A Dual-Band Shared-Hardware 900 MHz 6.25 Mbps DQPSK and 2.4 GHz 1.0 Mbps Bluetooth Low Energy (BLE) Backscatter Uplink for Wireless Brain-Computer Interfaces

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Introduction

Backscatter communication is an appealing technology for wireless brain-computer interfaces (BCIs) that must continuously stream high volumes of data from energy constrained devices [1]. A trade-off when using backscatter communication is choosing whether to use a custom [2] or standards-based communication approach [3]. Custom modes offer greater flexibility and can be used to achieve high data rates with high per-bit energy efficiencies but require custom receivers that could be burdensome to end-users because of higher cost and complexity than fully-integrated single-chip receivers available for standards-based approaches. **We present a dual-mode backscatter uplink combining the benefits of custom and standards-based uplinks. The system provides a custom 900 MHz differential quadrature phase-shift-keying (DQPSK) backscatter uplink with 6.25 Mbps throughput and a 2.4 GHz single sideband (SSB) BLE-compatible backscatter uplink with 1.0 Mbps data rate.** The uplink meets the needs of multiple stakeholders involved in BCI research, providing flexibility without incurring significant hardware or software complexity (Fig. 1).

Experimental | Health & Status (H&S)

Fig 1: Examples of different use cases for wireless brain-computer interfaces (BCIs)

Methods

The dual-mode wireless backscatter uplink presented in this paper was designed for the NeuroDisc brain-computer interface, an FPGA-based neural recorder that can measure microvolt-scale electrophysiological signals and wirelessly uplink data via a switched-impedance backscatter modulator. A dual-protocol, time-division-multiplexed backscatter uplink was implemented on the NeuroDisc using the Verilog hardware description language. **A unique feature of this system is that both protocols share the same backscatter modulator and discrete impedances.** By sharing the backscatter modulator, the size, weight, power consumption, and overall complexity of the circuit are reduced. If commercially-available active radios were used instead, the system would likely incur significant increases in cost, complexity, and power consumption.

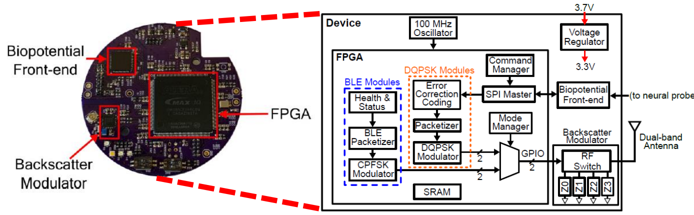


Fig. 2: (left) Photo of the NeuroDisc's FPGA printed circuit board, including an Intan Technologies RHS2116 biopotential front-end, an Altera MAX10 FPGA, and an Analog Devices ADG904 RF switch for the backscatter modulator, (right) block diagram of the FPGA-based digital logic that was written in Verilog HDL.

Backscatter Modulator Power Consumption

Table I: Summary of power consumption, data rate, and per-bit radio efficiency for the DQPSK and BLE backscatter uplinks

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

Conclusion

This system provides real-time neural data uplink across both the 900 MHz and 2.4 GHz ISM bands, which to the best of our knowledge is unique in the literature on wireless BCIs. The dual-band compatibility of the backscatter front-end provides end-users and researchers the ability to leverage frequency diversity depending on the communication channel, offering experimental flexibility that could be advantageous in commercial applications outside of neural engineering as well.

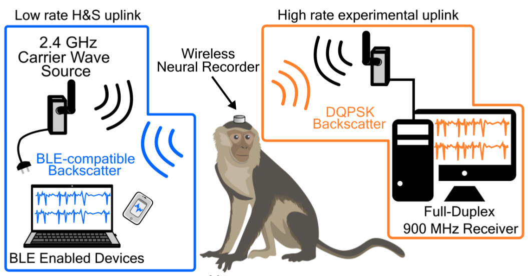
References

[1] R. Muller et al., "A Minimally Invasive 64-Channel Wireless µECoG Implant," in IEEE Journal of Solid-State Circuits, vol. 50, no. 1, pp. 344-359, Jan. 2015.

[2] E. Kampianakis, A. Sharma, J. Arenas and M. S. Reynold, "A Dual-Band Wireless Power Transfer and Backscatter Communication Approach for Real-Time Neural/EMG Data Acquisition," in IEEE Journal of Radio Frequency Identification, vol. 1, no. 1, pp. 100-107, March 2017

[3] J. Rosenthal and M. S. Reynolds, "A 1.0-Mb/s 198-pJ/bit Bluetooth Low-Energy Compatible Single Sideband Backscatter Uplink for the NeuroDisc Brain–Computer Interface," in IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 10, pp. 4015-4022, Oct. 2019.

Dual-band Backscatter Uplink Overview & Example results



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

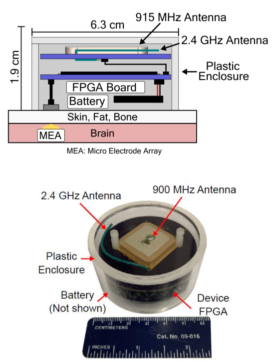
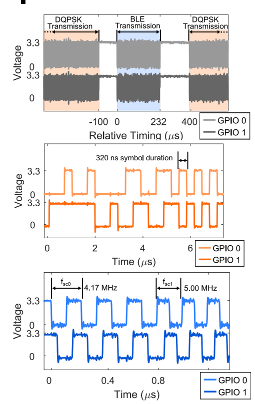
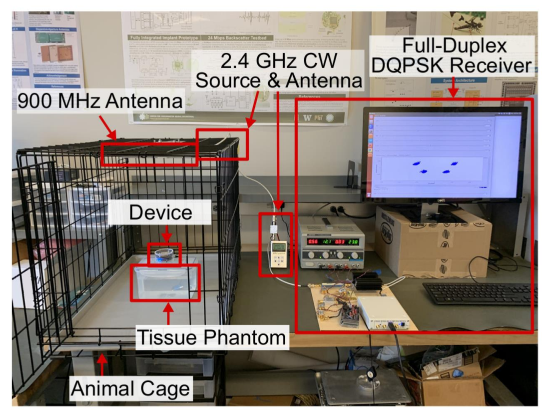


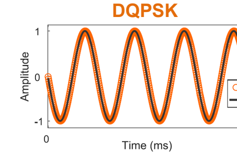
Diagram and photo of the NeuroDisc



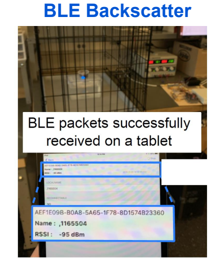
Oscilloscope measurements of the modulator control signals, GPIO 0 and 1, illustrating time-division multiplexing



DQPSK



BLE Backscatter



Test setup and received data from both uplinks during over-the-air validation

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