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A Dual-Mode 900 MHz DQPSK 6.25 Mbps and 2.4 GHz 1.0 Mbps Bluetooth Low Energy Compatible Backscatter Uplink for Wireless Brain-Computer Interfaces

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Outline

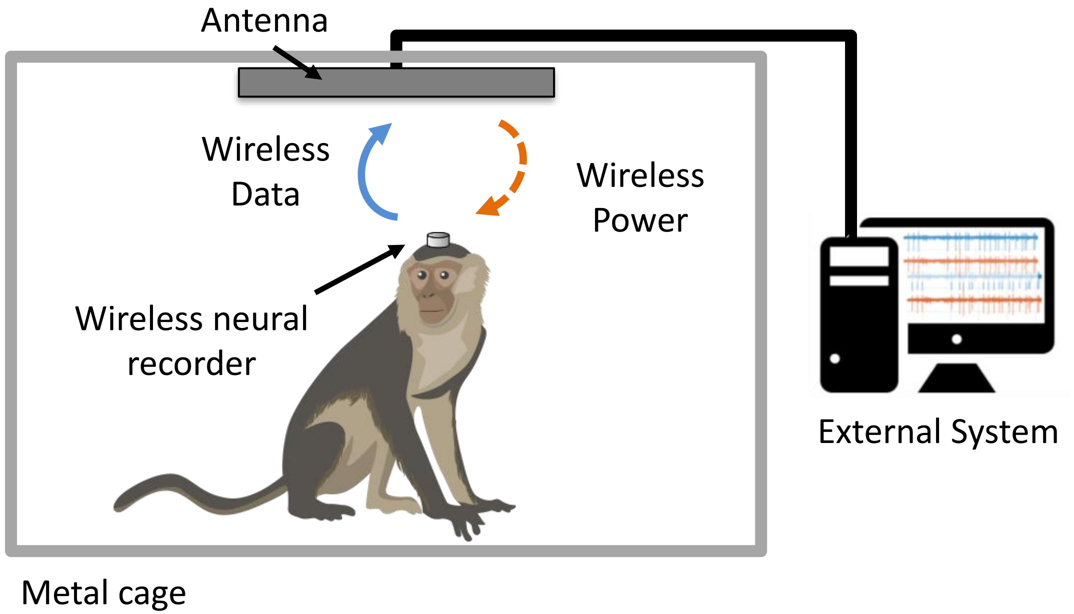
1) Background
2) System Overview
3) Validation
4) Conclusions & Future Work

Motivation

Motivation: Improve the viability of neural prosthetics for research & medicine

Challenge: The high power consumption of conventional radios is impeding progress

Goal: Explore if backscatter communication can enable new experiments and devices

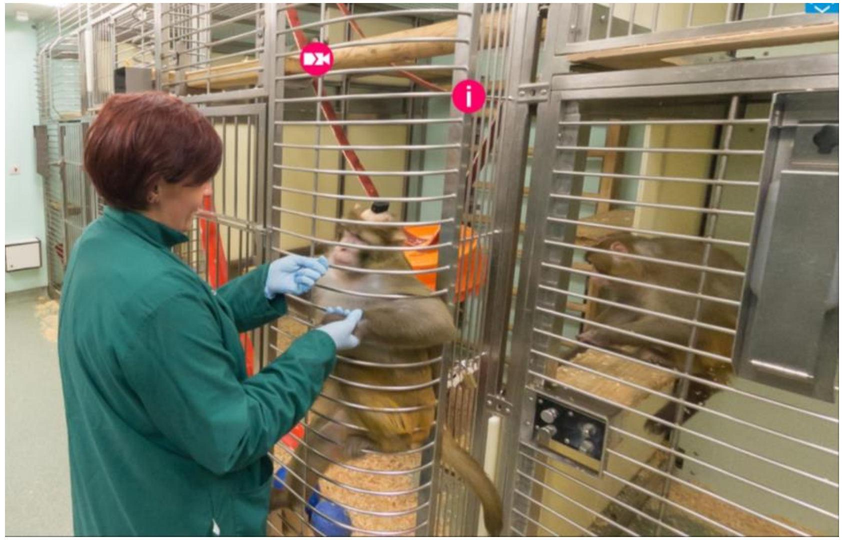


Motivation for Two Uplink Modes

Different use cases for neural recorders may impose different requirements on the wireless data uplink

Experimental

Health & Status (H&S)



University of Oxford. https://speakingofresearch.com/2017/06/19/usda-publishes-2016-animal-research-statistics-7-rise-in-animal-use/
Rajangam, S., Tseng, P., Yin, A. et al. Wireless Cortical Brain-Machine Interface for Whole-Body Navigation in Primates. Sci Rep 6, 22170 (2016).

The Challenge with Conventional Radios

Power Consumption and *Data Rate* are opposing requirements

Protocol	Radio Power Consumption	Data Rate	Radio Efficiency
Wi-Fi (IEEE 802.11n) [1]	800 mW	100 Mbps	8 nJ/bit
BLE [2]	10 mW	1 Mbps	10 nJ/bit
16 QAM Backscatter [3]	1.5 mW	96 Mbps	0.016 nJ/bit

Backscatter communication is >100X more energy efficient

WL1807MOD Wi-Fi

TI.com

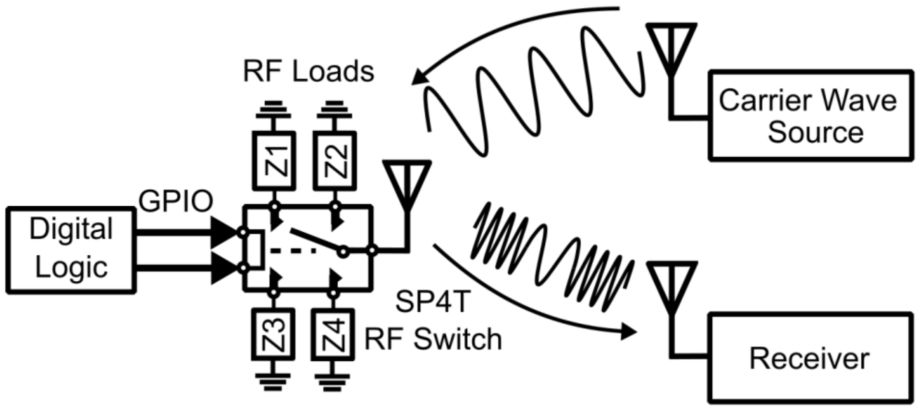
nRF24L01+ BLE

Sparkfun.com

J. A. Fernandez-Leon et al., “A wireless transmission neural interface system for unconstrained non-human primates,” J. Neural Eng, 2015.
D. A. Schwarz et al., “Chronic, wireless recordings of large-scale brain activity in freely moving rhesus monkeys,” Nature Methods, 2014.
S. J. Thomas and M. S. Reynolds, “A 96 Mbit/sec, 15.5 pJ/bit 16-QAM modulator for UHF backscatter communication,” in Proc. IEEE RFID, 2012.

Switched-Impedance Backscatter Modulation

RF switches can provide low power consumption,
fast switching rates, and wideband operation



Functional block diagram

Example Part

Analog Devices ADG904

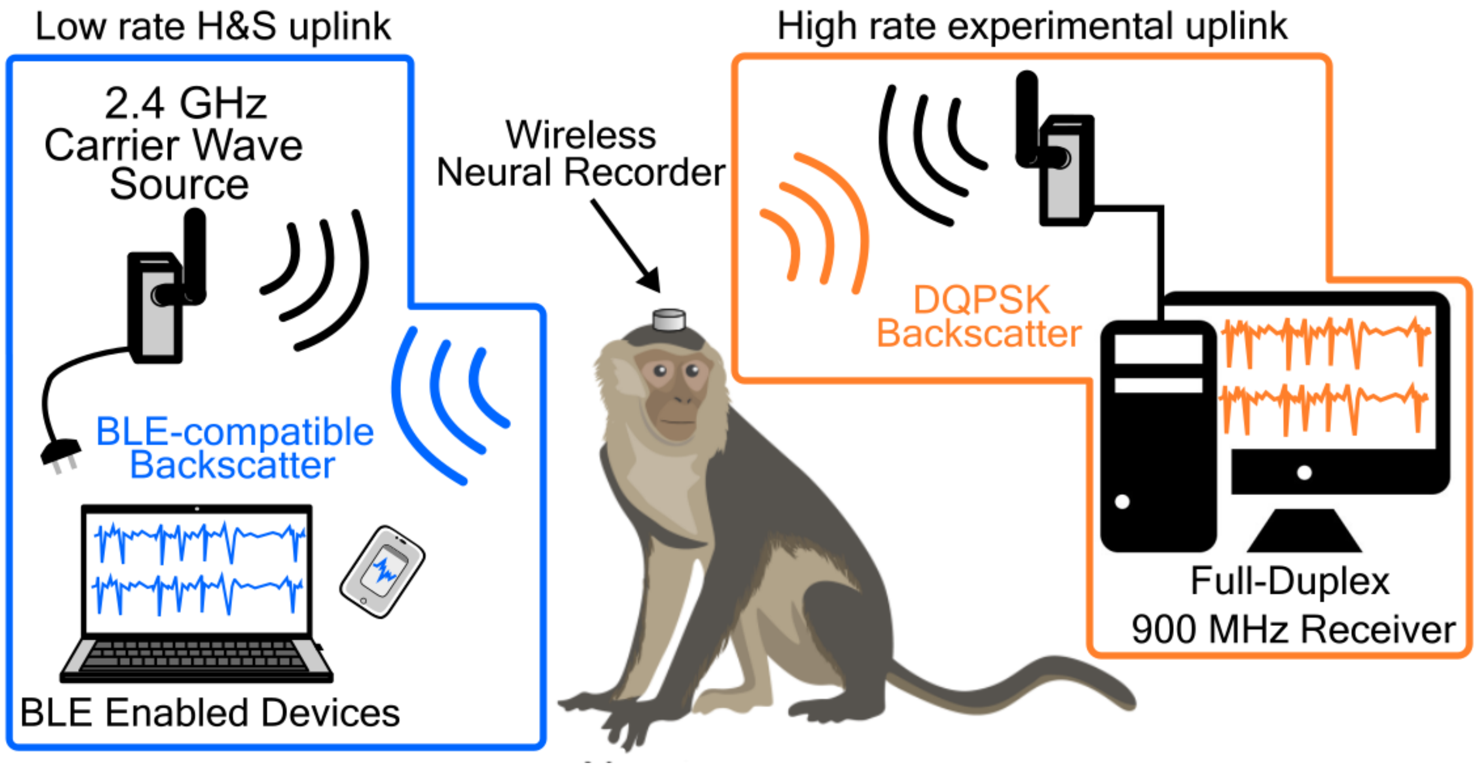
Specifications

- CMOS
- Operation up to 3.3V
- ≤3 dB insertion loss up to 2.5 GHz
- Low Power: 94 uA (static + dyanimc) at 12.5 MHz switching rate
- Switching time: <20 nsec
- Single Pole 4-Throw

J. Rosenthal, A. Sharma, E. Kampianakis, M.S. Reynolds, "A 25 Mbps, 12.4 pJ/bit Backscatter Data Uplink for the NeuroDisc Brain Computer Interface," IEEE Trans. On Biomedical Circuits and Systems , 2019.

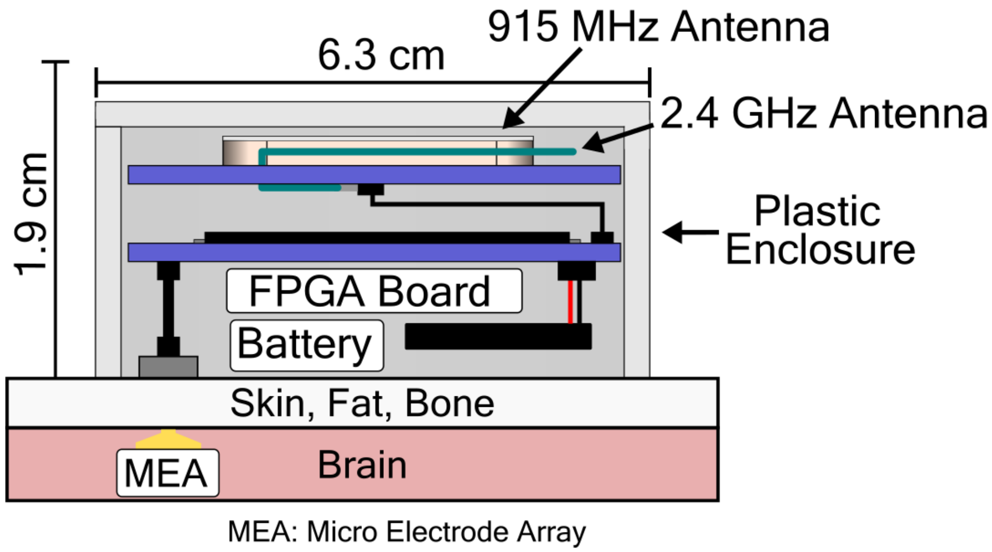
System Overview

Both data uplinks implemented using the same backscatter modulator



System Overview

The complete design is made using off-the-shelf components and low-cost processes (e.g. 4-layer PCB using FR4 dielectric)



Side view drawing of the neural recorder

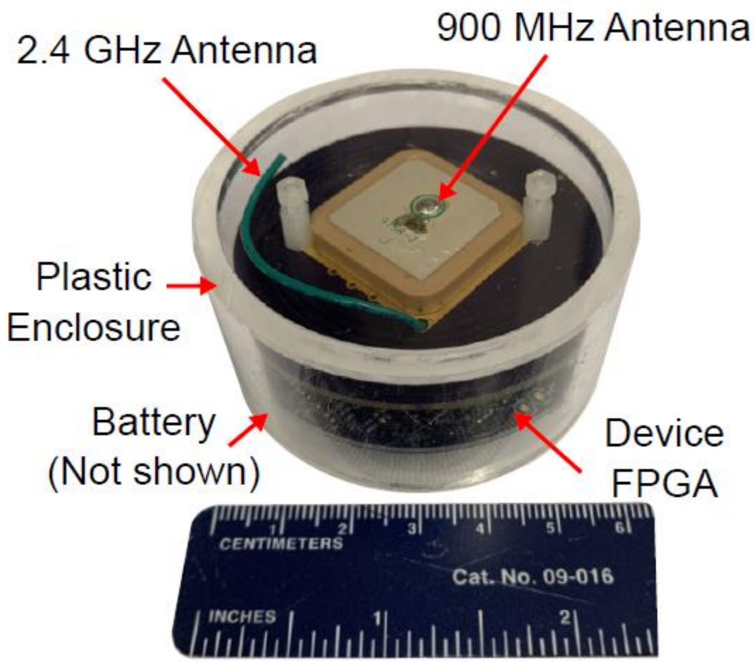


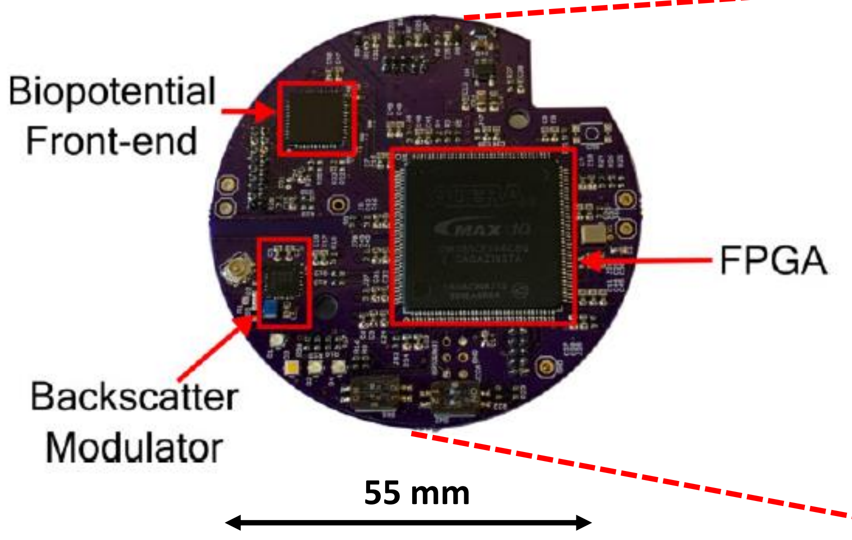
Photo of the assembled device

J. Rosenthal, A. Sharma, E. Kampianakis, M.S. Reynolds, "A 25 Mbps, 12.4 pJ/bit Backscatter Data Uplink for the NeuroDisc Brain Computer Interface," IEEE Trans. On Biomedical Circuits and Systems , 2019.

J. Rosenthal and M.S. Reynolds, "A 1.0 Mbps 198 pJ/bit Bluetooth Low Energy (BLE) Compatible Single Sideband Backscatter Uplink for the NeuroDisc Brain-Computer Interface," IEEE Trans. on Microwave Theory and Techniques, 2019.

System Overview

Complexity is reduced by using a shared-hardware approach



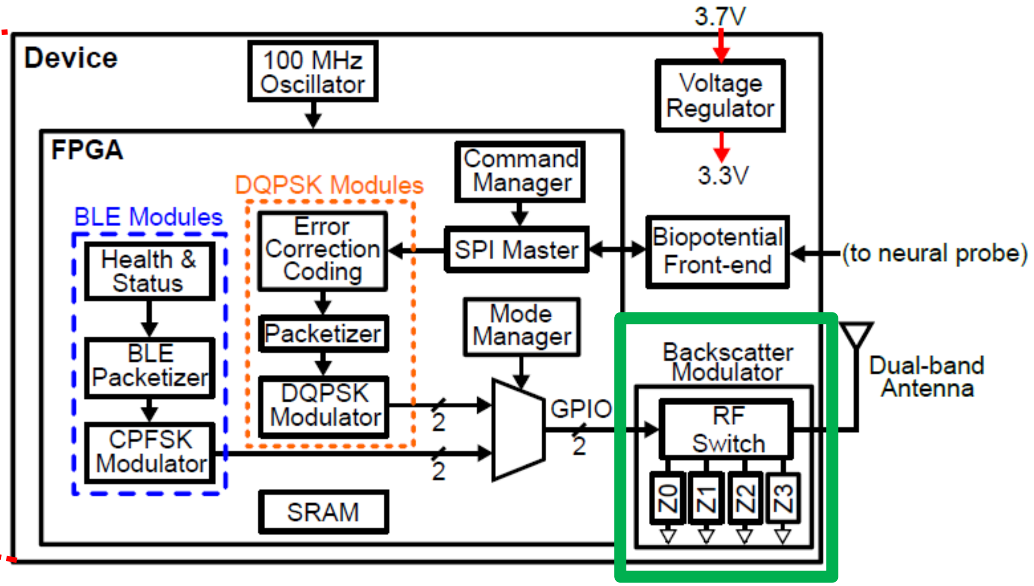


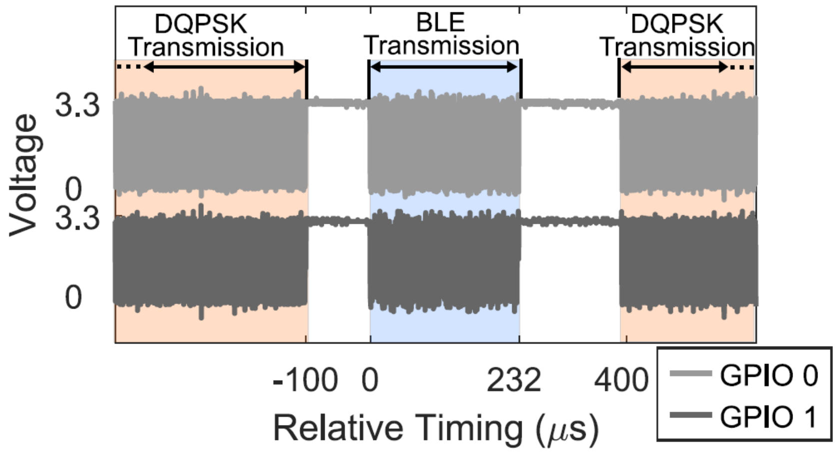
Photo of the FPGA Board

Block diagram of the system

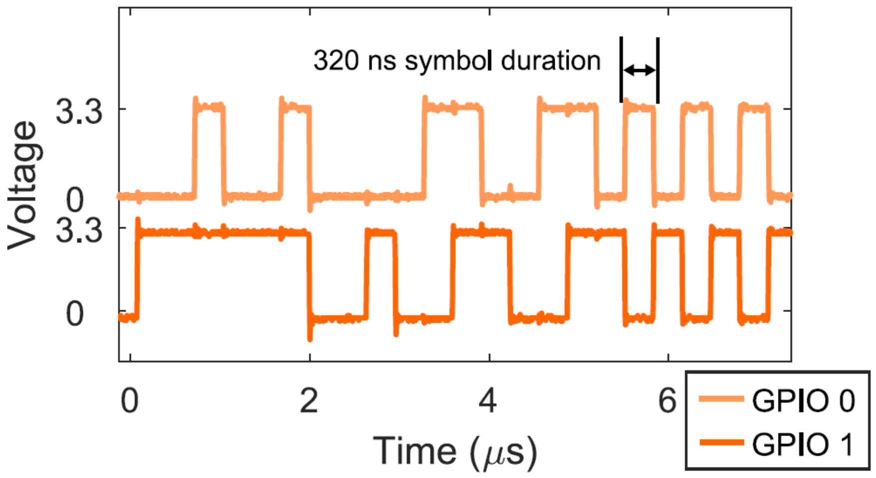
Time-Division Multiplexing

The two protocols are transmitted using time-division multiplexing

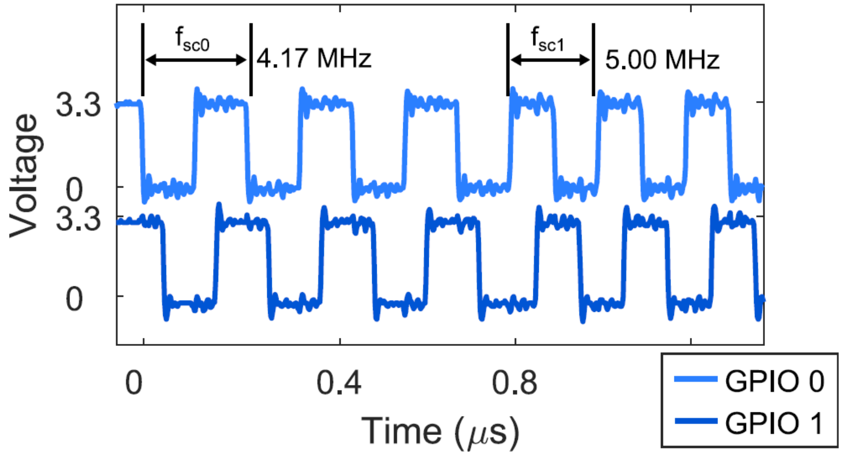
Oscilloscope Measurement



DQPSK Zoomed In

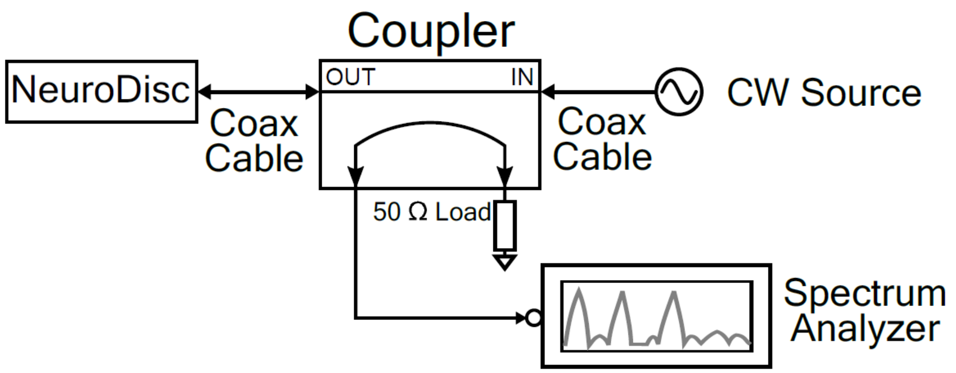


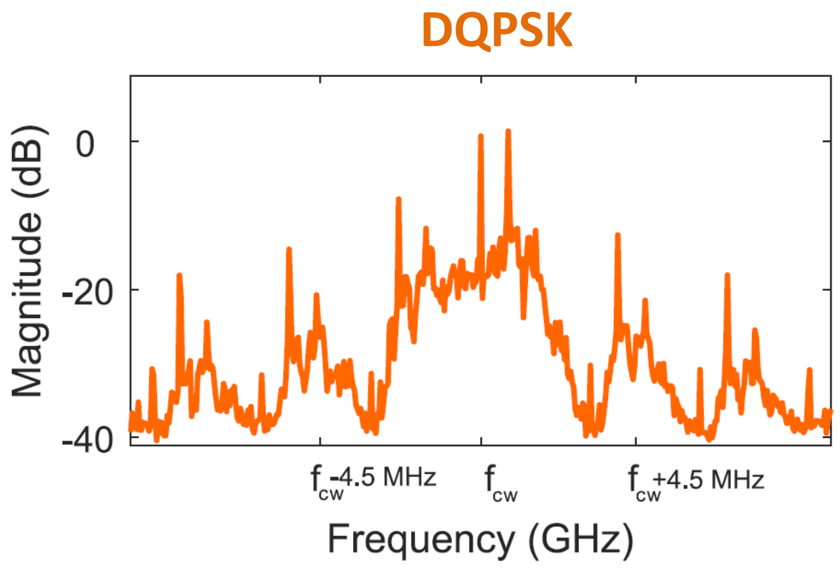
BLE Zoomed In

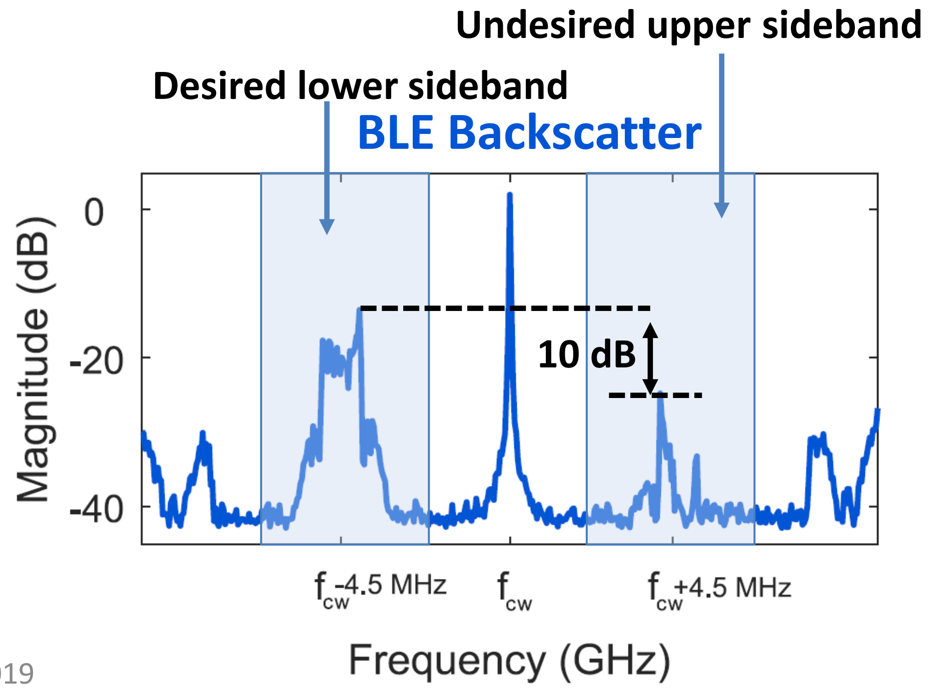


Frequency Spectra

Measurement Setup

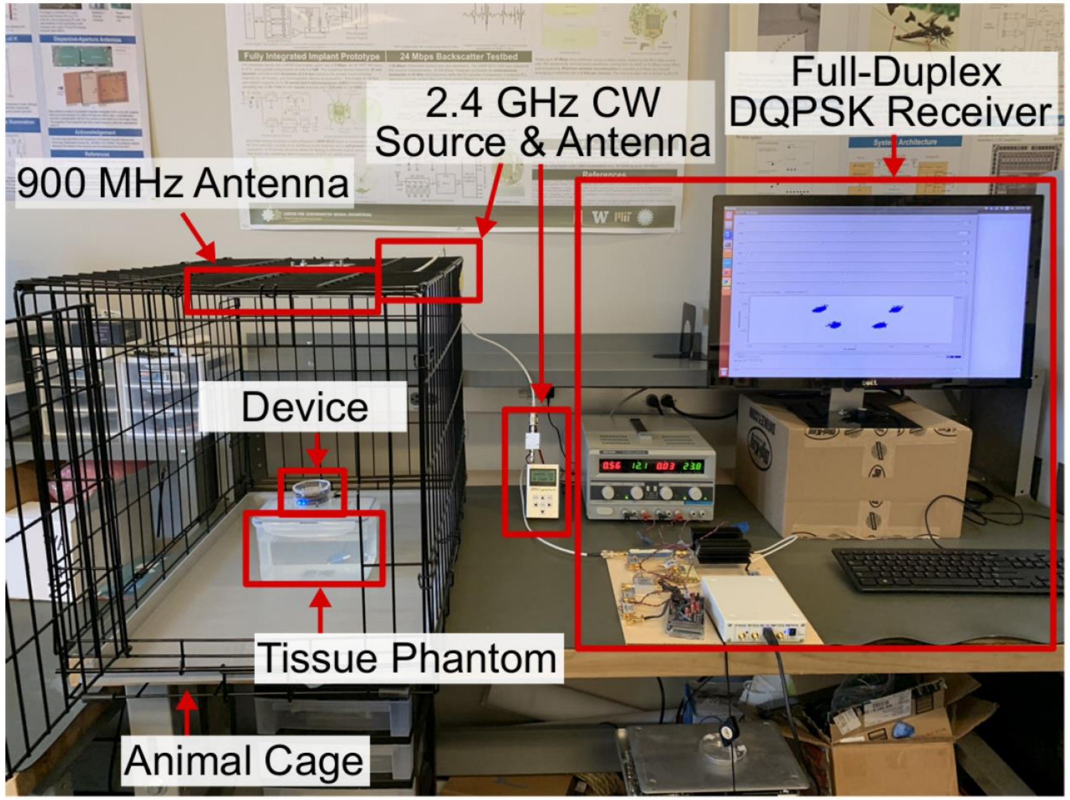






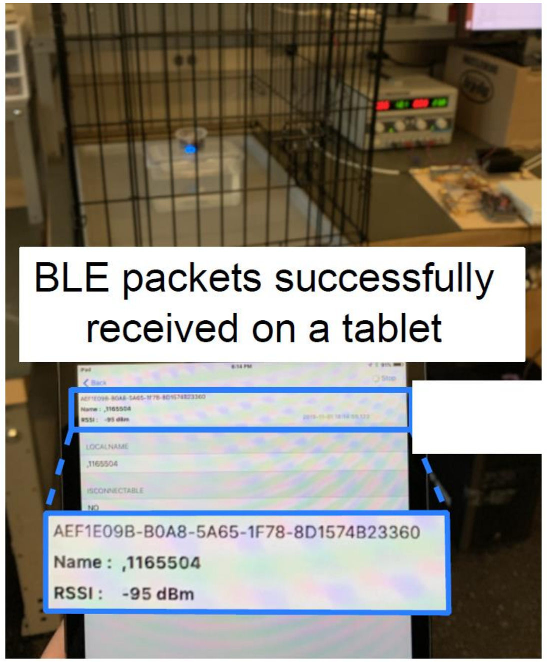
Over-the-air Validation

Data from both protocols was successfully received and decoded

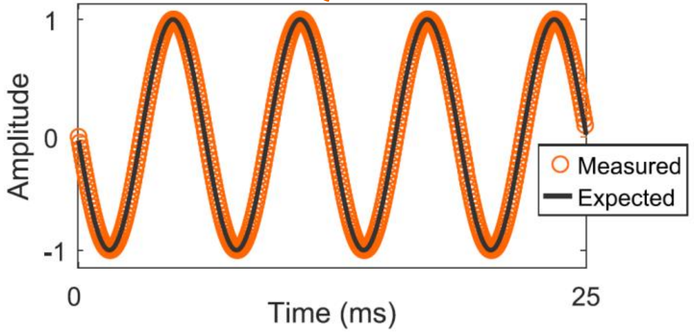


J. Rosenthal, A. Sharma, E. Kampianakis, M.S. Reynolds, "A 25 Mbps, 12.4 pJ/bit Backscatter Data Uplink for the NeuroDisc Brain Computer Interface," IEEE Trans. On Biomedical Circuits and Systems , 2019.

BLE Backscatter



DQPSK



Conclusions

- Demonstrated a dual-band, dual-mode backscatter uplink

Protocol	Radio Power Consumption	Data Rate	Radio Efficiency
DQPSK	75 µW	6.25 Mbps	12.4 pJ/bit
BLE Backscatter	198 µW	1 Mbps	198 pJ/bit

- Used time division multiplexing to switch between protocols
  - Fully simultaneous transmission could be achieved by engineering the BLE backscatter and DQPSK spectra

Future Work

- Mature the system for *in vivo* electrophysiology experiments
- Implement on a custom application specific integrated circuit (ASIC)
  - Reduce the size, weight, and power consumption.
- Explore simultaneous uplinks using orthogonal frequency modulation techniques

Acknowledgements

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  - Prof. Matthew S. Reynolds
- For any further questions, please contact James Rosenthal: jamesdrosenthal@gmail.com

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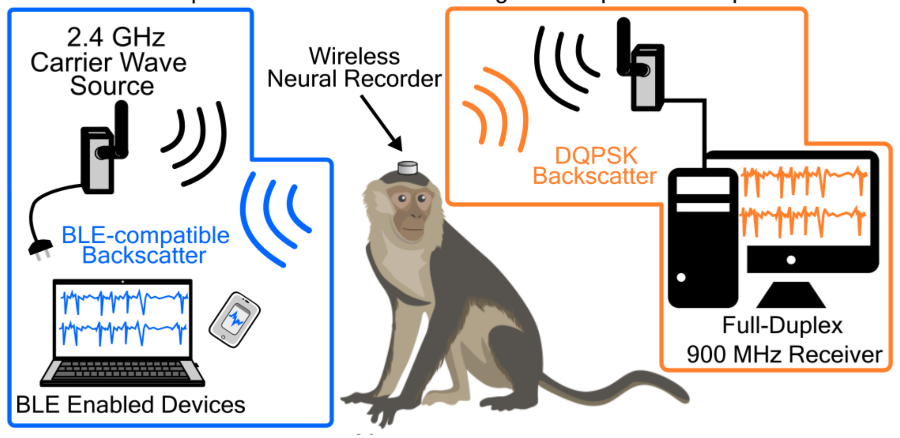
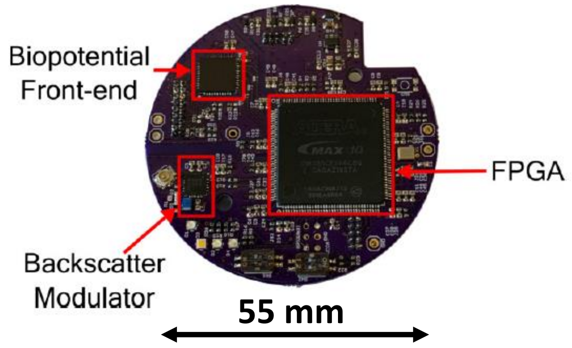
Concept

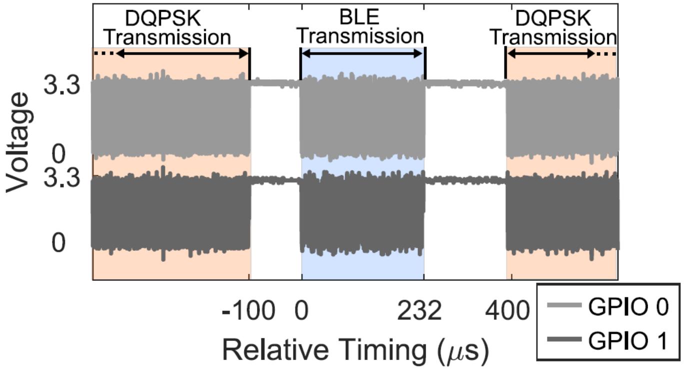


Example deployment of a wireless neural recorder leveraging a dual-band backscatter uplink

Protocol	Radio Power Consumption	Data Rate	Radio Efficiency
DQPSK	75 µW	6.25 Mbps	12.4 pJ/bit
BLE Backscatter	198 µW	1 Mbps	198 pJ/bit

Implementation

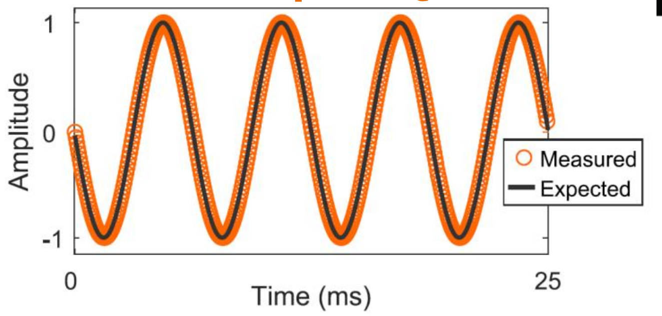




Oscilloscope measurement of the modulator control signals

Results

6.25 Mbps DQPSK



1.0 Mbps SSB BLE Backscatter