-favorable link budget



Conventional RF Uplinks

$$P_R \propto \frac{1}{(4\pi R)^2}$$

vs.

Backscatter Uplinks

$$P_R \propto \frac{1}{(4\pi R)^4}$$

BLE Backscatter Communication

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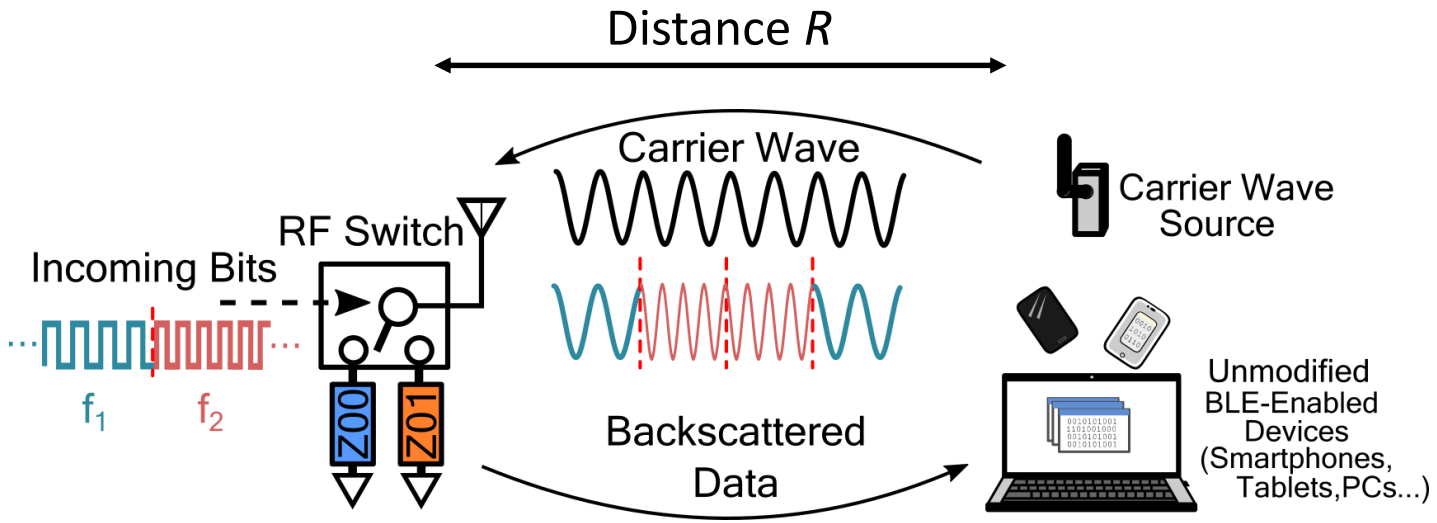

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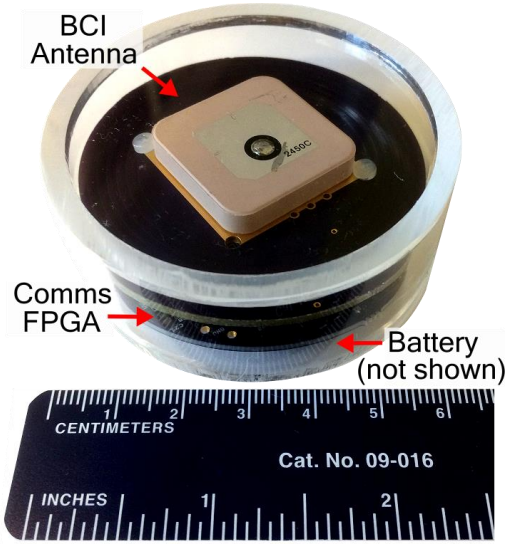
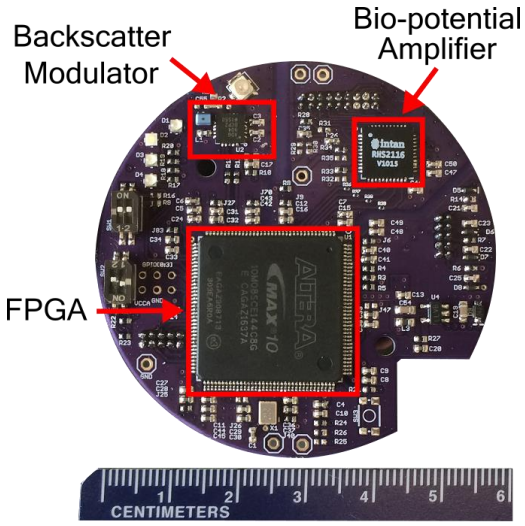
NeuroDisc Design

Our NeuroDisc architecture meets the design requirements





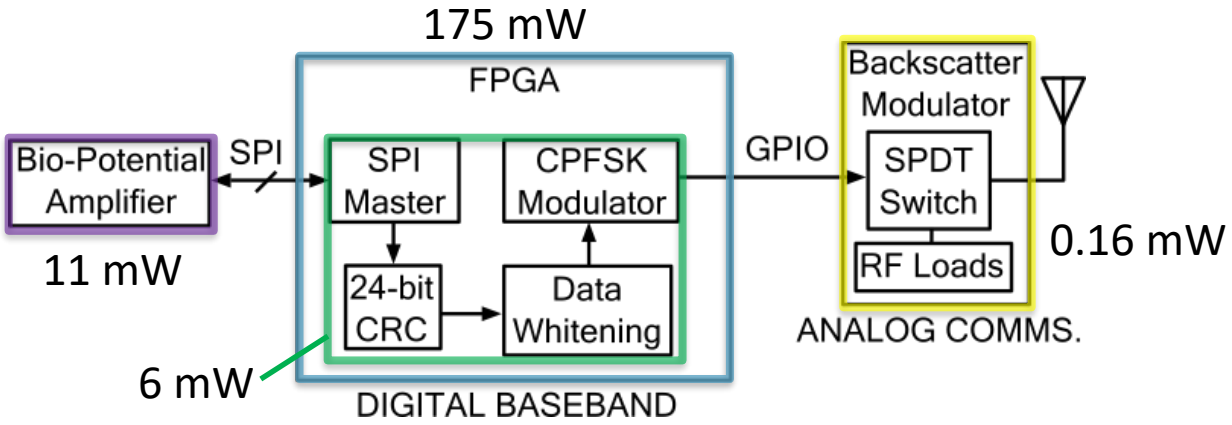
Comms FPGA

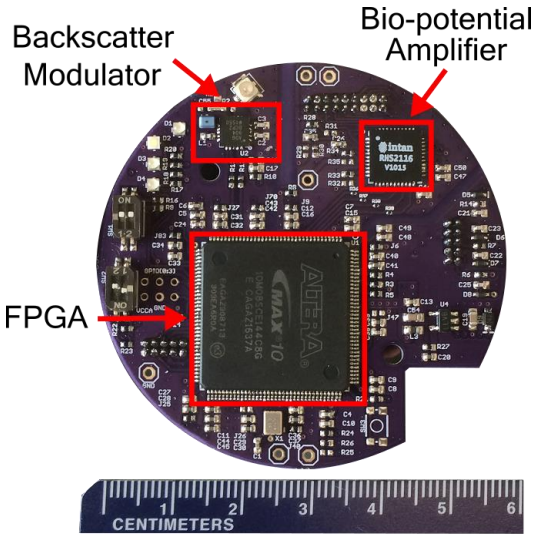
Sensing Features

- 16 Channels
- 16-bit resolution
- 296 payload bits per packet
- Up to 500 packets per sec.

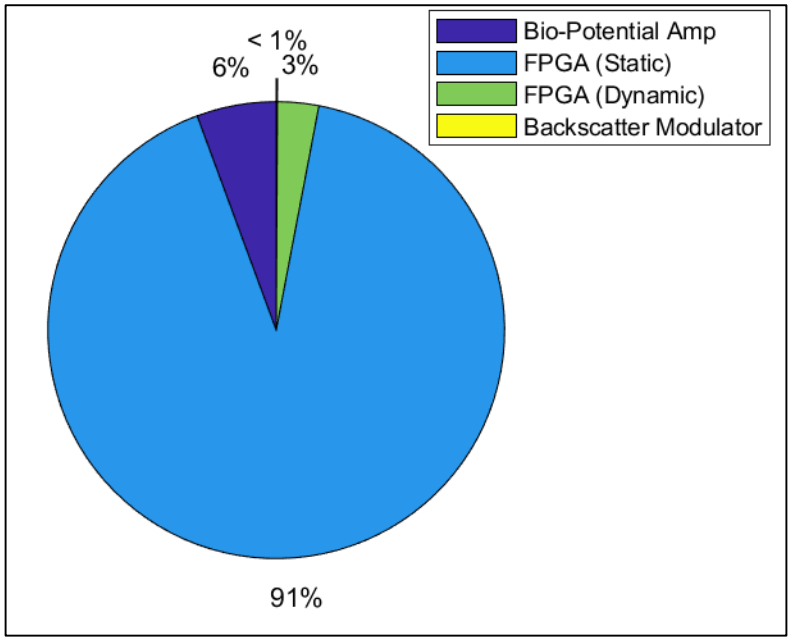
Bio-potential Amplifier: Intan RHS2116. http://intantech.com/

NeuroDisc Power Consumption



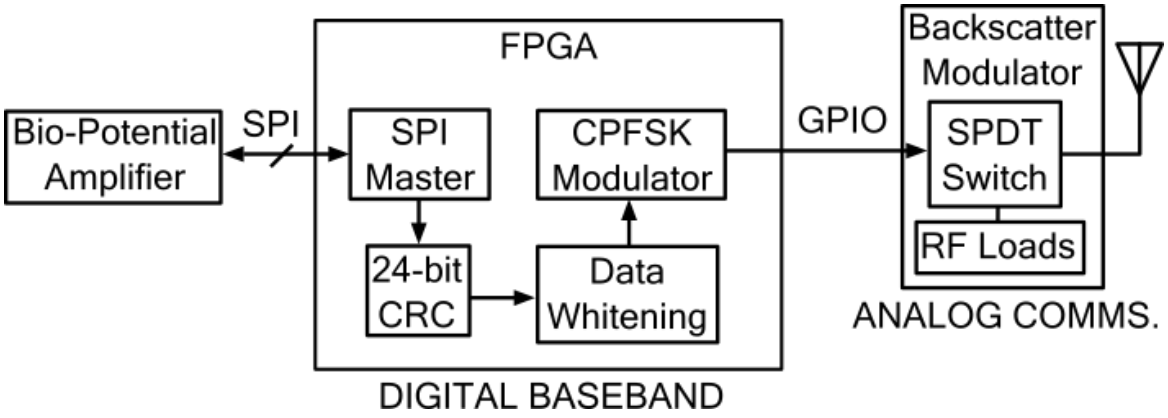


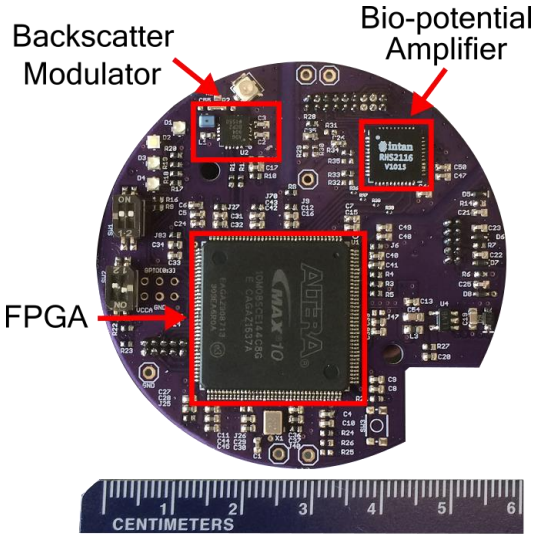
Comms FPGA



Power Consumption Breakdown

NeuroDisc System Overview





Comms FPGA

Intan RHS2116. http://intantech.com/

Complete system could be integrated onto a single chip to further reduce size, weight, and power

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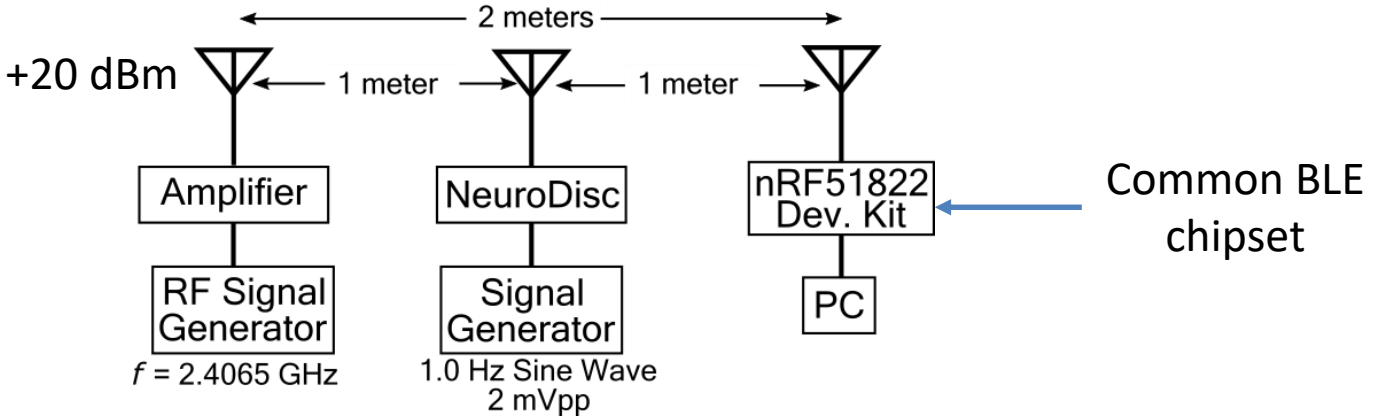
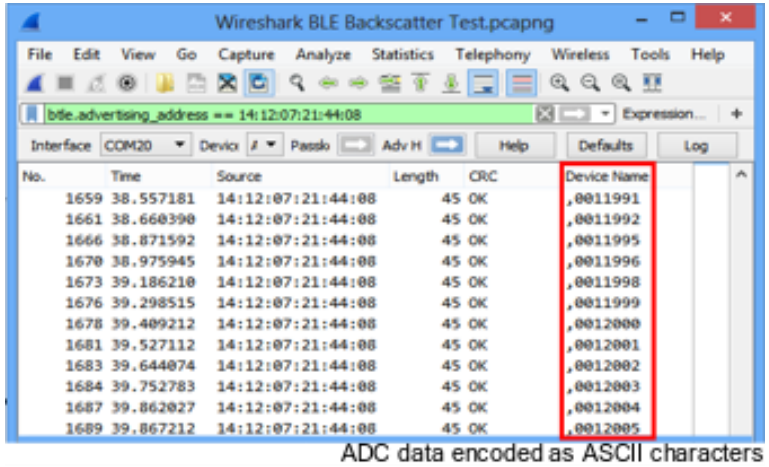
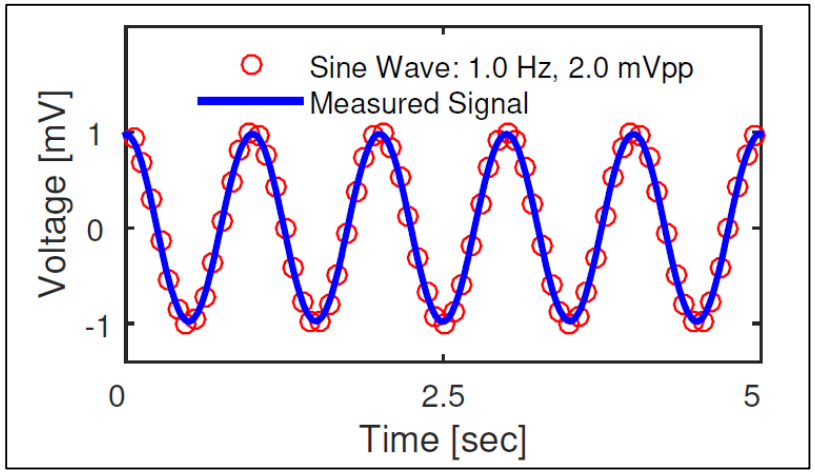
Experimental Results

Uplinked data shows good agreement with original data





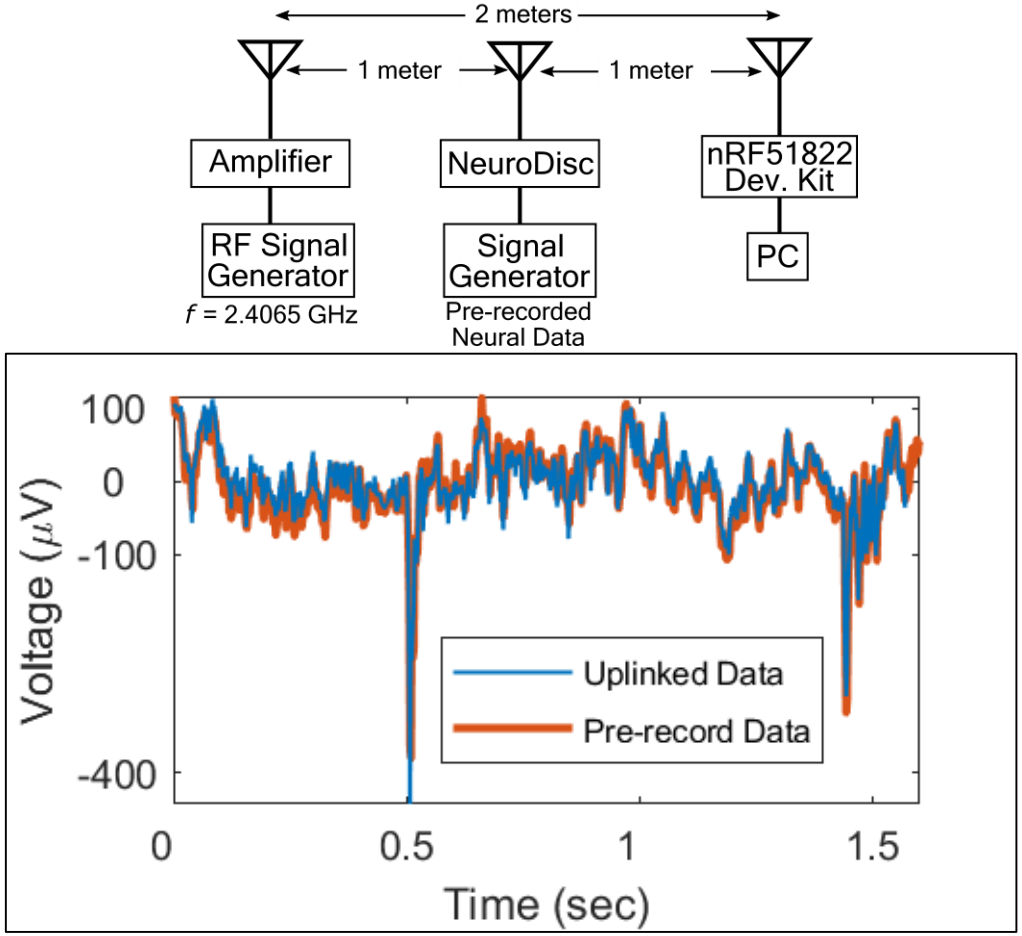
Screenshot from Wireshark



Sensor data can be reconstructed at the receiver

Experimental Results

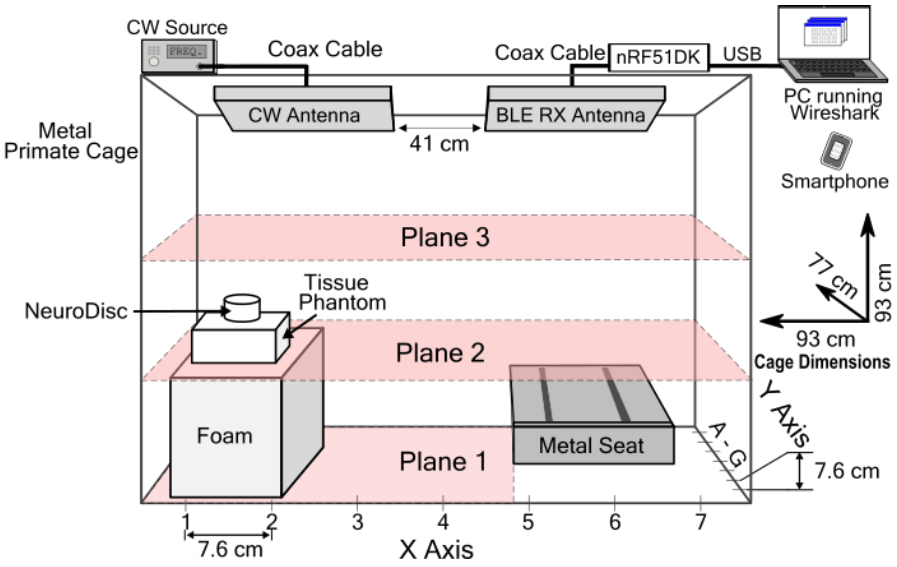
NeuroDisc can successfully uplink sensor data



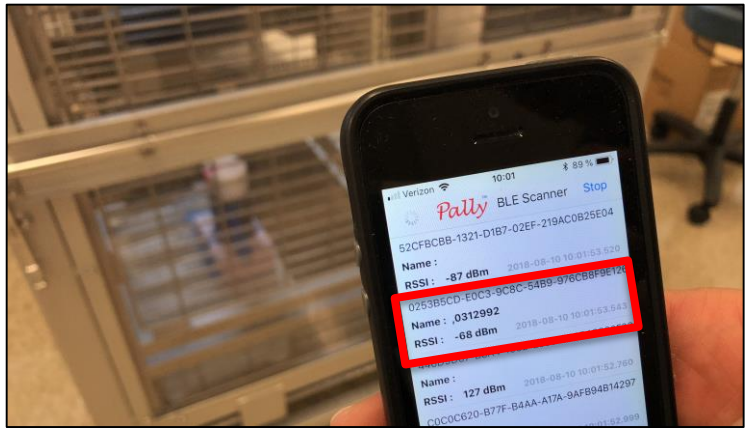
Sensor data shows good agreement with the original data

Experimental Results

NeuroDisc can successfully uplink data from within a metal animal cage



Test setup within a metal monkey cage



Successful reception of packets outside the cage on an unmodified smartphone

J. Rosenthal, A. Pike, and M. S. Reynolds. "BLE Compatible Backscatter Communications in an Animal Home Cage." IEEE RFID Conference. 2019 (under review).

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Conclusions & Future Work

- Validated that the NeuroDisc meets the intended design requirements
- Demonstrated that BLE Backscatter could be a viable alternative to commercially available uplinks

Conclusions & Future Work

Future Work

- Develop a single chip implementation
- Validate the BLE backscatter uplink in *in vivo* experiments
- Improve distance/compliance with single sideband modulation
- Multi-mode uplink: Integrate BLE backscatter with a 25 Mbps UHF backscatter communication

Acknowledgements

- Lab members:
  - Joshua Ensworth, Ph.D. (Impinj), Eleftherios Kampianakis, Apoorva Sharma, Alex Hoang, Claire Watts, Andreas Pedross-Engle, Anissa Dadkhah
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Thank you for your time!

Questions?

Range Testing