Optical Neurolink for a High Data-Rate Brain-Computer Interface

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Background & Introduction

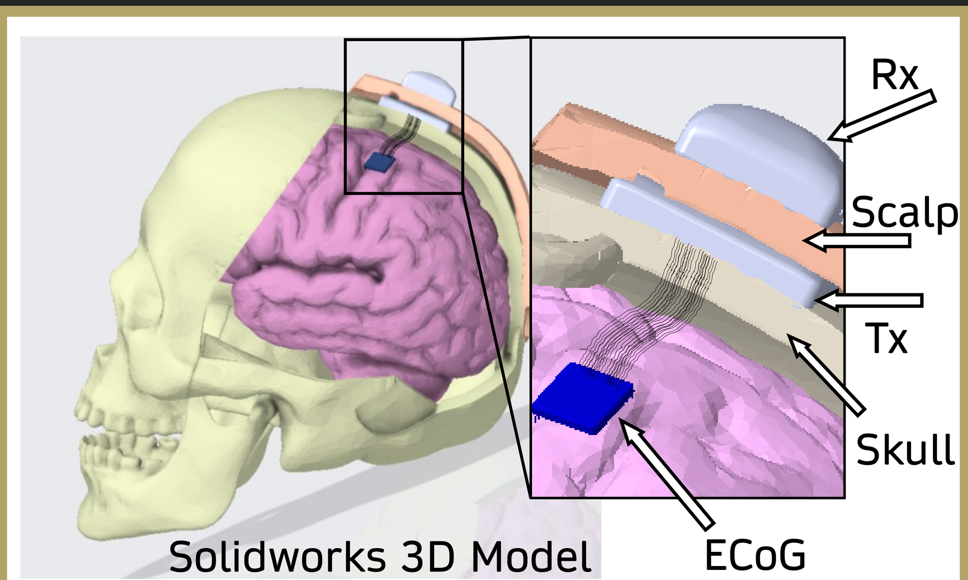
Brain-Computer Interfaces (BCIs) allow direct communication between the brain and an external device by receiving brain signals via electrodes, transmitting the signals to a computer for analysis, and turning them into action through implants or robotics. The most common technologies are Electrocorticogram (ECoG) arrays and Electroencephalography (EEG). Although offering much higher fidelity than EEG, current applications of ECoG arrays require a direct computer connection through an open wound into the skull, leaving a patient immobile and susceptible to infection. An Optical Neurolink may answer the immediate need for a safe and accurate, wireless BCI.

Goal & Objectives

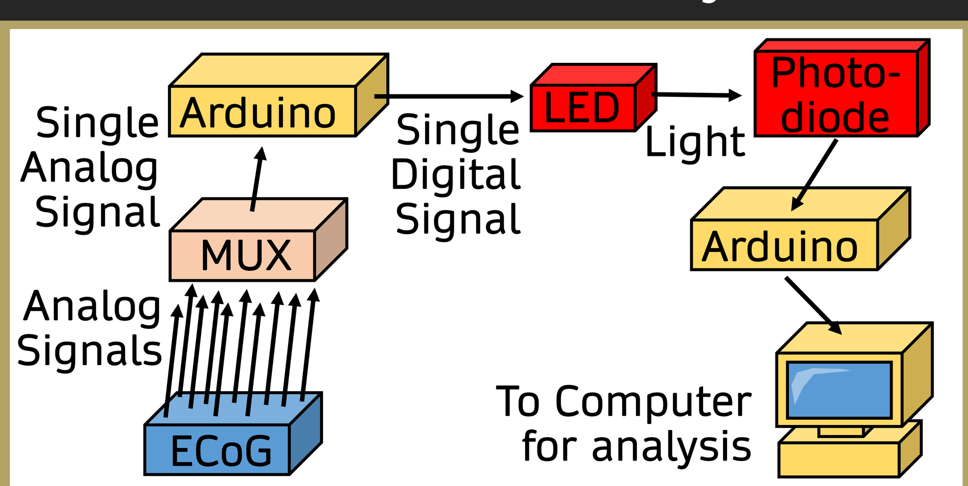
The goal of the Optical Neurolink Device is to transmit a signal wirelessly from an ECoG-like array through models of biological skin. This goal was divided into the following objectives:

1. ✓ Build a transmitter circuit that amplifies and transmits ECoG-like signals wirelessly.
2. ✓ Build a receiver that detects the wirelessly transmitted signals through a tissue phantom.
3. ✓ Utilize tissue phantoms with similar properties to skin for prototype development.
4. ✓ Analyze the thermal changes that occur in the device to ensure safety for the patient.

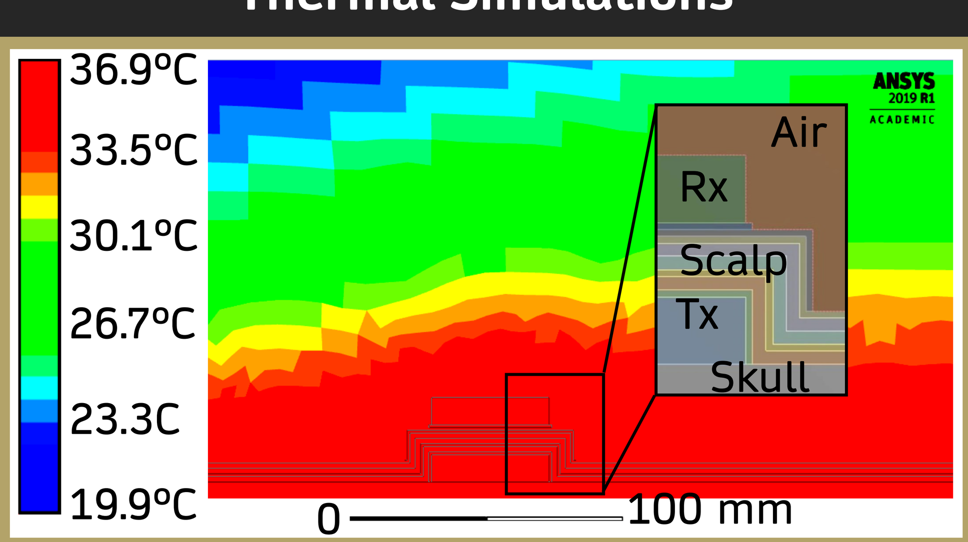
Optical Neurolink in Biological Model



Software & Circuitry



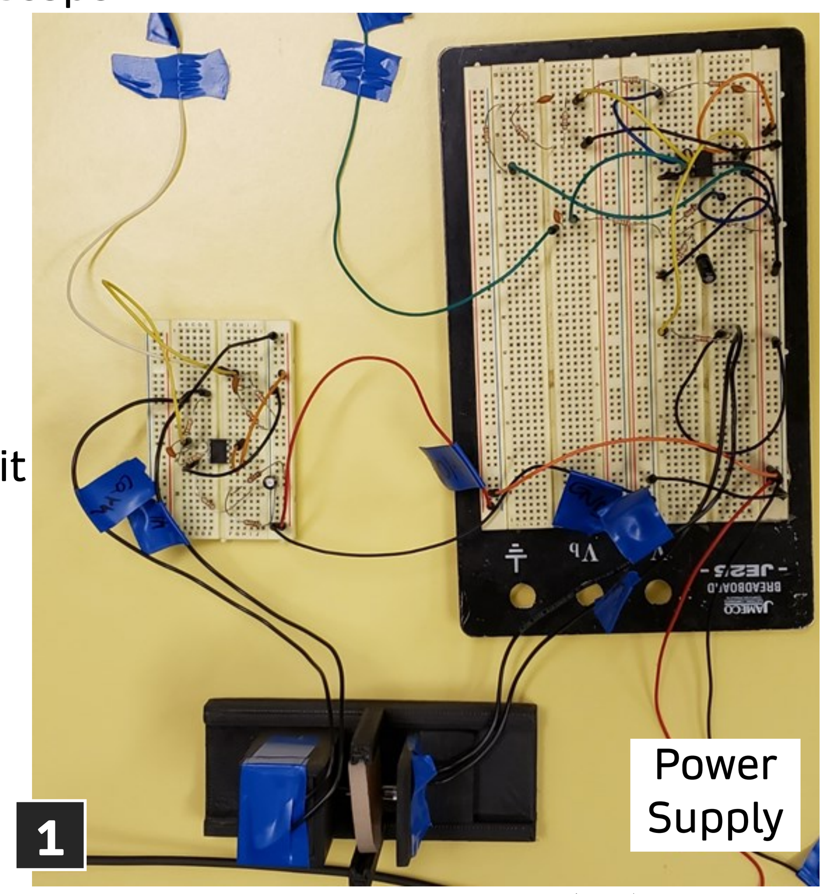
Thermal Simulations

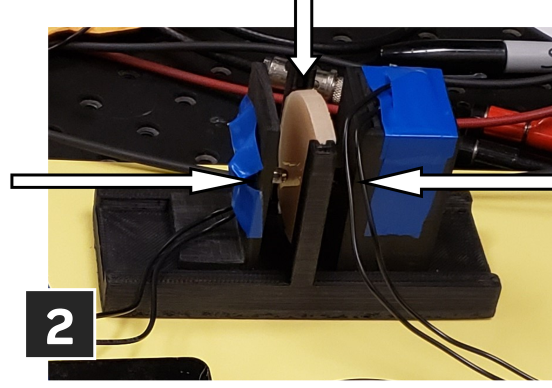


Prototype 1 (Sept.-Oct.)

Prototype 1 **(1)** features:

- Tissue phantom with skin-like refractive index
- Sliding track alignment and 3D printed housing **(2)**
- Breadboard circuitry implementation

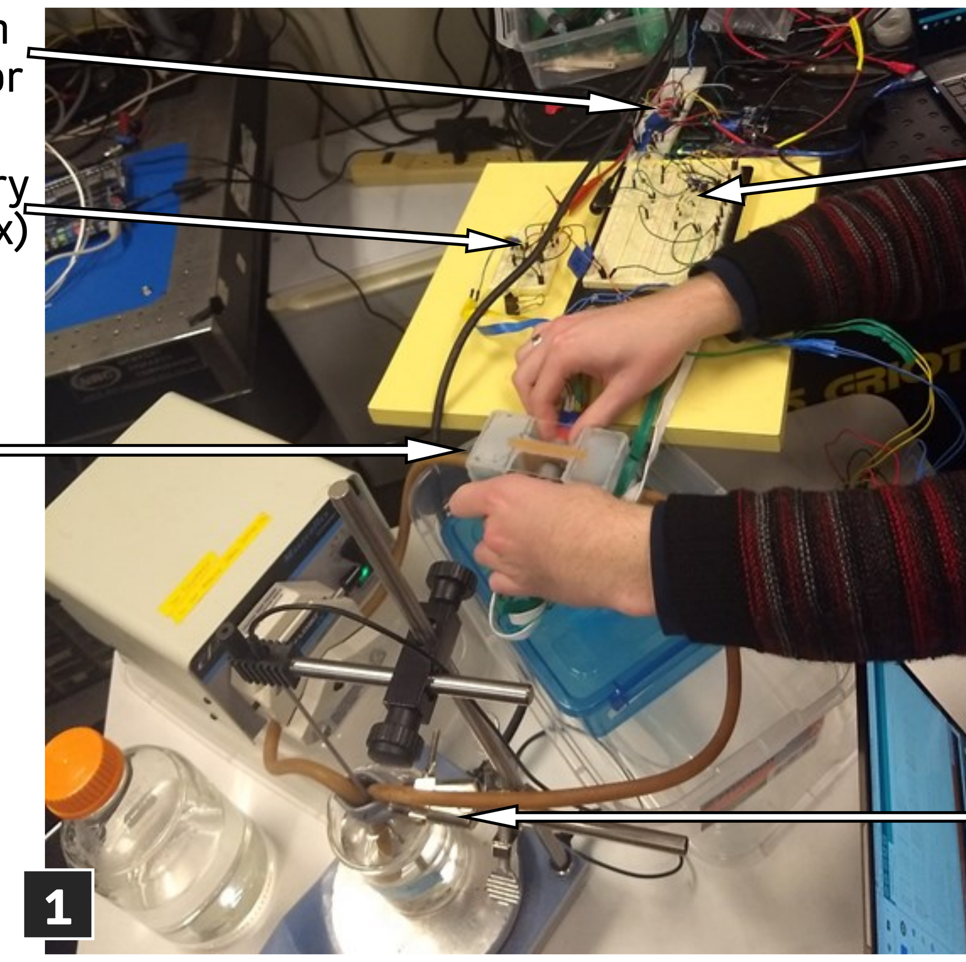


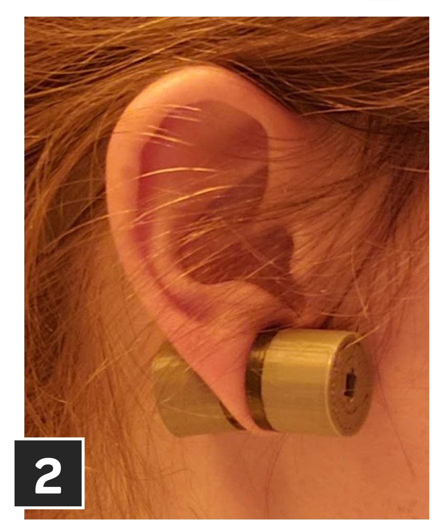


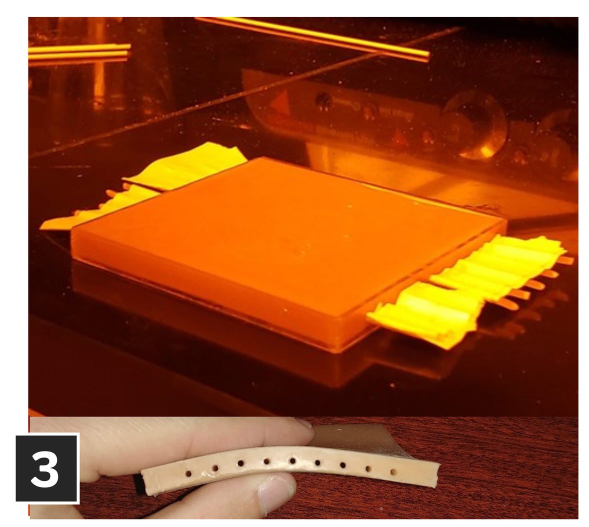
Prototype 2 (Oct.-Feb.)

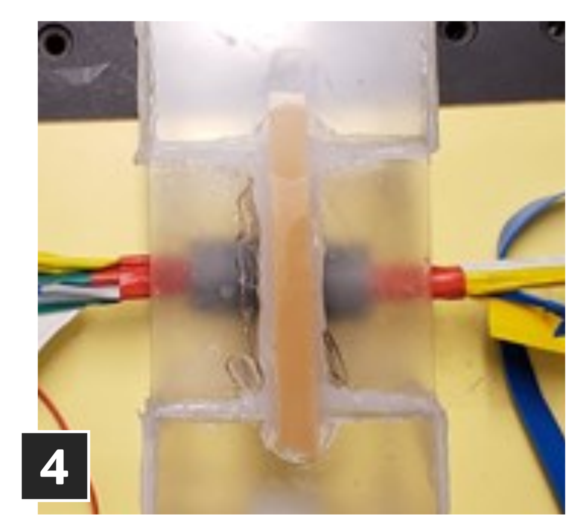
Prototype 2 **(1)** features:

- Magnetic alignment and 3D printed housing system **(2)**
- Linearly vascularized tissue phantom **(3, 4)**
- Encoding and decoding software, driven by an Arduino Uno and multiplexor





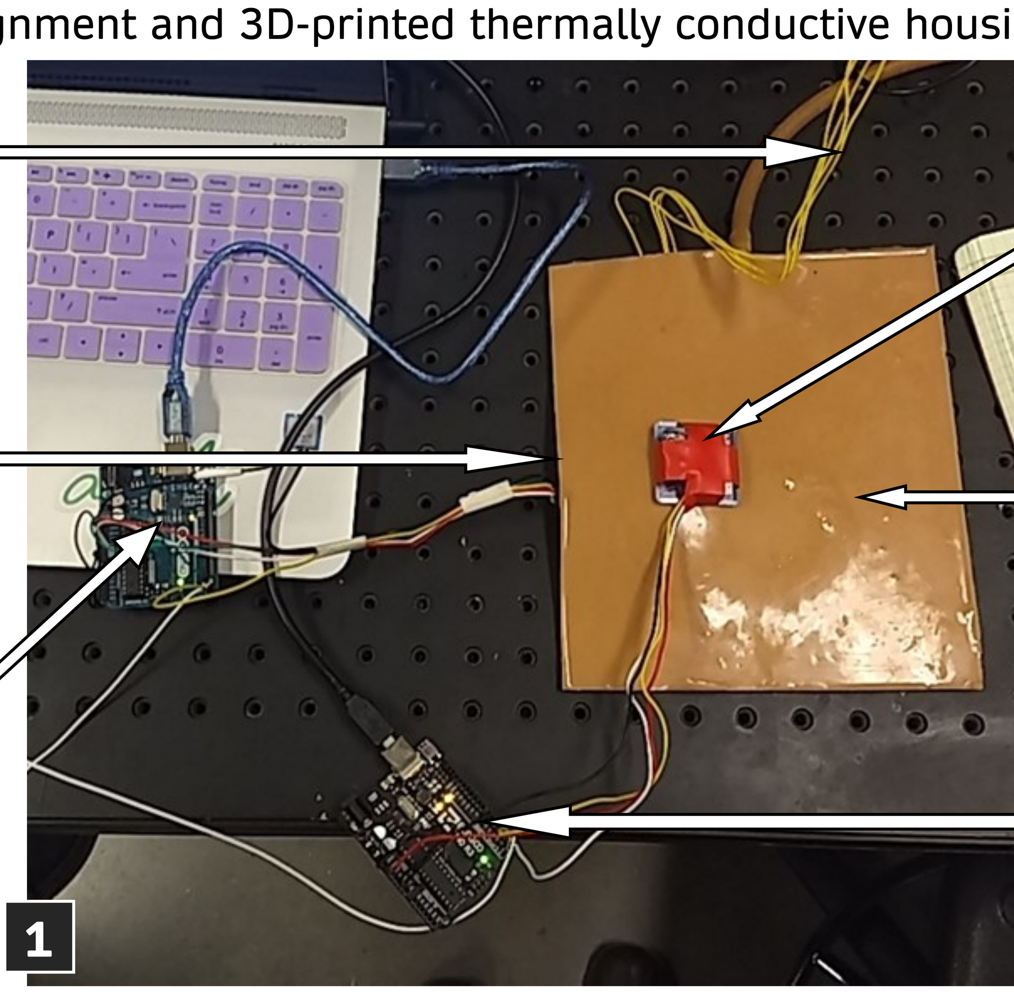


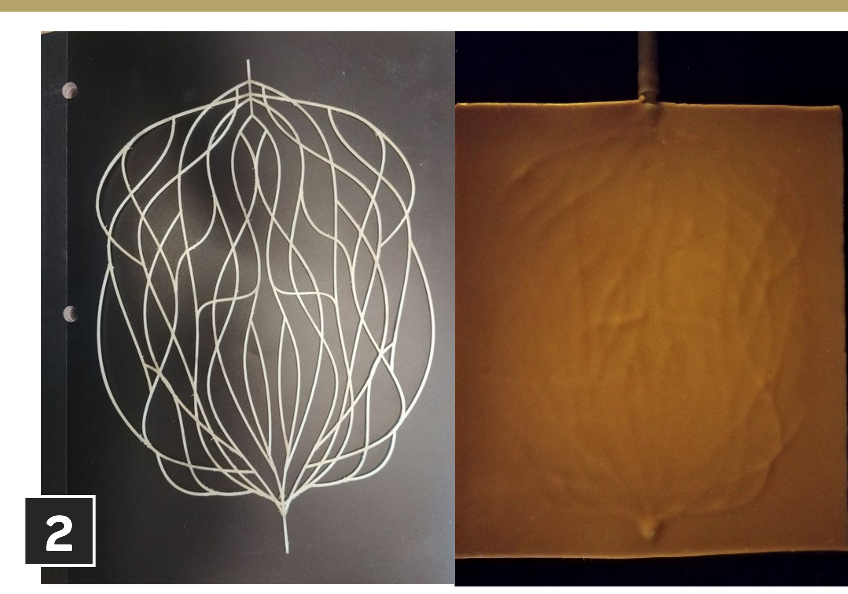


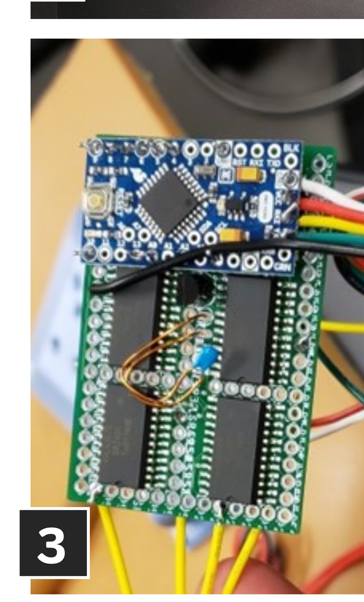
Prototype 3 (Feb.-Mar.)

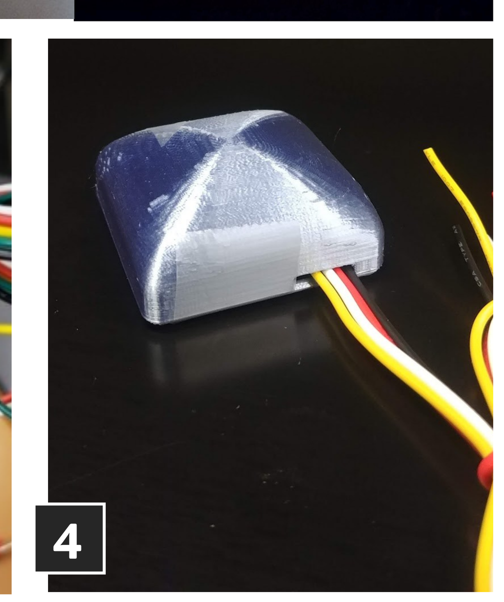
Prototype 3 **(1)** features:

- Complex 3D-printed vasculature in tissue phantom **(2)**
- Custom-designed PCB implemented **(3)**
- Quad-magnetic alignment and 3D-printed thermally conductive housing **(4)**









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Validation of Results vs. Requirements

Criterion	Requirement / Limit	Prototype 1 Results	Prototype 2 Results	Prototype 3 Results
Tx Temperature Change	≤ 2 °C	Δ from baseline: 1.2°C	Avg. temp.: 36.75°C Δ from body temp.: -0.15°C	Δ from baseline: 1.27°C
Rx Temperature Change	≤ 2 °C	Δ from baseline: 1.2°C	Avg. temp.: 39.15°C Δ from body temp.: 2.15°C	Δ from baseline: 0.56°C
Tissue	1.33-1.50	1.42	1.42	1.42
Aggregate Data Rate	≥ 1 Mb/s	510Hz-1.5kHz	351Hz-2.44kHz	3.67 kb/s
Aggregate Error Rate	$< 10^{-6}$	N/A	N/A	54%
Transmission Distance	0.908 mm < d < 6.96 mm	6.96 mm: 3.35 V_{PP} received	6.96 mm: 40 mV_{PP} received	6.96 mm: 640.6 mV_{PP} rec.d
Number of Signals	≥ 10 electrodes in one ECoG-like device	1 signal No ECoG-like device	1 signal, 16 possible inputs No ECoG-like device	4 signals, 64 possible inputs No ECoG-like device
Alignment	Transmitter stays aligned with receiver	No TP: Maintains x-y, does not return to home position. TP: Maintains x-y, does not return to home position.	No TP: Maintains x-y, returns to home position. TP: Not maintained.	No TP: Maintains x-y, returns to home position. TP: Not maintained.
Thermal Simulations	Closely approximates measured temp. in device.	20mW heat generation from Tx and Rx; Δ from body temperature= 0.09 °C 200mW heat generation from Tx and Rx; Δ from body temperature= 4.738 °C Max. temperature that can be sustained by tissue: 43°C.		

Ethical Considerations

- Patient long-term health
- Security of transmitted information
- No animal testing
- Considered diverse skin tones

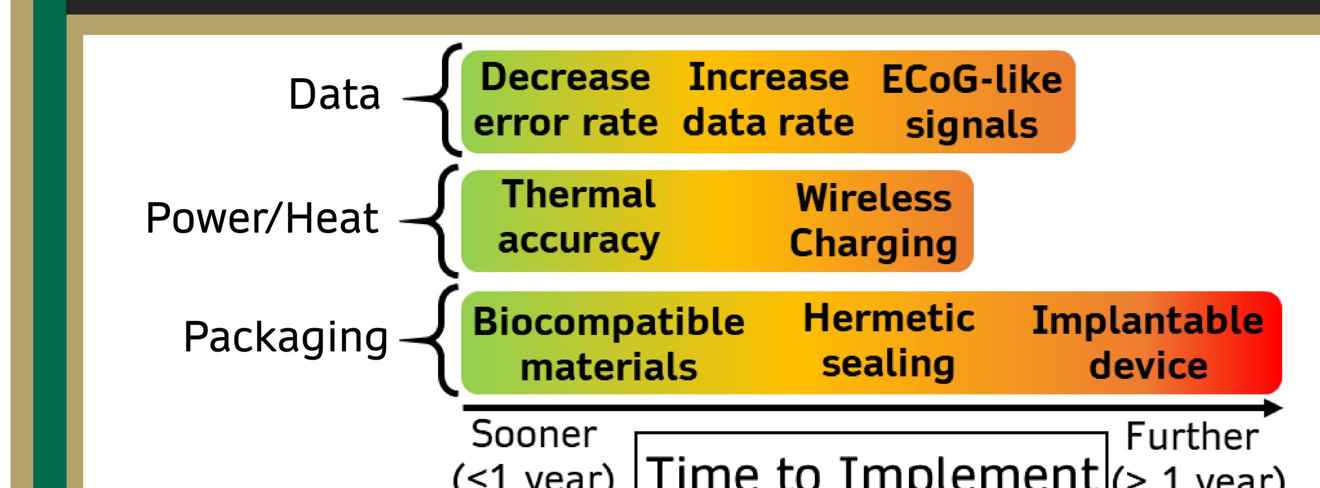
Conclusion

- 3 iterative prototypes demonstrated that a wireless, Optical Neurolink is feasible
- Some objectives were met, others will require future work.

Accomplishments

- Publication in Rocky Mountain Bioengineering Symposium
- Successful proof of concept
- All four team members experienced project leadership
- Created a foundation for project continuation
- Cross-disciplinary engineering experience
- Founded a long-term project

Future Work



Lessons Learned

- Communication skills
- Adapting to various leadership styles
- Managing tasks/time for a large project (i.e. Gantt charts)
- Start and fail early: make incremental prototypes sooner rather than later
- Asking/trusting team members for help
- Documenting more than is anticipated to be necessary
- Adapting to impossible-to-predict circumstances (🦠)