Marmoset Neural Logger Project

Building a high performance neural logging system for free-moving marmoset monkeys.

Student: **Martin Lombard**
Supervisors: **Tim Constandinou, Ian Williams**

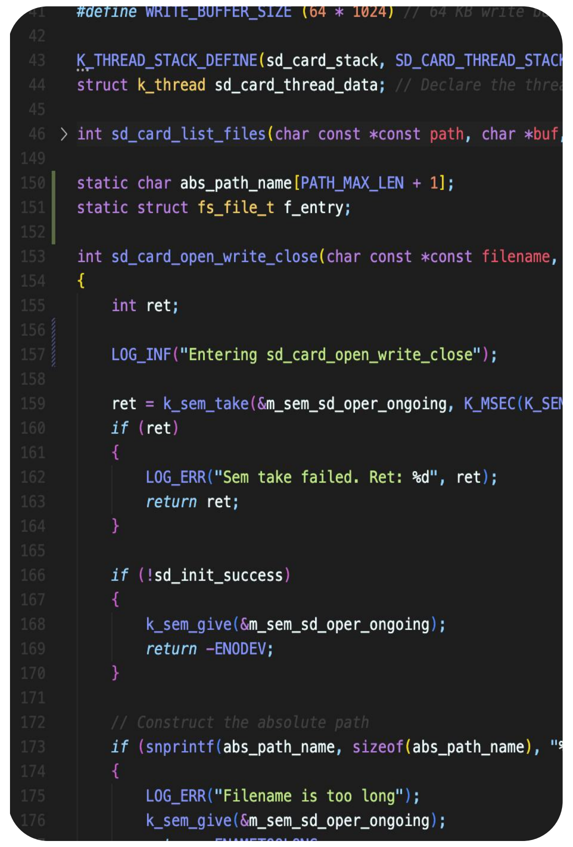
Newcastle University

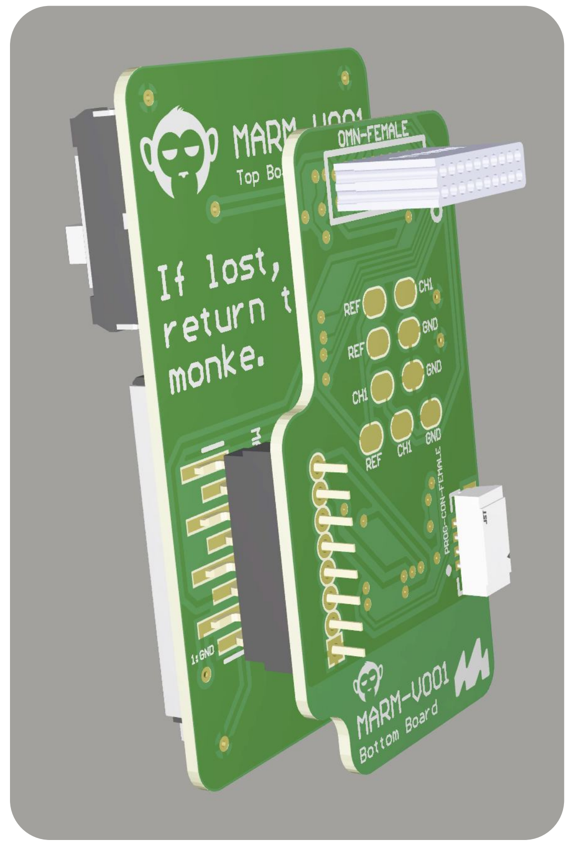
Collaboration

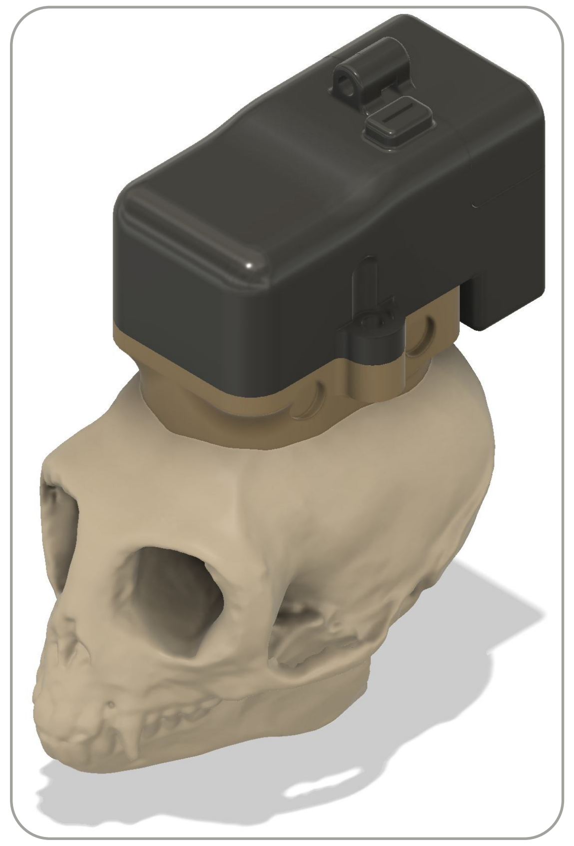
IMPERIAL

Neuroscience Study

Device Development

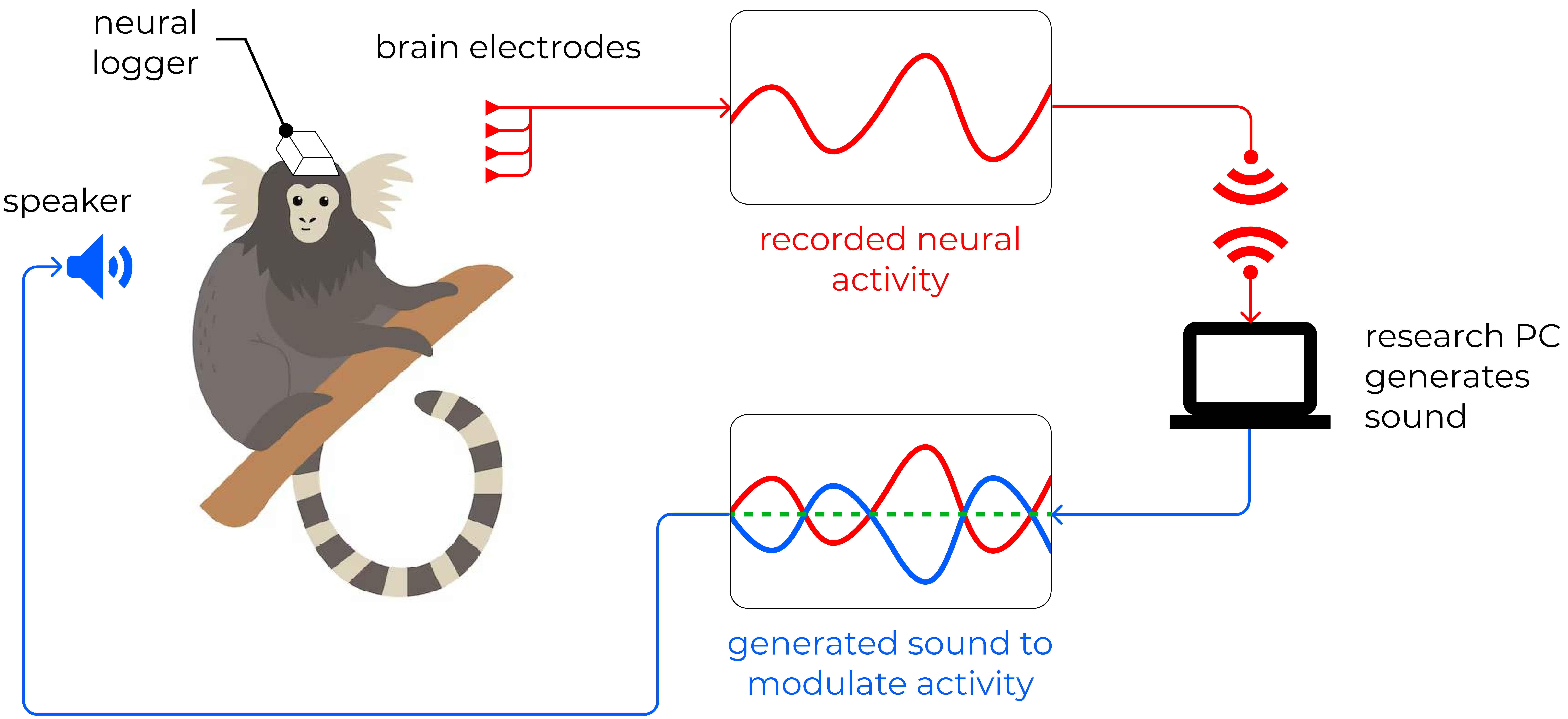




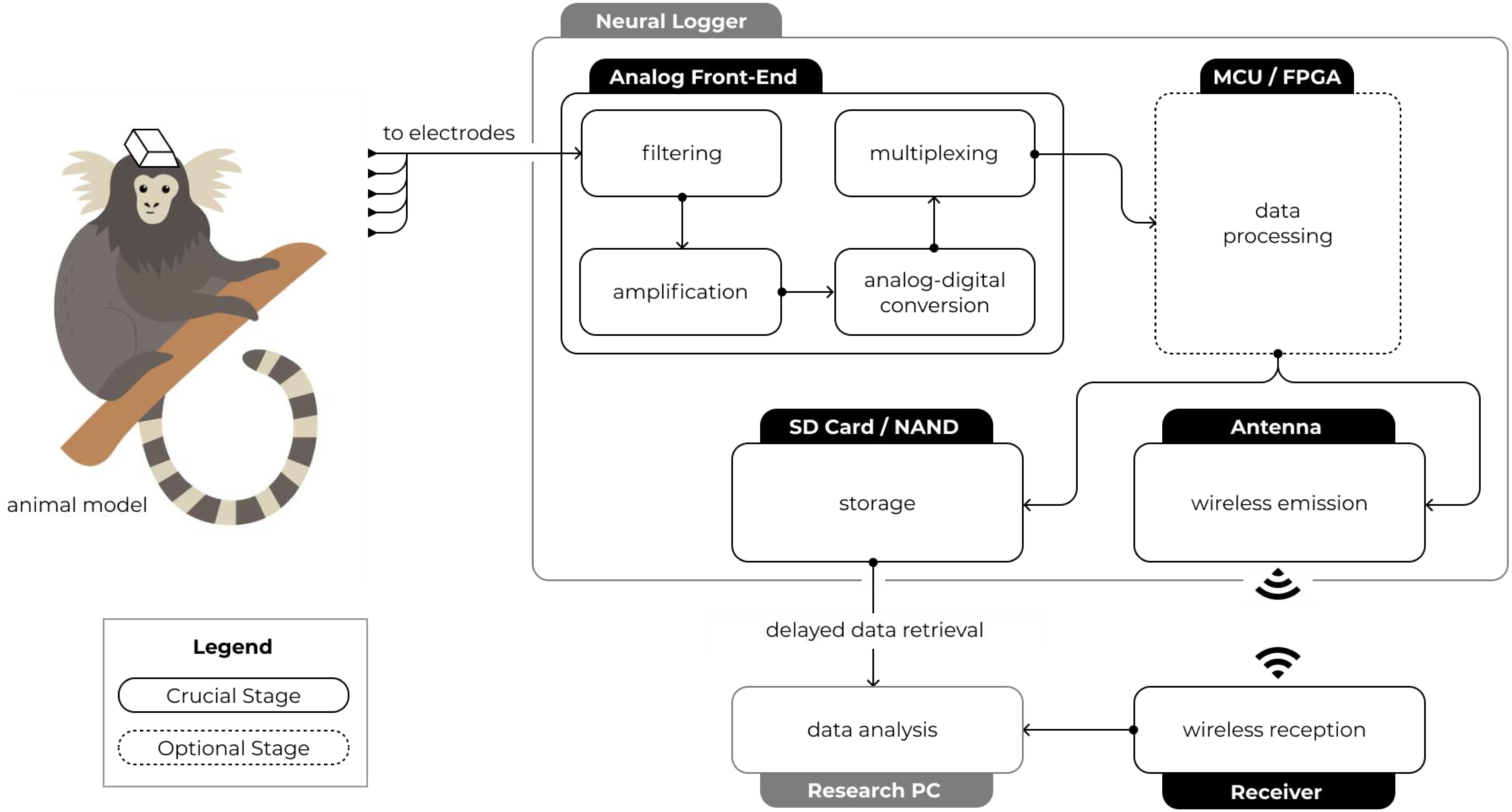


Full System

CLAS - Closed Loop Auditory Stimulation



Neural Loggers



www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

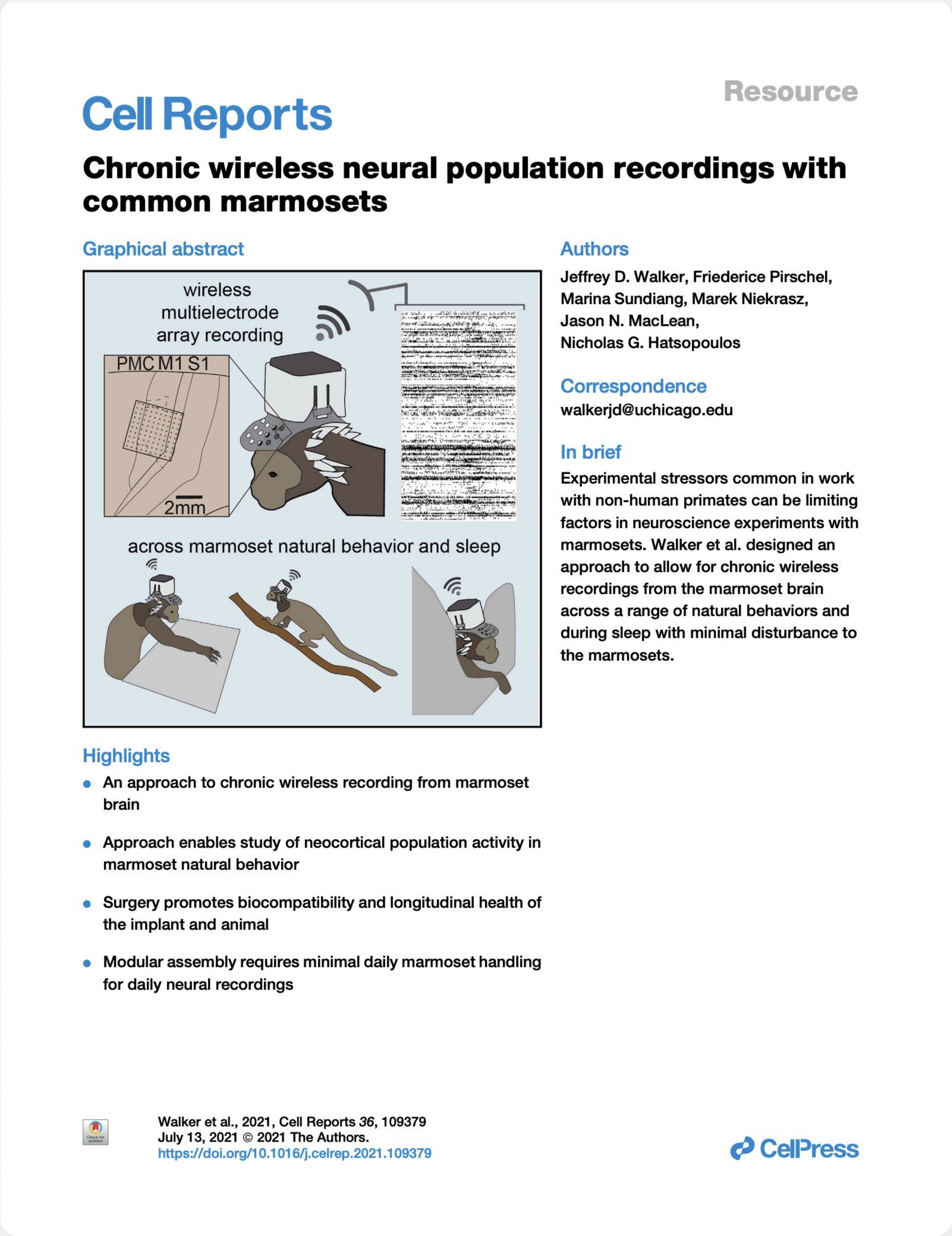
TaiNi: Maximizing research output whilst improving animals' welfare in neurophysiology experiments

Received: 9 March 2017
Accepted: 4 July 2017
Published online: 14 August 2017

Zhou Jiang[1,4], John R. Huxter[2], Stuart A. Bowyer[1,4], Anthony J. Blockeel[2], James Butler[2], Syed A. Imtiaz[1,4], Keith A. Wafford[2], Keith G. Phillips[2], Mark D. Tricklebank[3], Hugh M. Marston[2] & Esther Rodriguez-Villegas[1,4]

Understanding brain function at the cell and circuit level requires representation of neuronal activity through multiple recording sites and at high sampling rates. Traditional tethered recording systems restrict movement and limit the environments suitable for testing, while existing wireless technology is still too heavy for extended recording in mice. Here we tested TaiNi, a novel ultra-lightweight (<2 g) low power wireless system allowing 72-hours of recording from 16 channels sampled at ~19.5 KHz (9.7 KHz bandwidth). We captured local field potentials and action-potentials while mice engaged in unrestricted behaviour in a variety of environments and while performing tasks. Data was synchronized to behaviour with sub-second precision. Comparisons with a state-of-the-art wireless system demonstrated a significant improvement in behaviour owing to reduced weight. Parallel recordings with a tethered system revealed similar spike detection and clustering. TaiNi represents a significant advance in both animal welfare in electrophysiological experiments, and the scope for continuously recording large amounts of data from small animals.

SCIENTIFIC REPORTS | 7: 8086 | DOI:10.1038/s41598-017-08078-8



Cell Reports

Resource

Chronic wireless neural population recordings with common marmosets

Graphical abstract

Authors

Jeffrey D. Walker, Friederice Pirschel, Marina Sundiang, Marek Niekrasz, Jason N. MacLean, Nicholas G. Hatsopoulos

Correspondence

walkerjd@uchicago.edu

In brief

Experimental stressors common in work with non-human primates can be limiting factors in neuroscience experiments with marmosets. Walker et al. designed an approach to allow for chronic wireless recordings from the marmoset brain across a range of natural behaviors and during sleep with minimal disturbance to the marmosets.

Highlights

- An approach to chronic wireless recording from marmoset brain
- Approach enables study of neocortical population activity in marmoset natural behavior
- Surgery promotes biocompatibility and longitudinal health of the implant and animal
- Modular assembly requires minimal daily marmoset handling for daily neural recordings

Walker et al., 2021, Cell Reports 36, 109379
July 13, 2021 © 2021 The Authors.
https://doi.org/10.1016/j.celrep.2021.109379

CellPress

Journal of Neuroscience Methods 316 (2019) 103–116

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

ONEIROS, a new miniature standalone device for recording sleep electrophysiology, physiology, temperatures and behavior in the lab and field

Bertrand Massot[a], Sébastien Arthaud[b], Baptiste Barrillot[b], Johanna Roux[b], Gianina Ungurean[b,c], Pierre-Hervé Luppi[b], Niels C. Rattenborg[c], Paul-Antoine Libourel[b,*]

ARTICLE INFO

ABSTRACT

1. Introduction

Neural Logger Literature


Cell Reports

Resource

Chronic wireless neural population recordings with common marmosets

Graphical abstract

wireless multielectrode array recording

PMC M1 S1

2mm

across marmoset natural behavior and sleep

Authors

Jeffrey D. Walker, Friederice Pirschel, Marina Sundiang, Marek Niekrasz, Jason N. MacLean, Nicholas G. Hatsopoulos

Correspondence

walkerjd@uchicago.edu

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https://doi.org/10.1016/j.celrep.2021.109379

CellPress

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REPORTS

ng research output
g animals' welfare
ogy experiments

Neural Logger Literature

\+

🔋 Autonomy
⚡ Channel Count
🧠 Sampling Rate
⚙️ Dimensions
💫 Plug-&-Play
🧑‍💻 Remote Operation

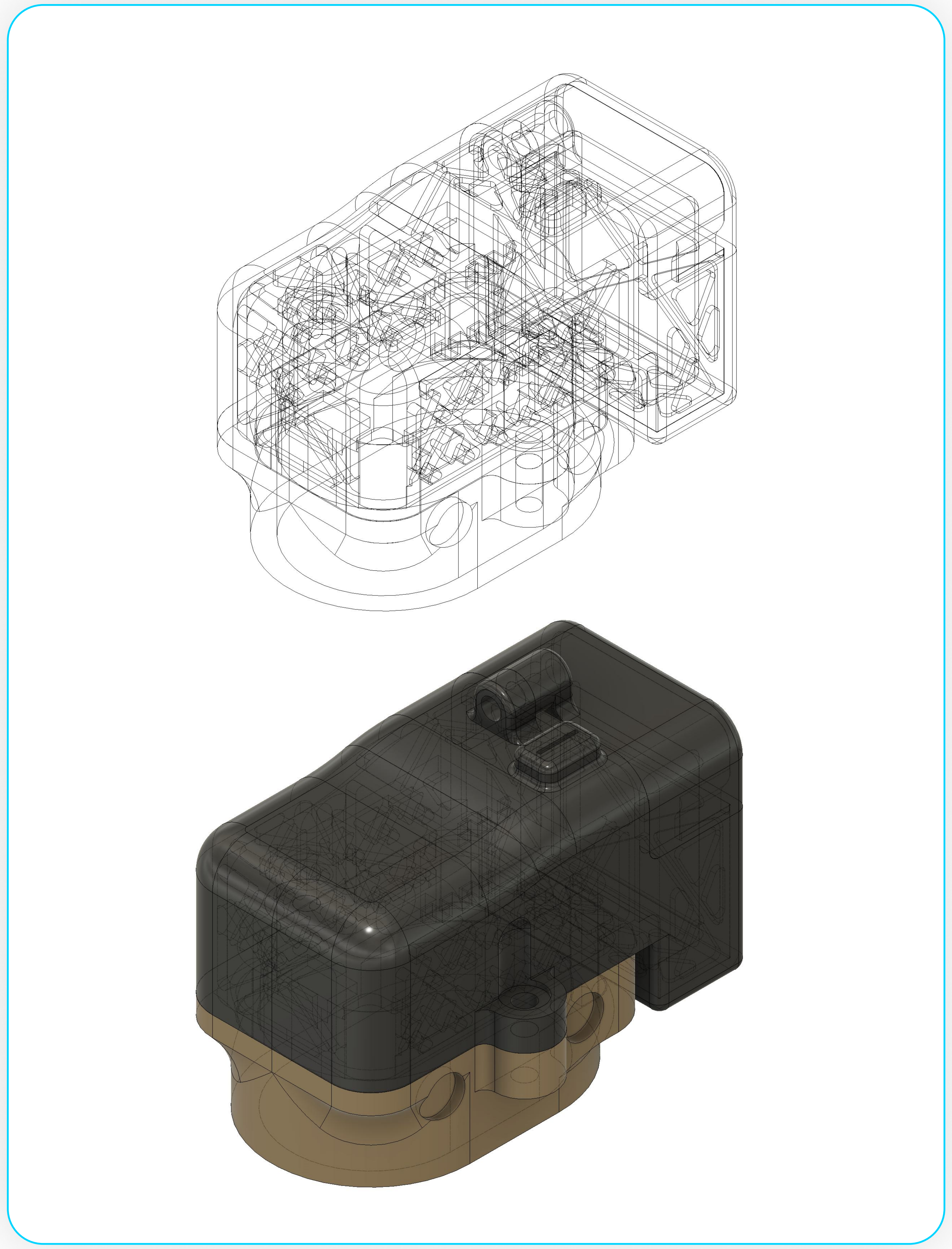
Newcastle University Needs

Target Specs

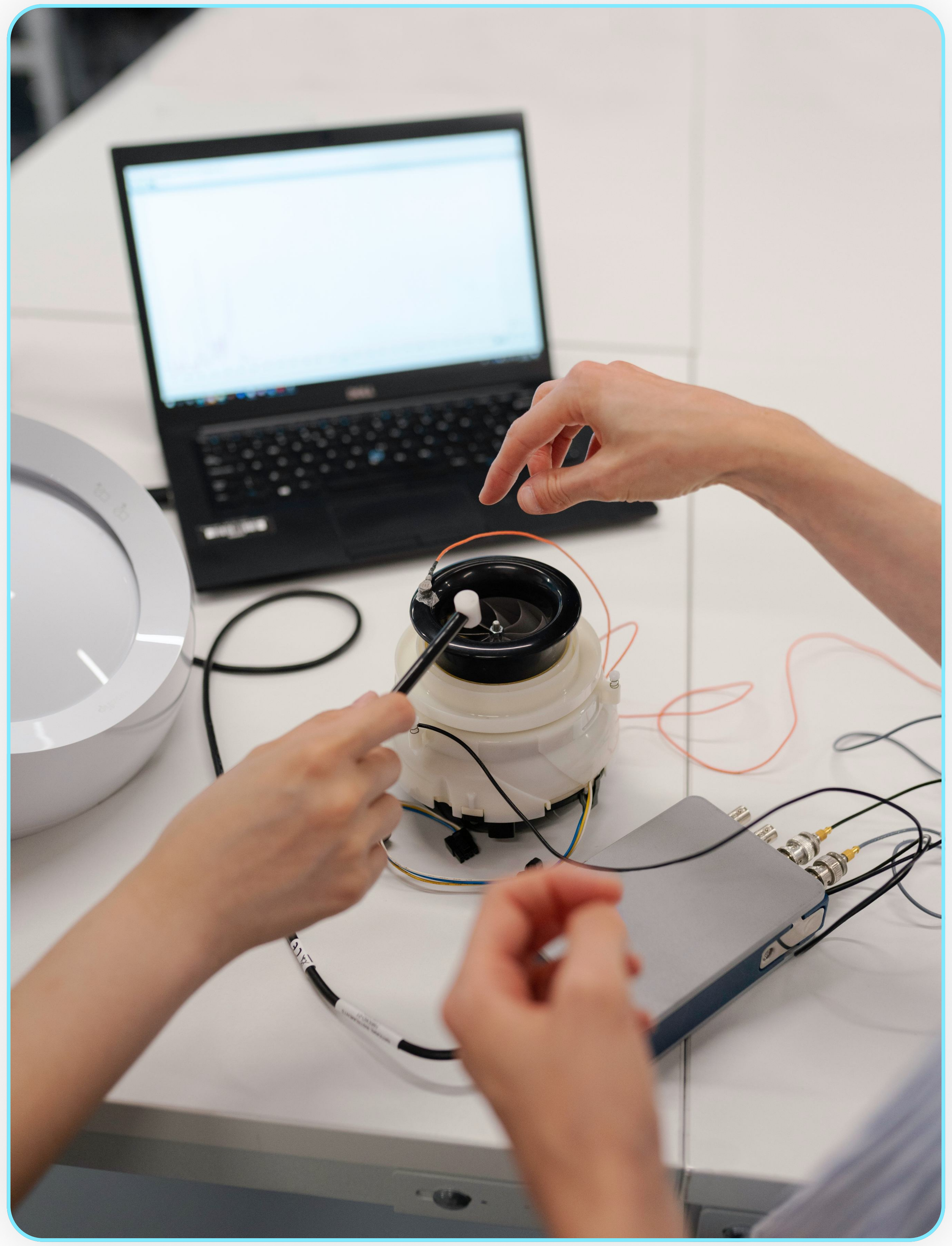
Code	Name	Value
E1	Autonomy	≥ 2 hrs
E2	Channel Count	≥ 16
E3	Sampling Rate	≥ 100 Hz/channel
M1	Dimensions	40 × 70 × 40 mm
M2	Weight	40-12 g
M3	Durability	High

Code	Name	Value
P1	Wireless Range	≥ 5 m
P2	Latency	< 10 ms
P3	Local Storage & Wireless	Yes
D1	Plug-&-Play	Under 2 min
D2	Remote Operation	Yes

Innovative Angles



Mechanical Focus



Ease of Use

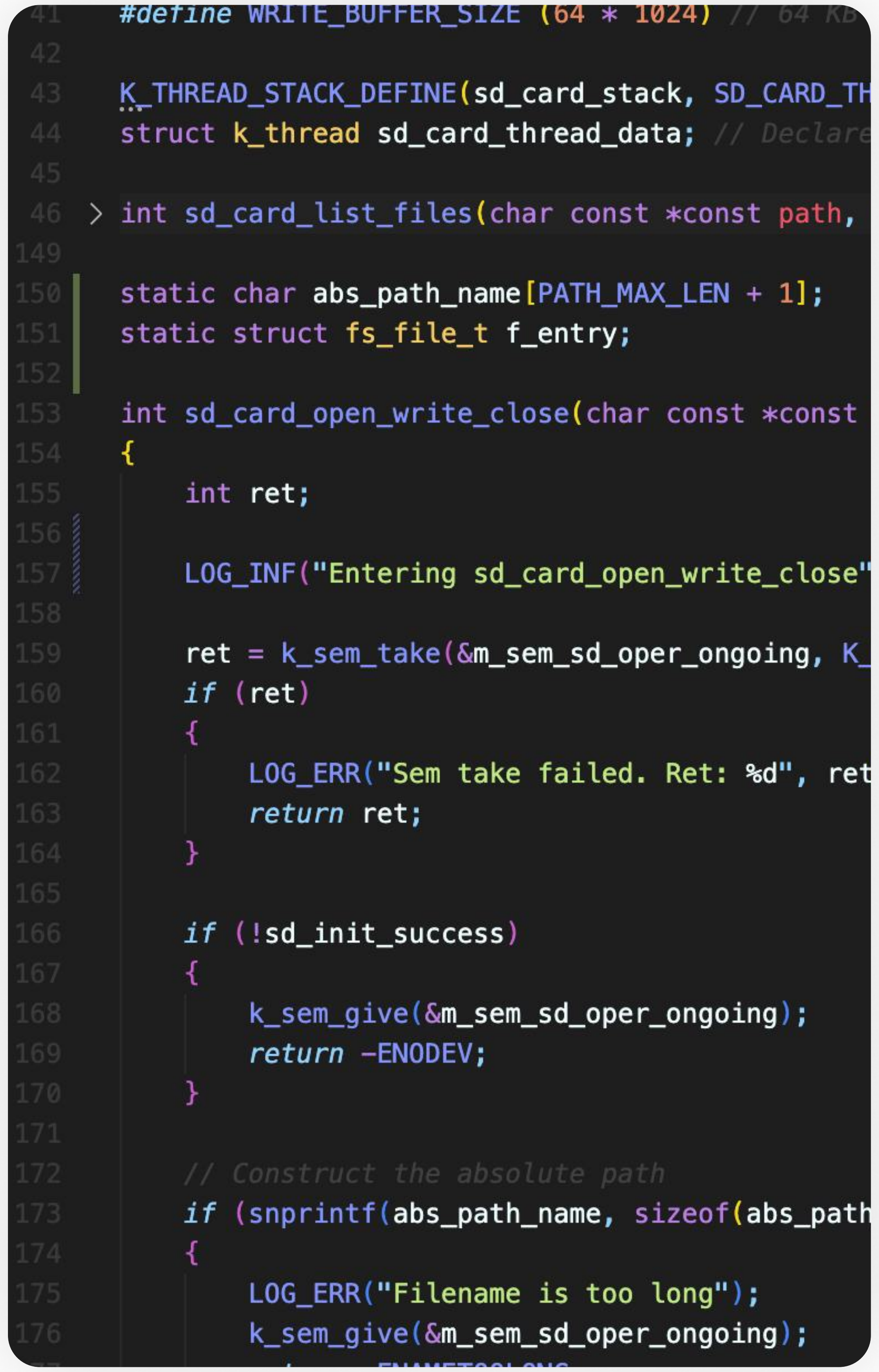
Simultaneous Wireless &
Local Storage

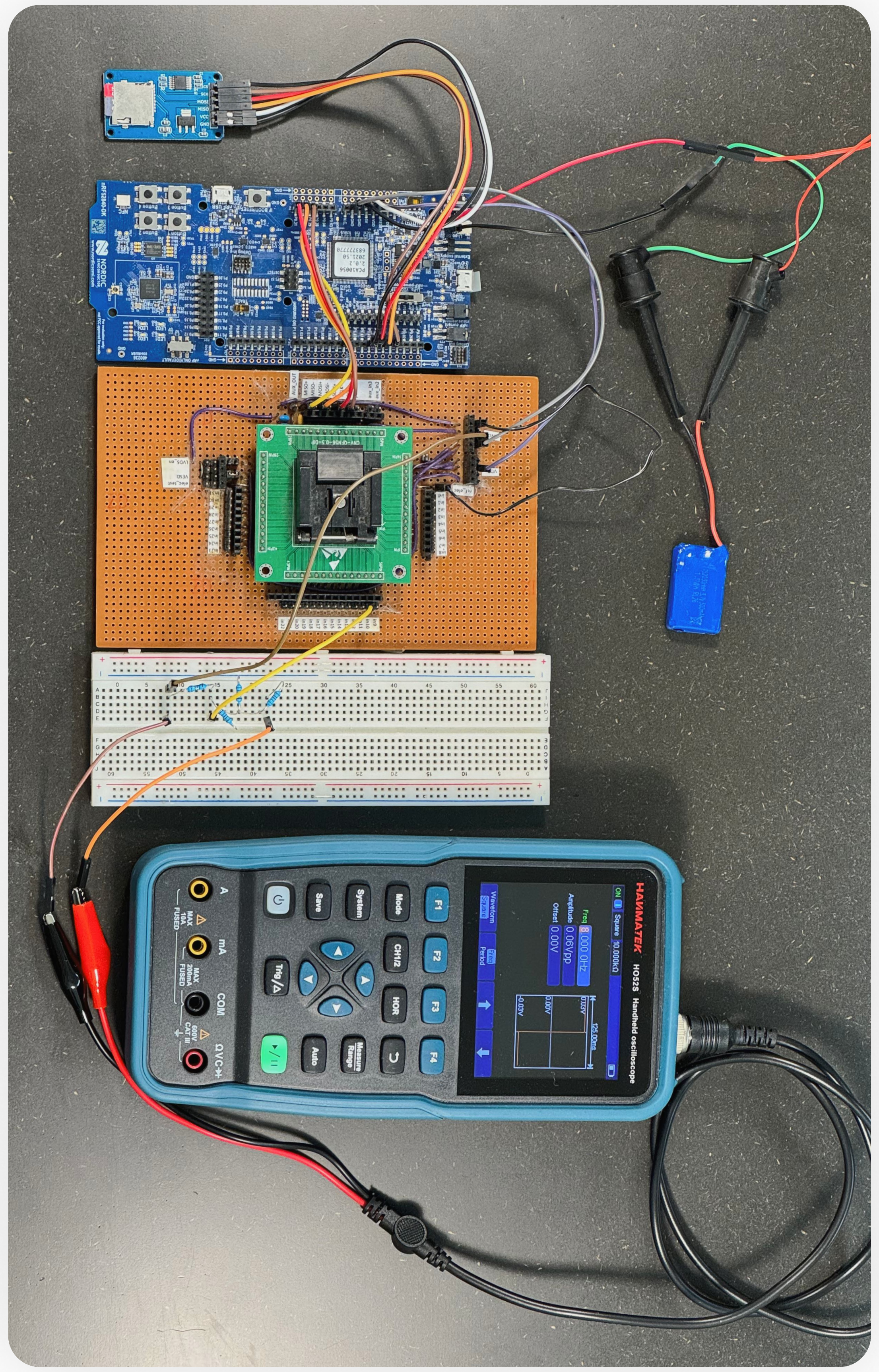
✅ **Full Firmware v1**

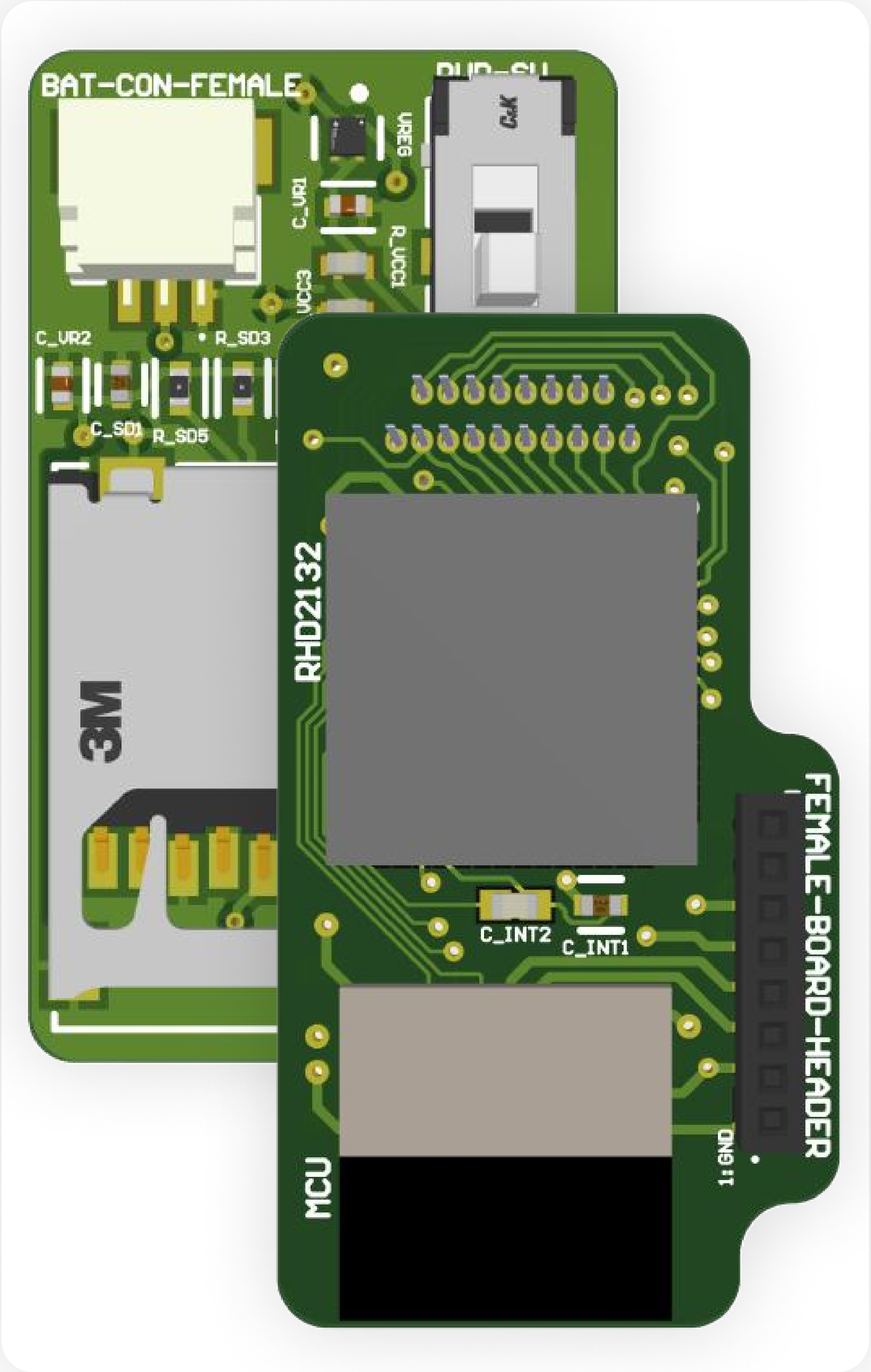
✅ **Electronics Prototype**

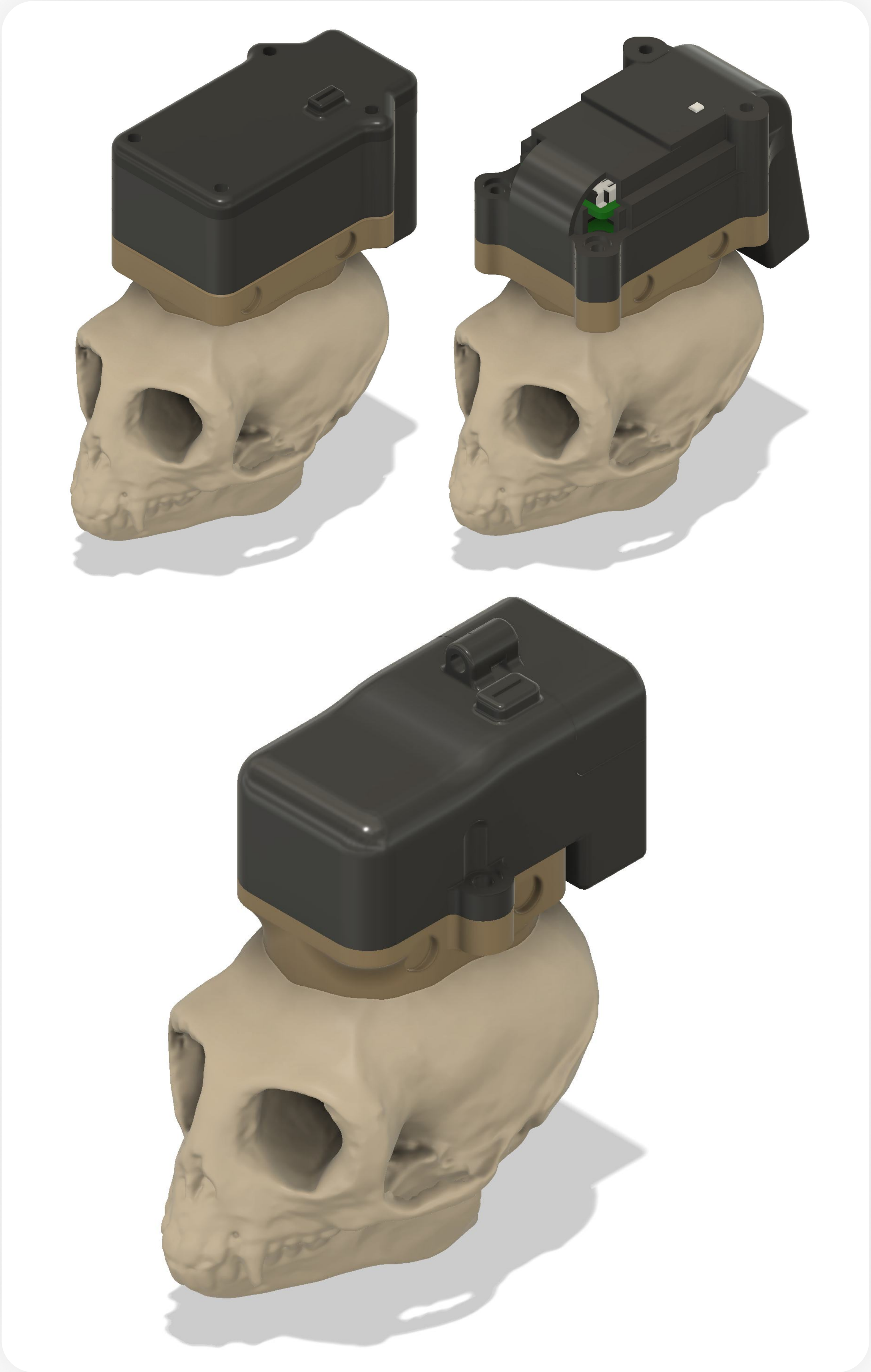
✅ **Stacked PCB Design**

✅ **3x Mechanical Iterations**



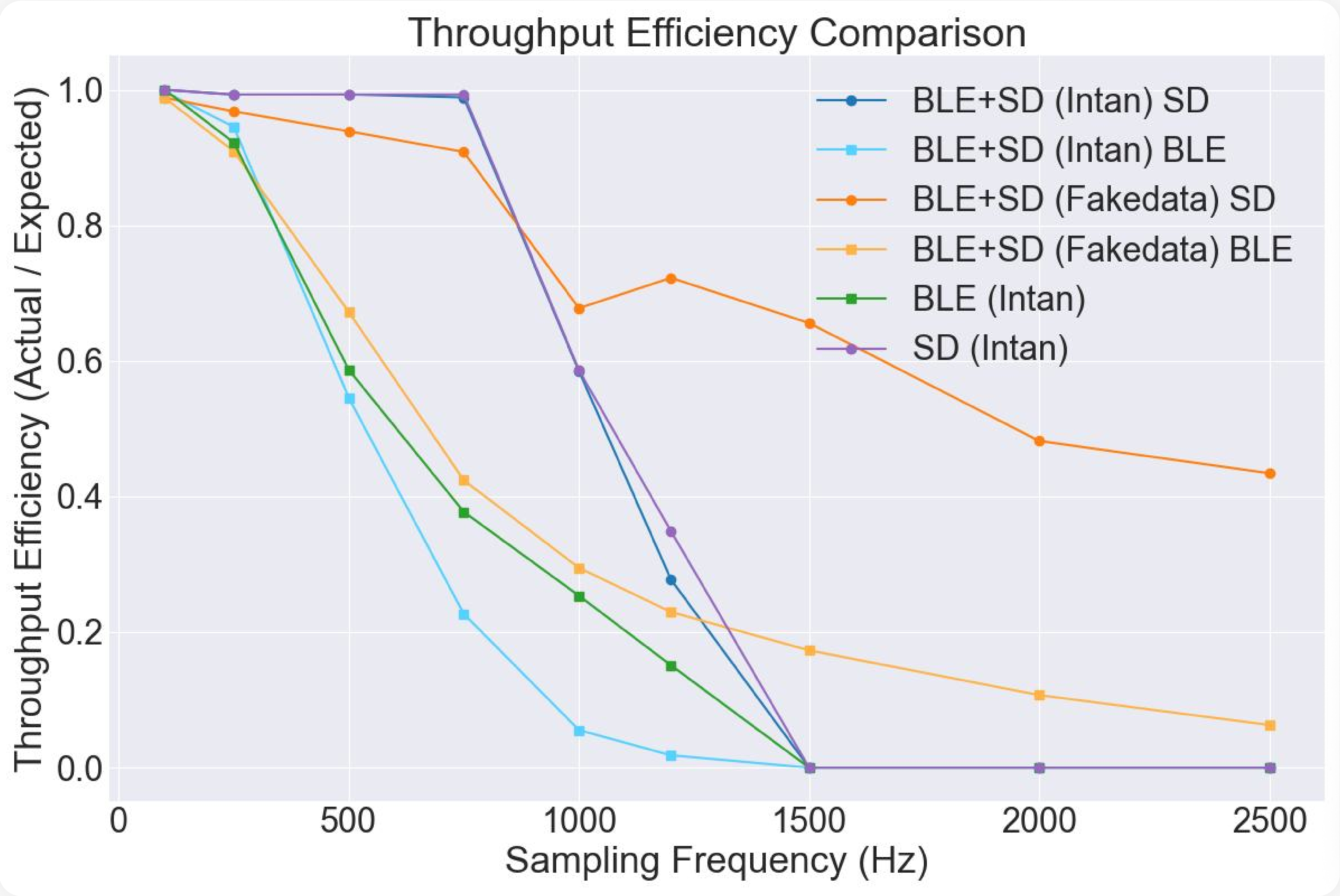


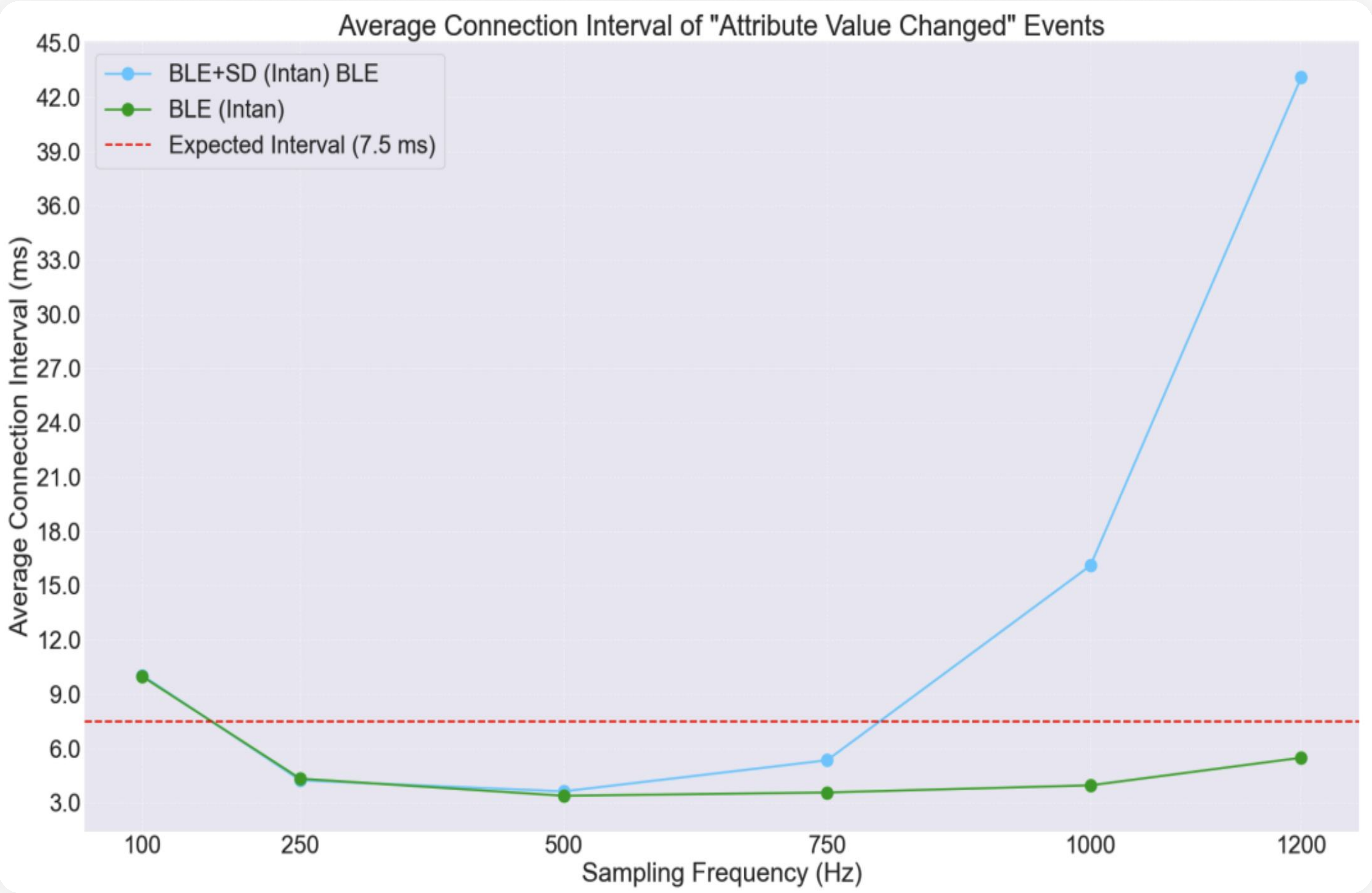




What I built!

Electronics & Firmware Results

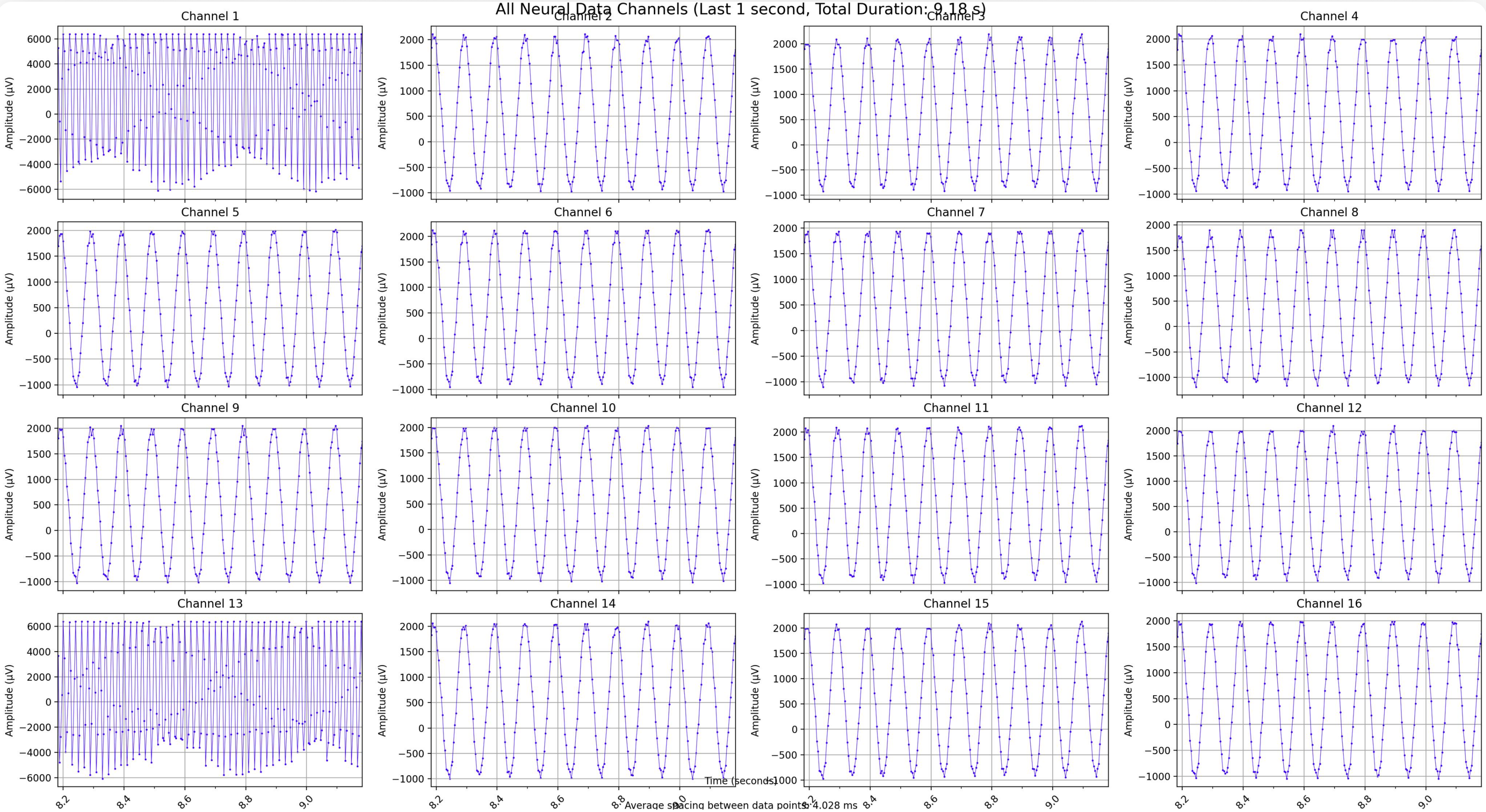




Highest stable recording frequency: **750 Hz**

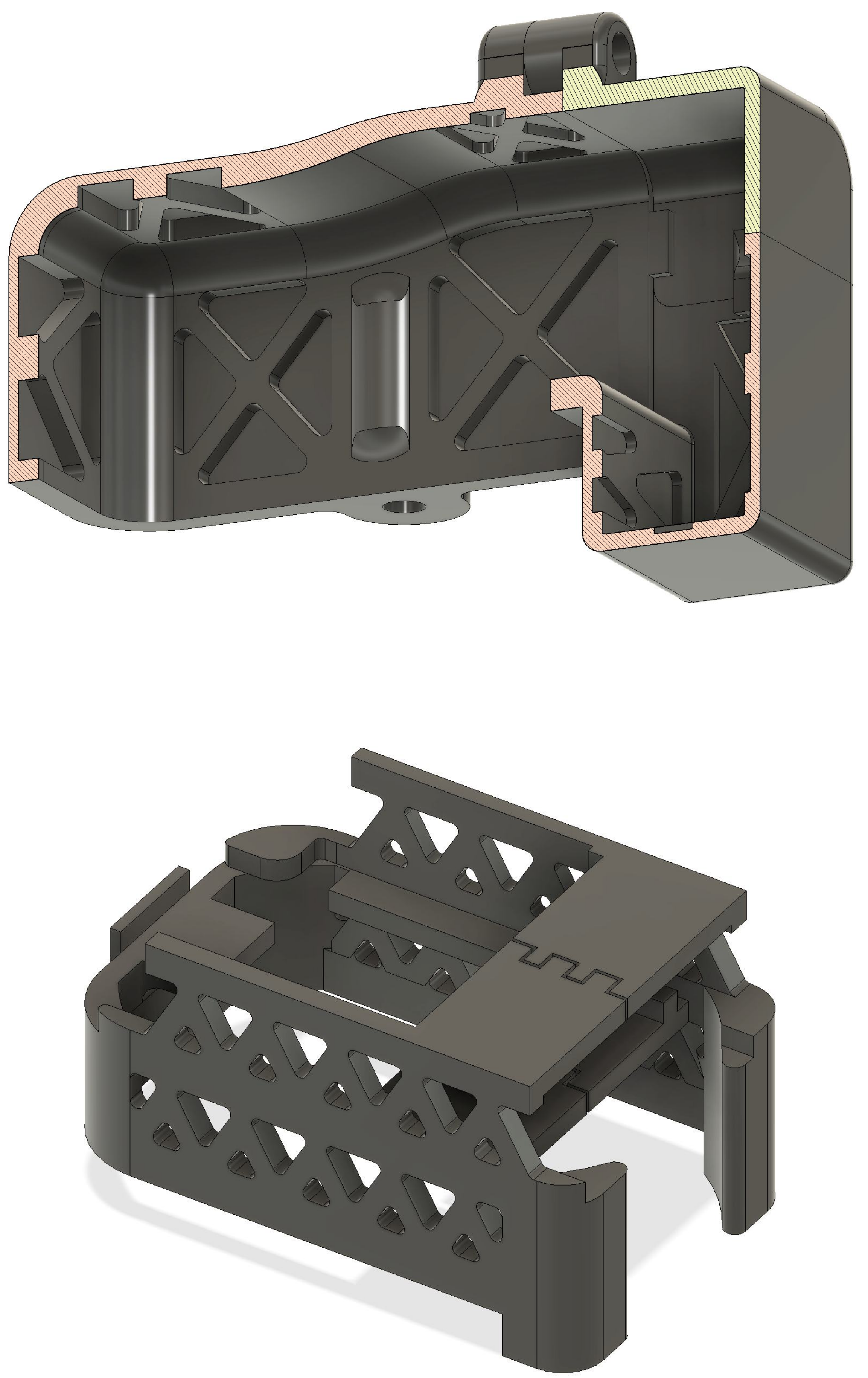
Highest recording frequency with appropriate BLE latency: **750 Hz**

Electronics & Firmware Results

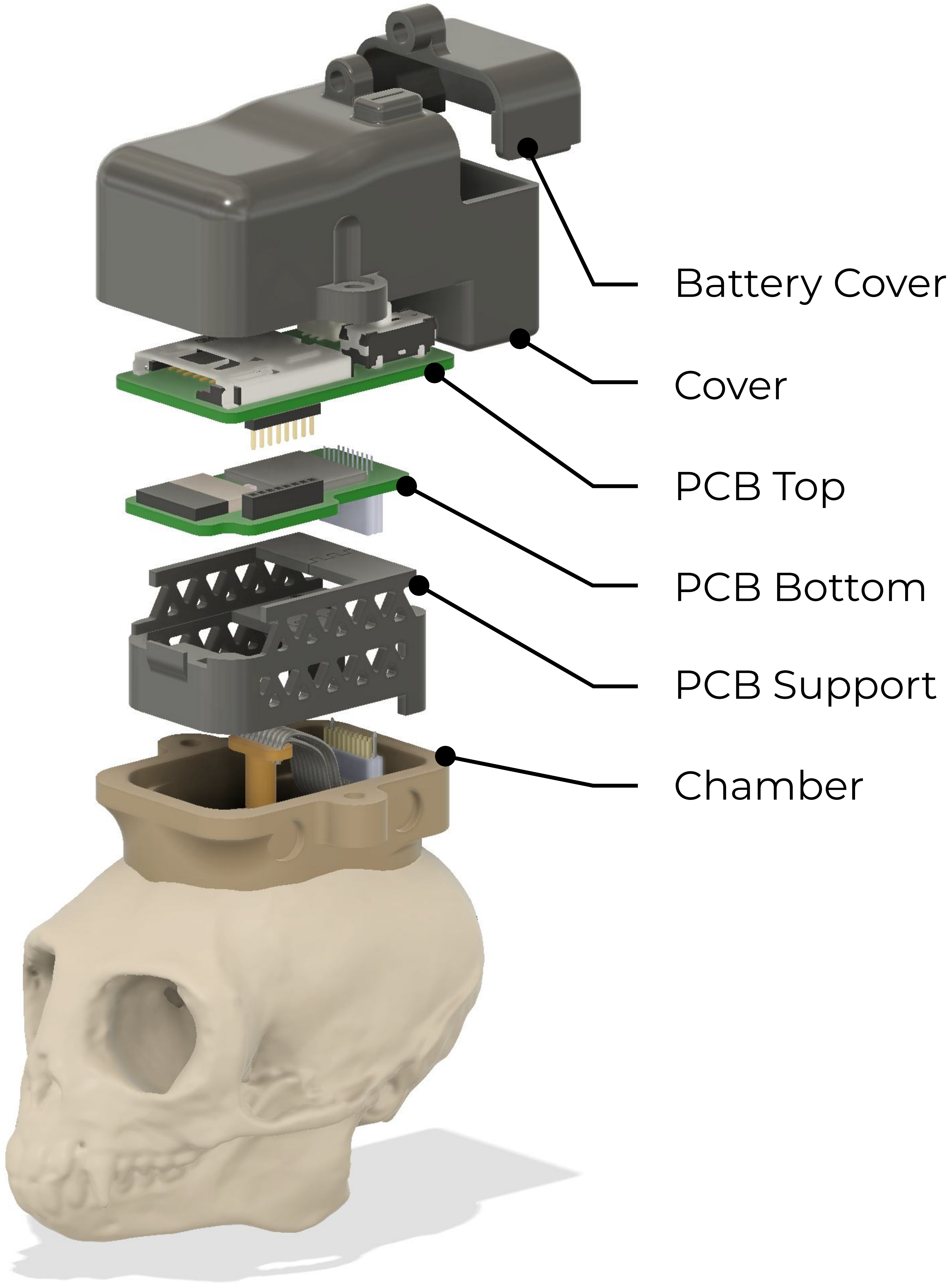


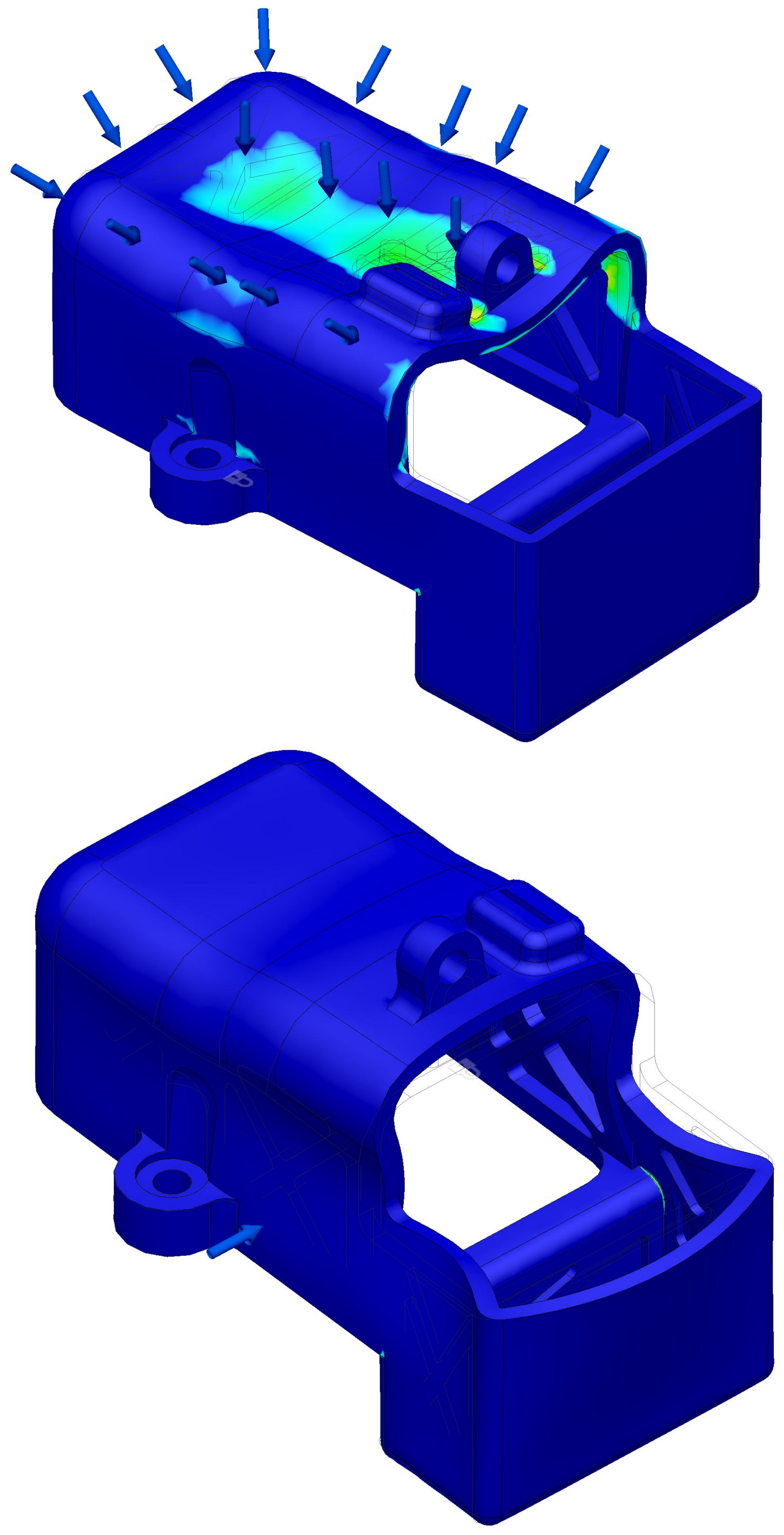
10 Hz sinusoidal signal recording

Mechanical Results



Weight Reduction Detail

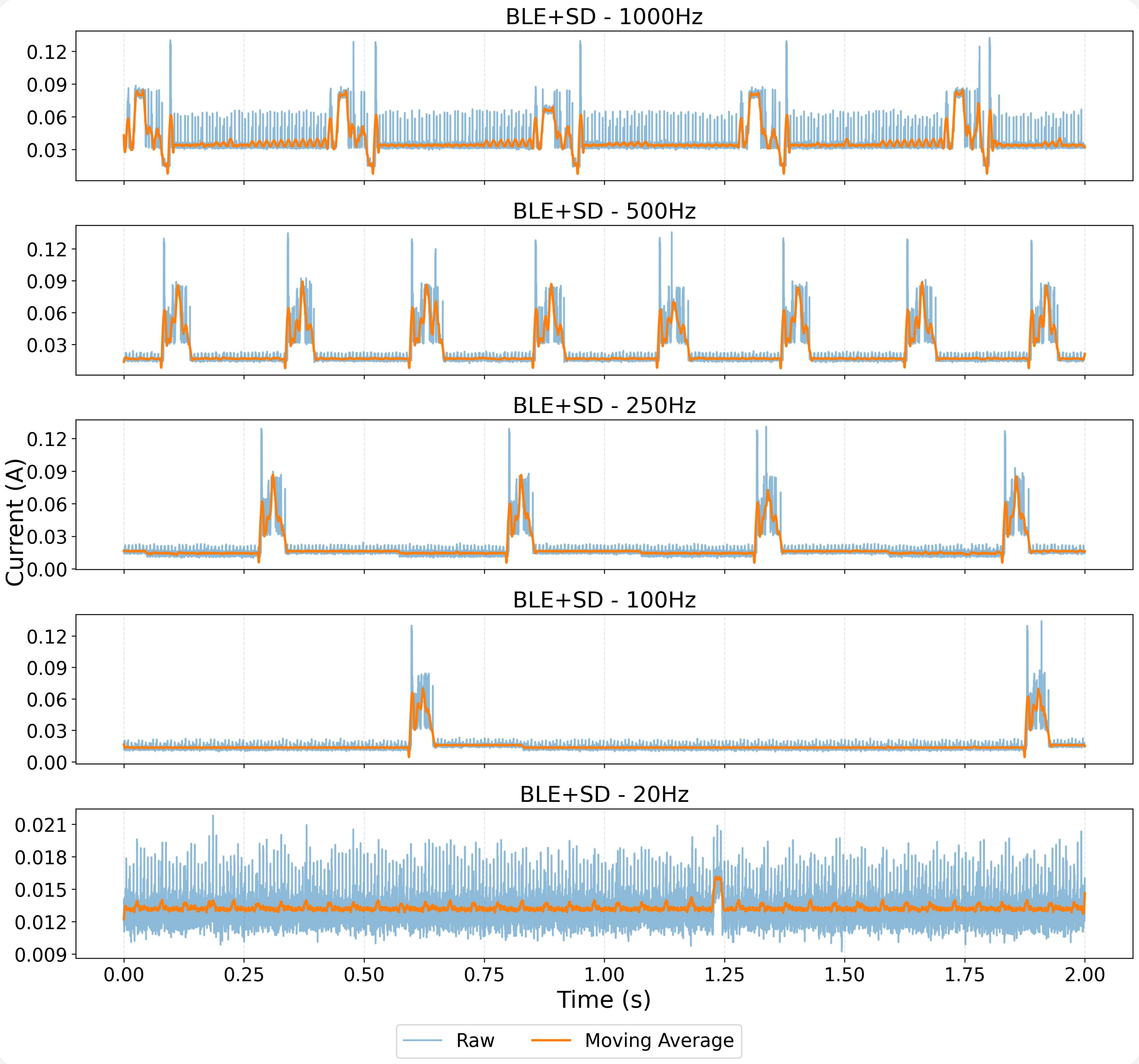


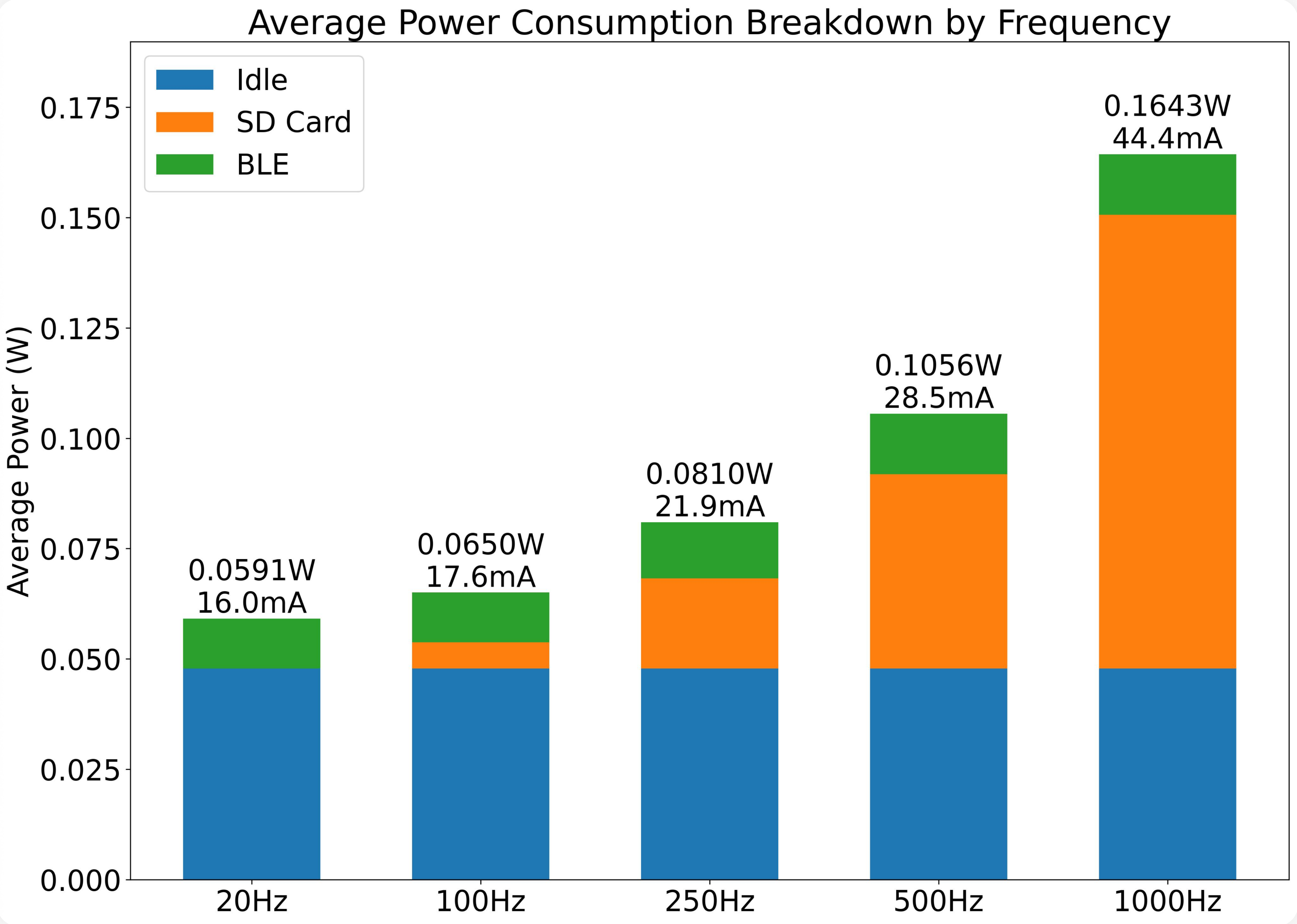


FEA Housing Toughness

Housing **resists drops**, and monkey **inquisitiveness.**

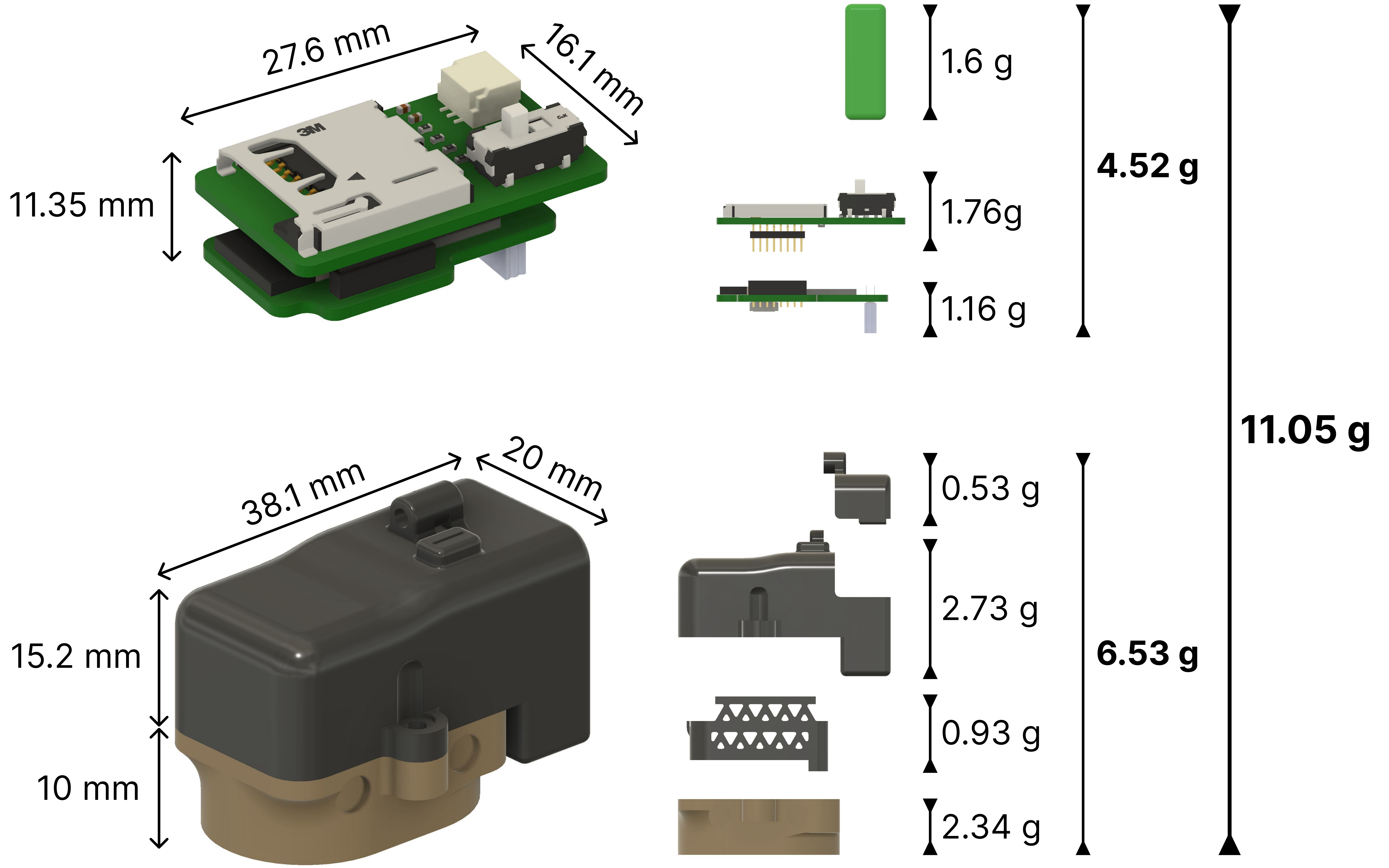
Electronics & Firmware Results



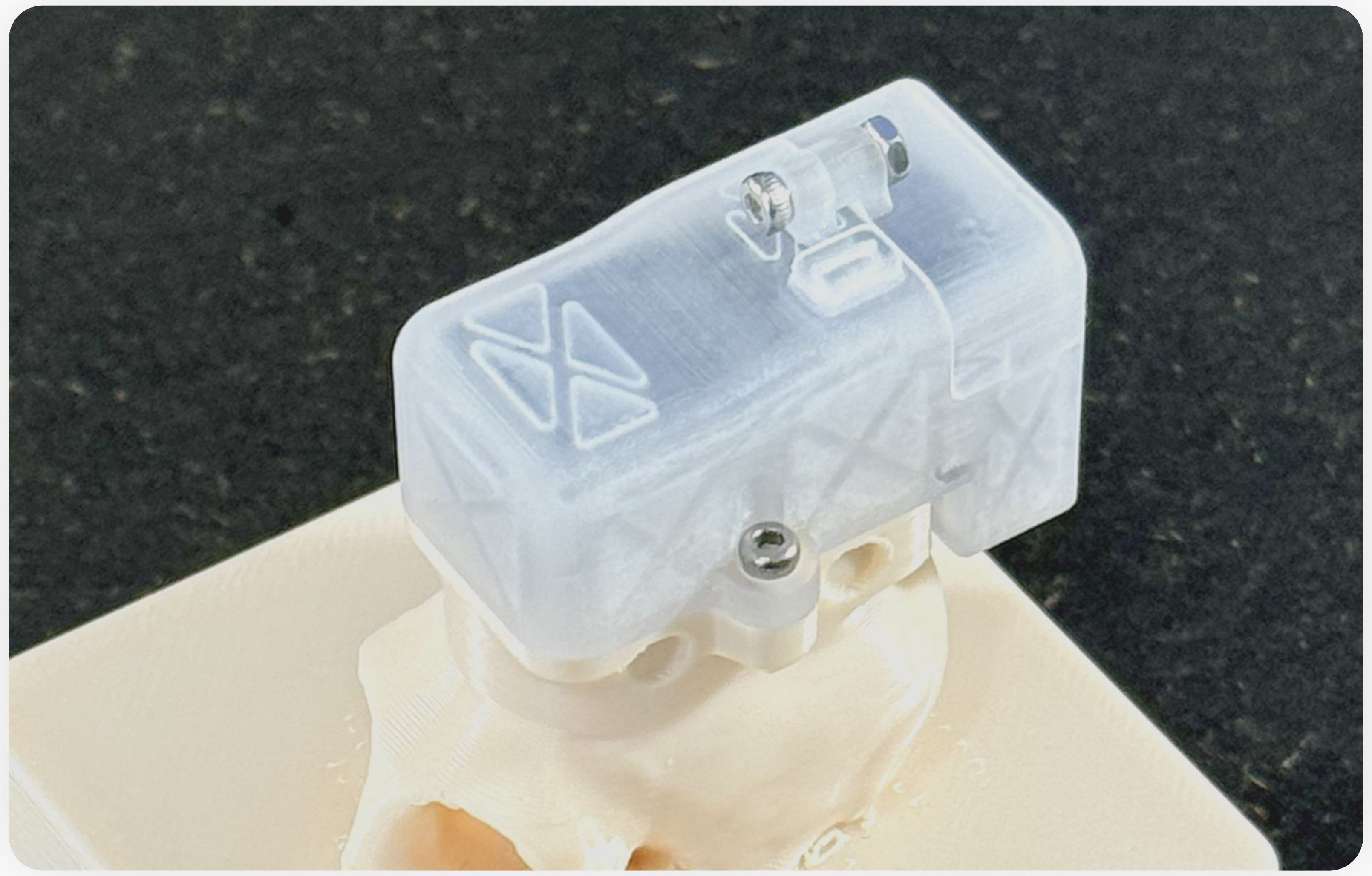


Expected autonomy around 500 Hz: **2 hrs 40 min**

Mechanical Results



Dimensions **Weight**



Final dimensions:
25.2 × 38.1 × 20 mm

Final Mass:
11.05 g

Battery Swap Time:
30 s

Device Limitations

- Insufficient sampling rate for APs
- System failure above 1200 Hz
- Missing PCB testing
- Remote operation pending
- Firmware inefficiencies
- Power consumption at high sampling rates

Results vs Initial Specifications

6 surpassed   3 achieved   2 unmet/untested

Code	Name	Target	Result
E1	Autonomy	≥ 2 hrs	2.67 hrs
E2	Channel Count	≥ 16	16
E3	Sampling Rate	≥ 100 Hz/ channel	750 Hz/channel
M1	Dimensions	40 × 70 × 40 mm	25.2 × 38.1 × 20 mm
M2	Weight	40-12 g	11.05 g
M3	Durability	High	High

Code	Name	Target	Result
P1	Wireless Range	≥ 5 m	Not Tested
P2	Latency	< 10 ms	< 7.5 ms
P3	Local Storage & Wireless	Yes	Yes
D1	Plug-&-Play	Under 2 min	< 1.5 min
D2	Remote Operation	Yes	Not Achieved

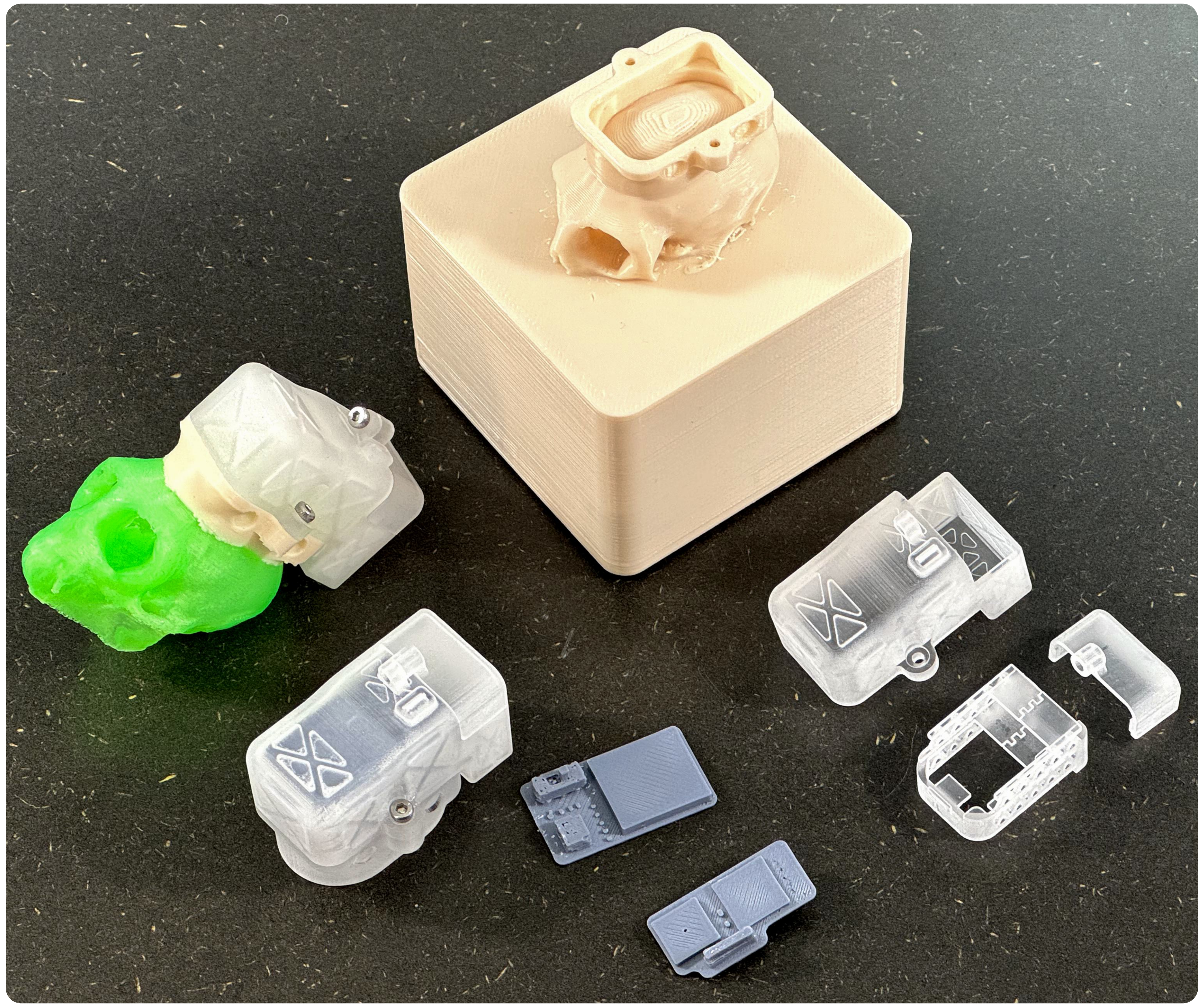
Resulting Opportunities & Future Work

- Insufficient sampling rate for APs
- System failure above 1200 Hz
- Missing PCB testing
- Remote operation pending
- Firmware inefficiencies
- Power consumption at high sampling rates

→

- Firmware optimisations
- GUI development for remote control
- Extra PCB boards creation
- Component upgrades
- Manufacturing and testing PCB

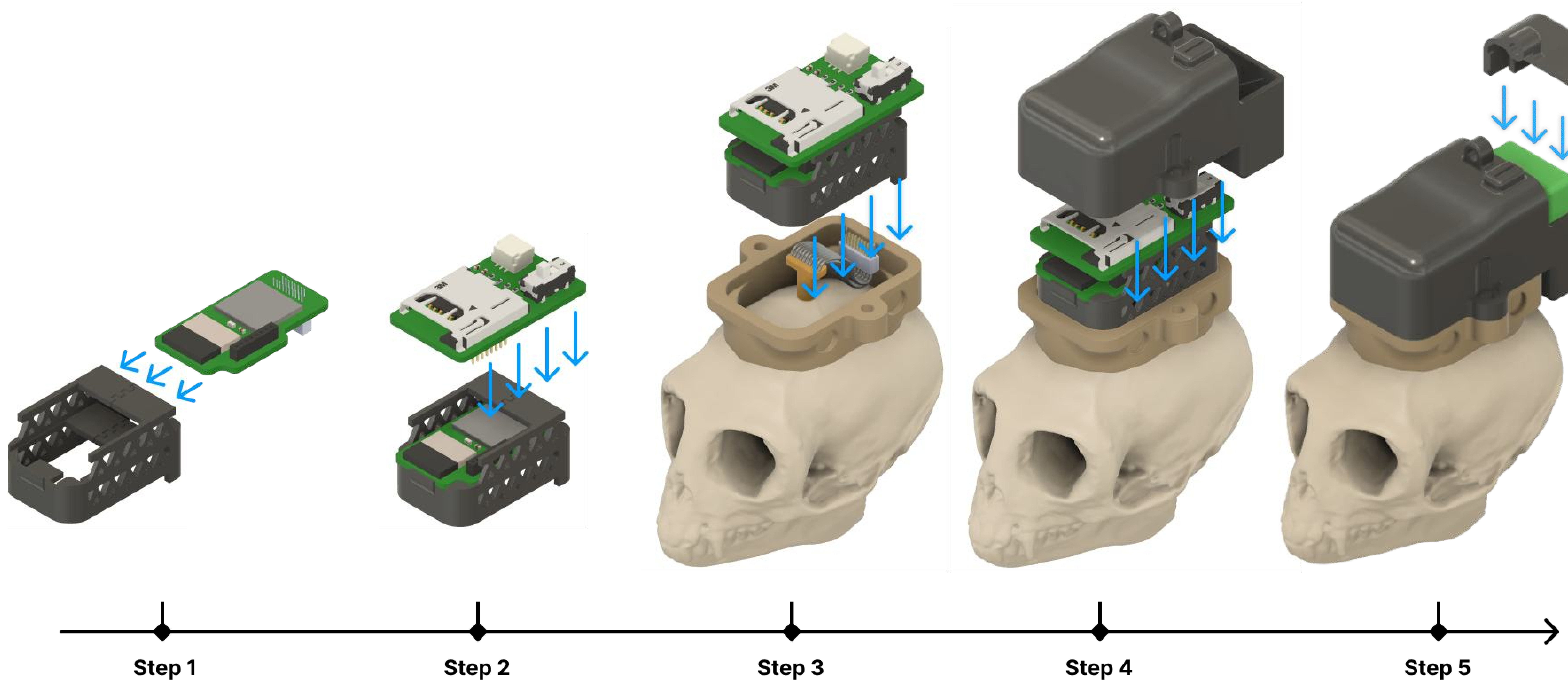
Thank you for listening :)



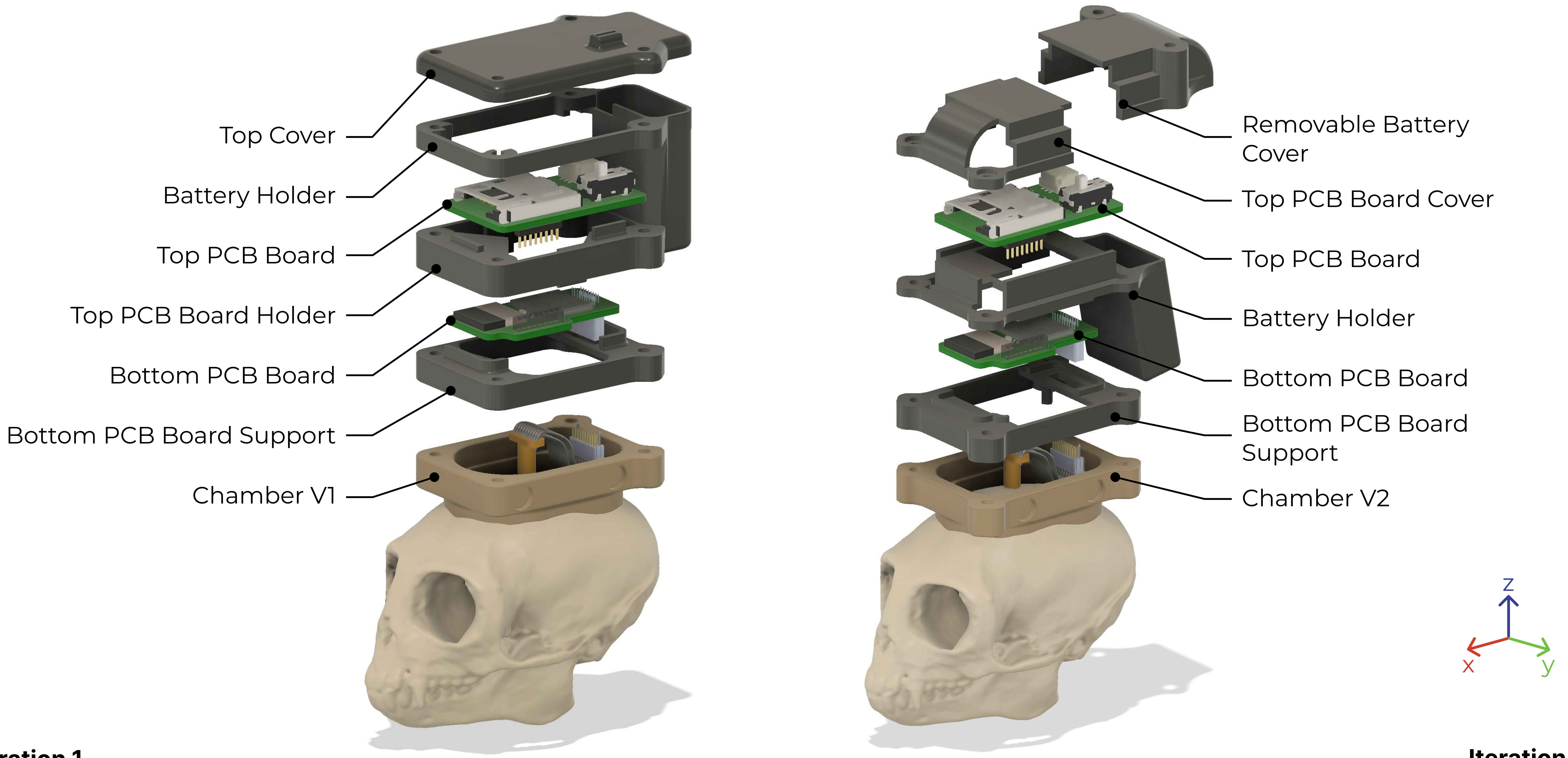
Assembly:
1m 27s

Full Disassembly:
1m

Battery Swap:
30s



Assembly Process



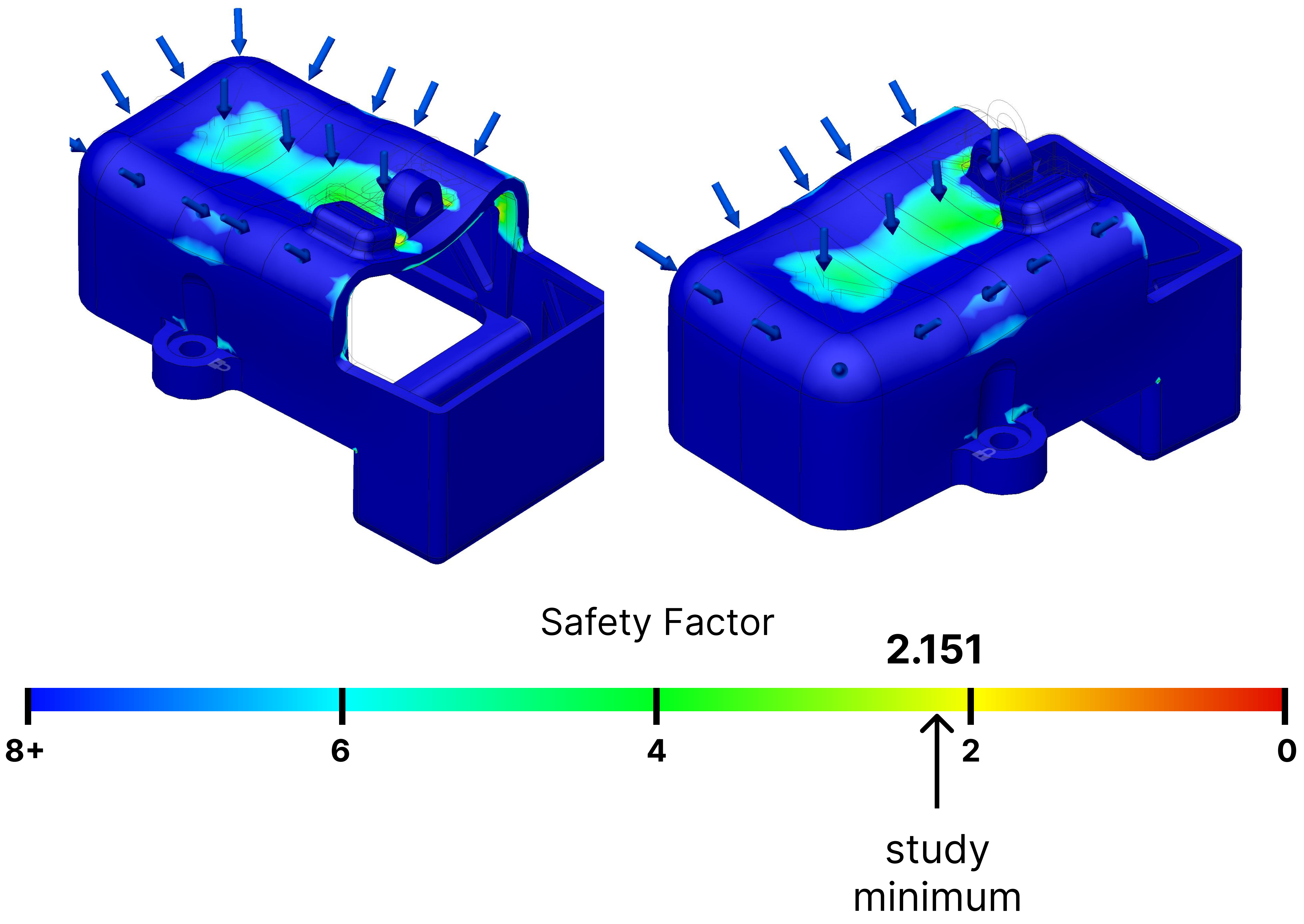
Iteration 1

Parts number (with screws):	**8**	Housing weight (with crown):	**7.7g**
Bounding Box (with crown):	**25.6 x 40.2 x 27.2 mm**	Housing Material:	**Visijet M2S-HT90**

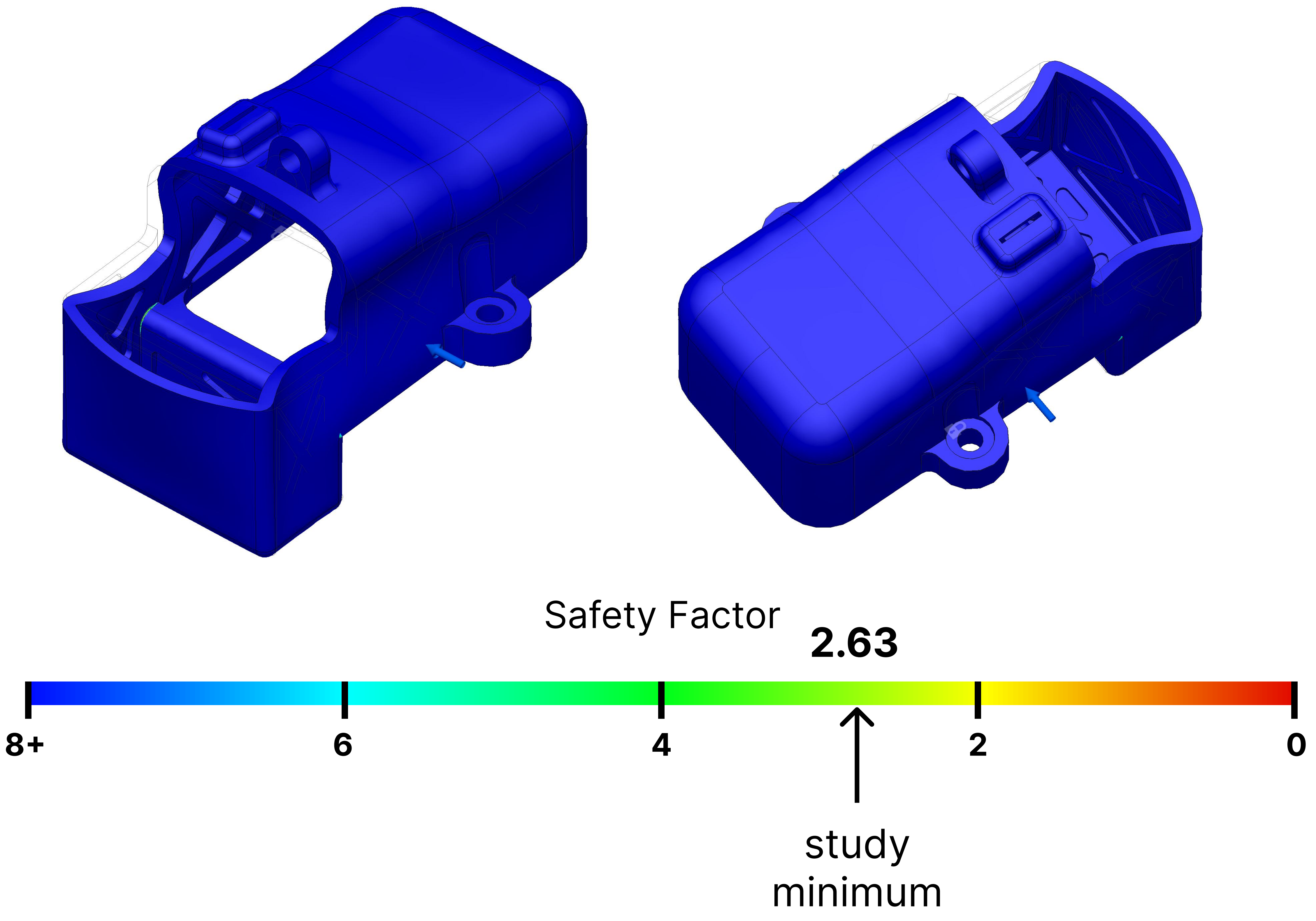
Iteration 2

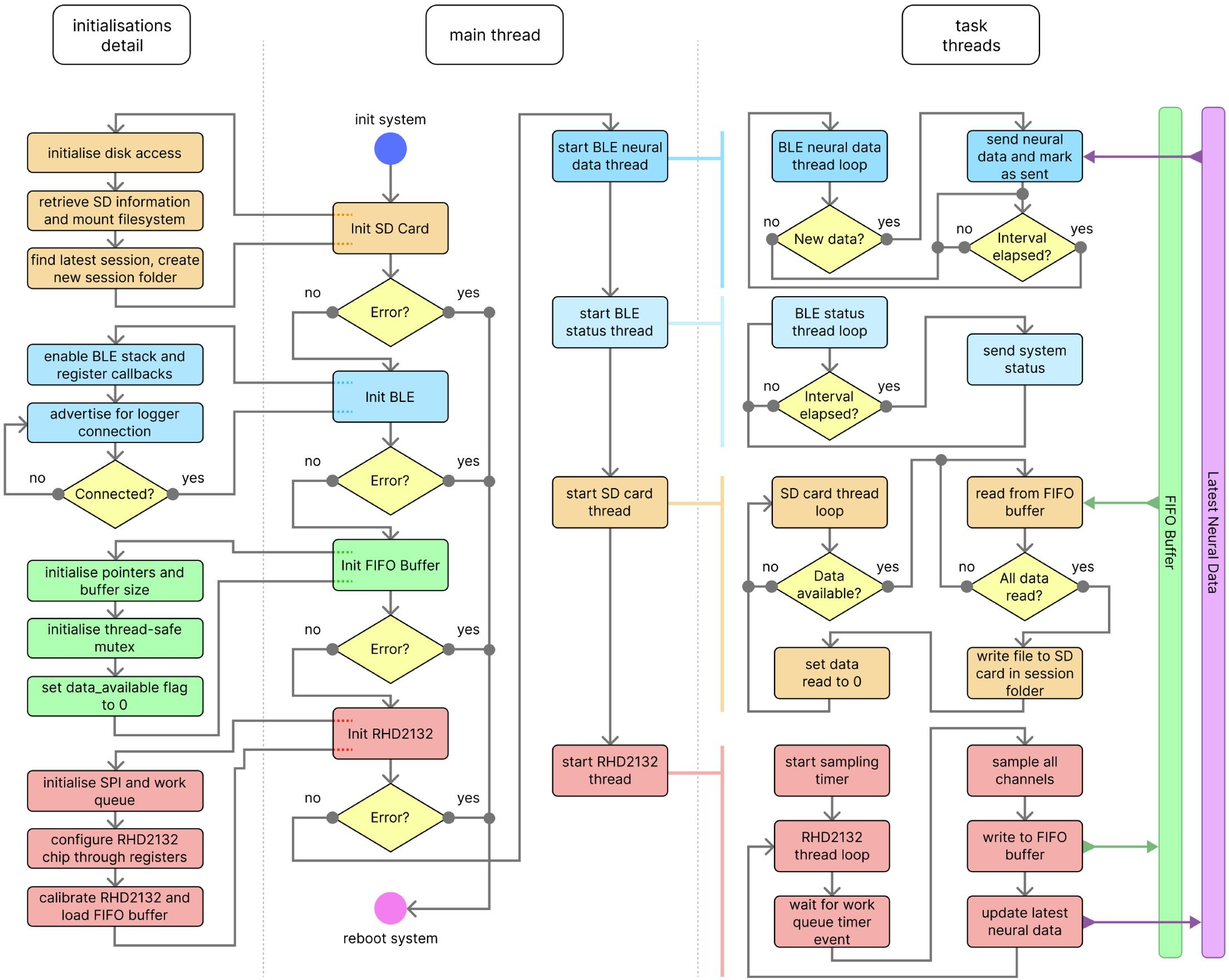
Parts number (with screws):	**8**	Housing weight (with crown):	**8.5g**
Bounding Box (with crown):	**25.6 x 45 x 31.4 mm**	Housing Material:	**Visijet M2S-HT90**

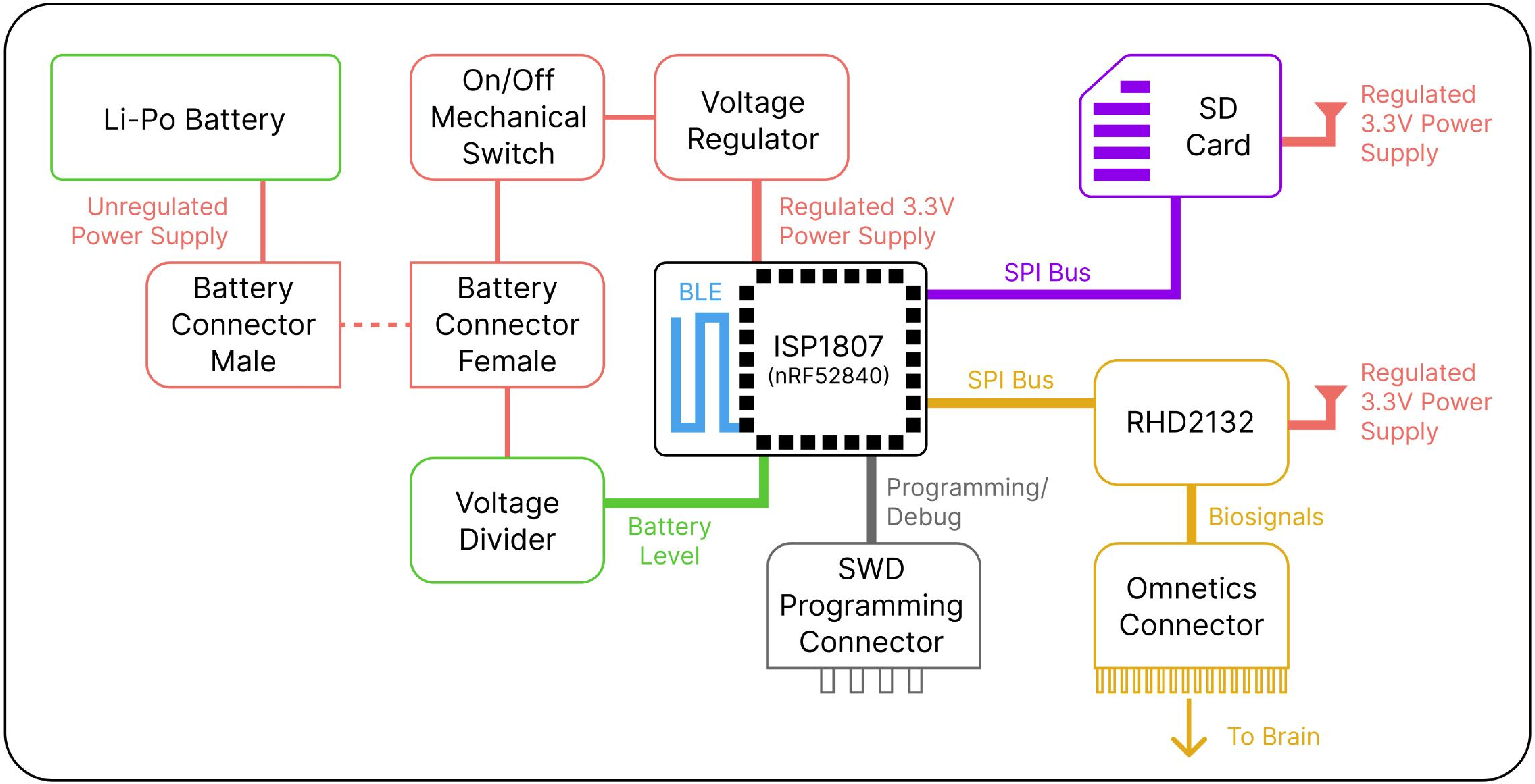
Top Housing Safety Factor FEA
Simulated Fall Analysis



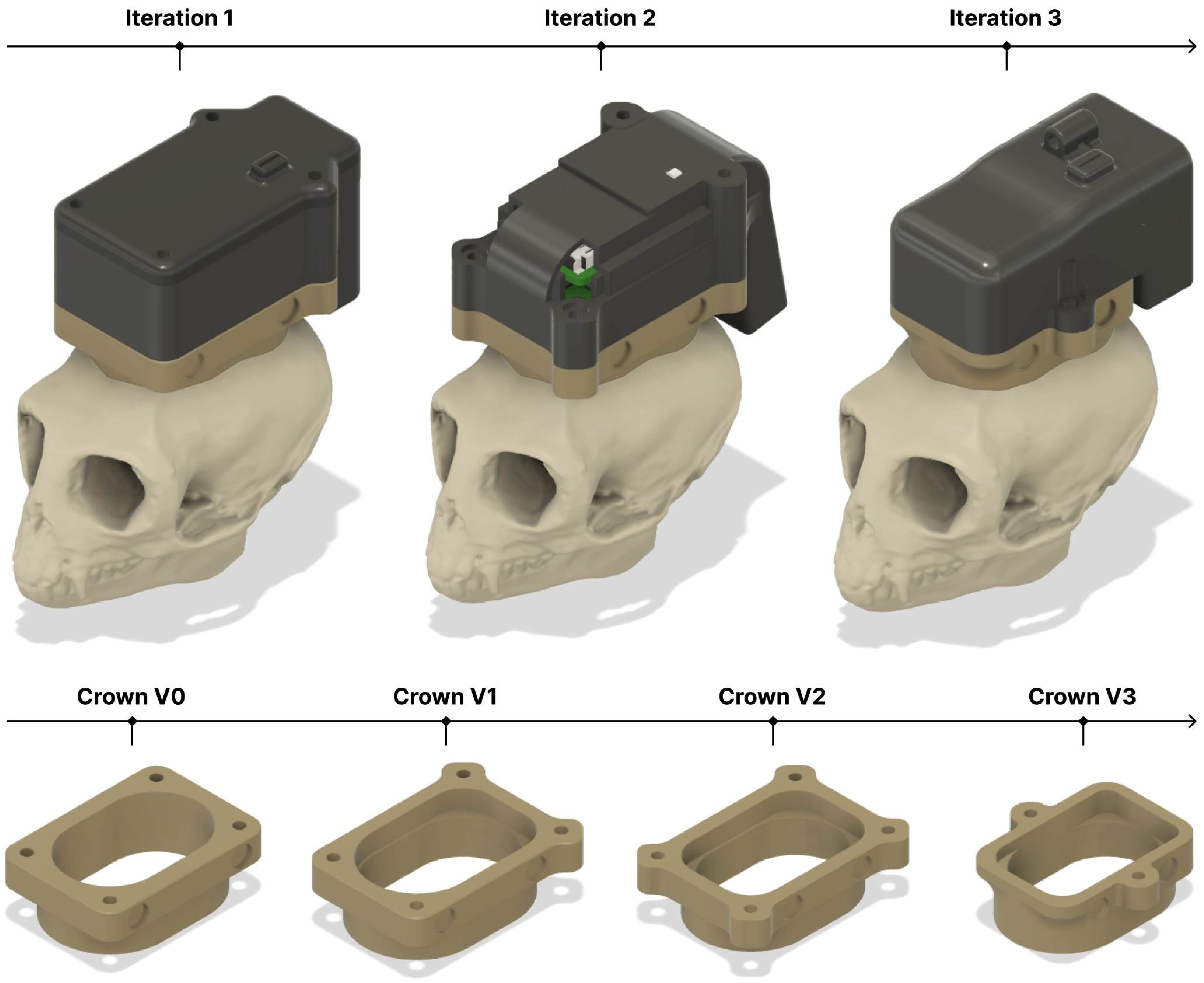
Top Housing Safety Factor FEA
Simulated Monkey Force

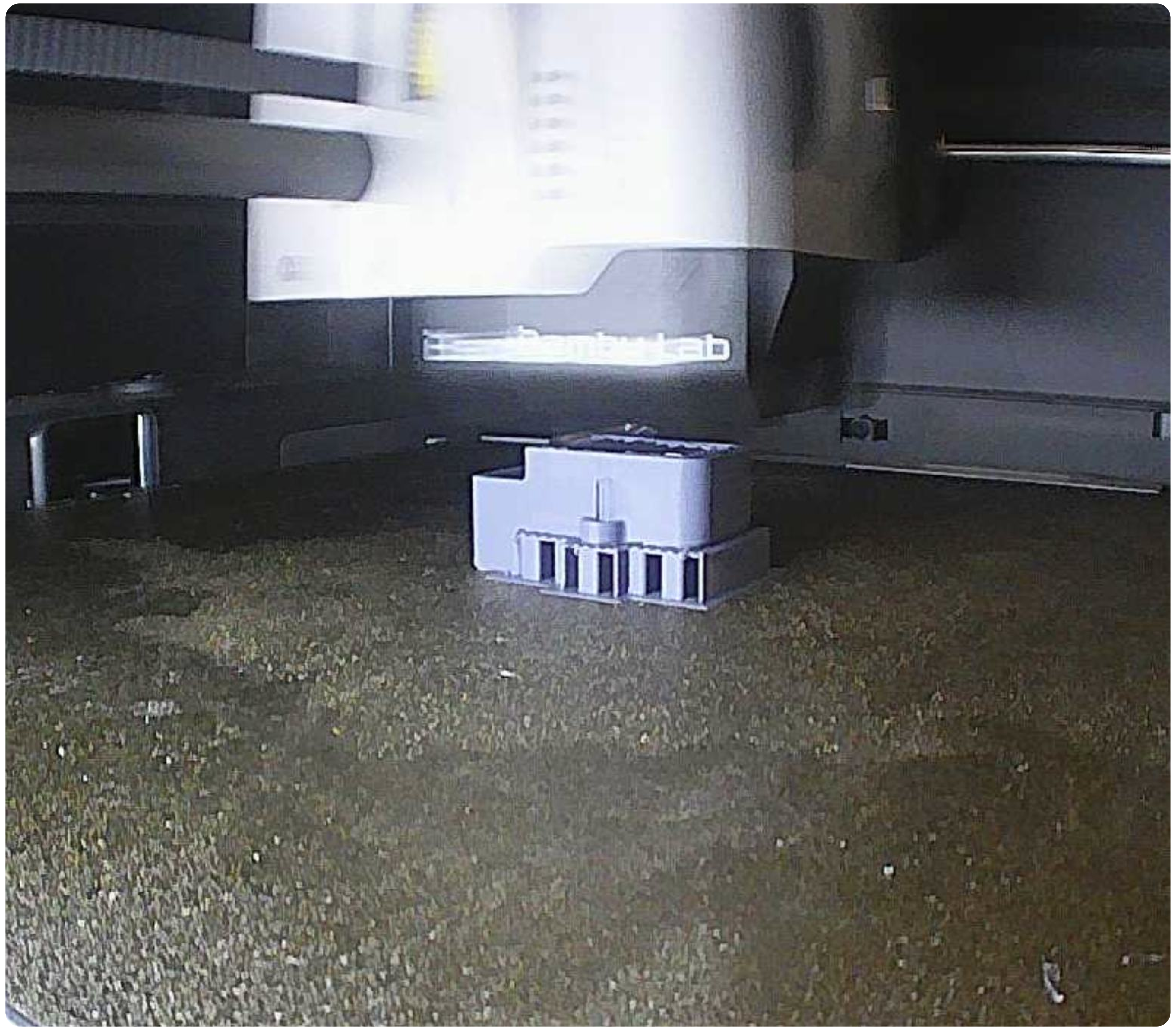


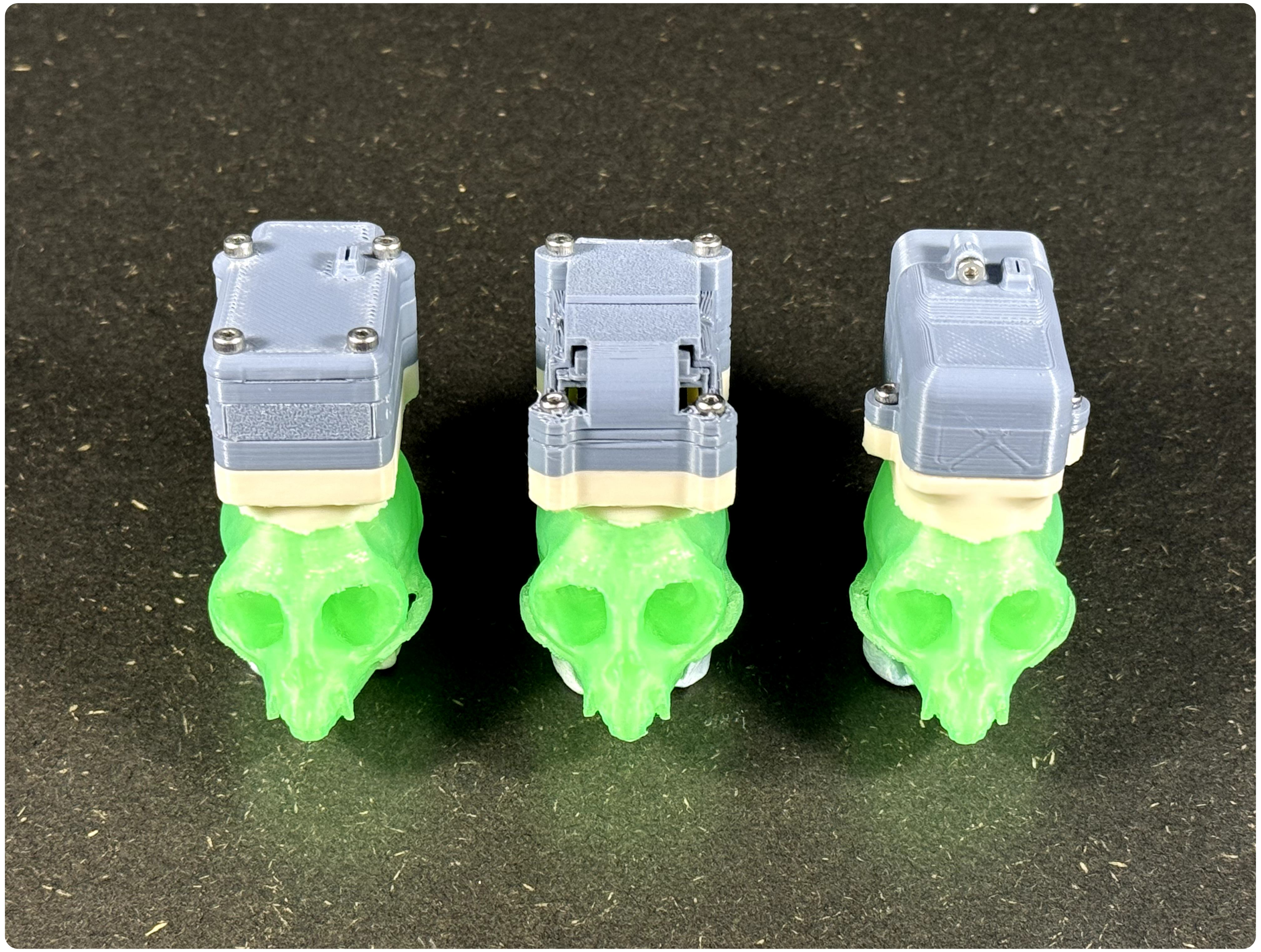

initialisations detail
main thread
task threads
initialise disk access
retrieve SD information and mount filesystem
find latest session, create new session folder
enable BLE stack and register callbacks
advertise for logger connection
Connected?
no
yes
initialise pointers and buffer size
initialise thread-safe mutex
set data_available flag to 0
initialise SPI and work queue
configure RHD2132 chip through registers
calibrate RHD2132 and load FIFO buffer
init system
Init SD Card
Error?
Init BLE
Init FIFO Buffer
Init RHD2132
reboot system
start BLE neural data thread
start BLE status thread
start SD card thread
start RHD2132 thread
BLE neural data thread loop
New data?
send neural data and mark as sent
Interval elapsed?
BLE status thread loop
send system status
SD card thread loop
Data available?
read from FIFO buffer
All data read?
set data read to 0
write file to SD card in session folder
start sampling timer
RHD2132 thread loop
wait for work queue timer event
sample all channels
write to FIFO buffer
update latest neural data
FIFO Buffer
Latest Neural Data



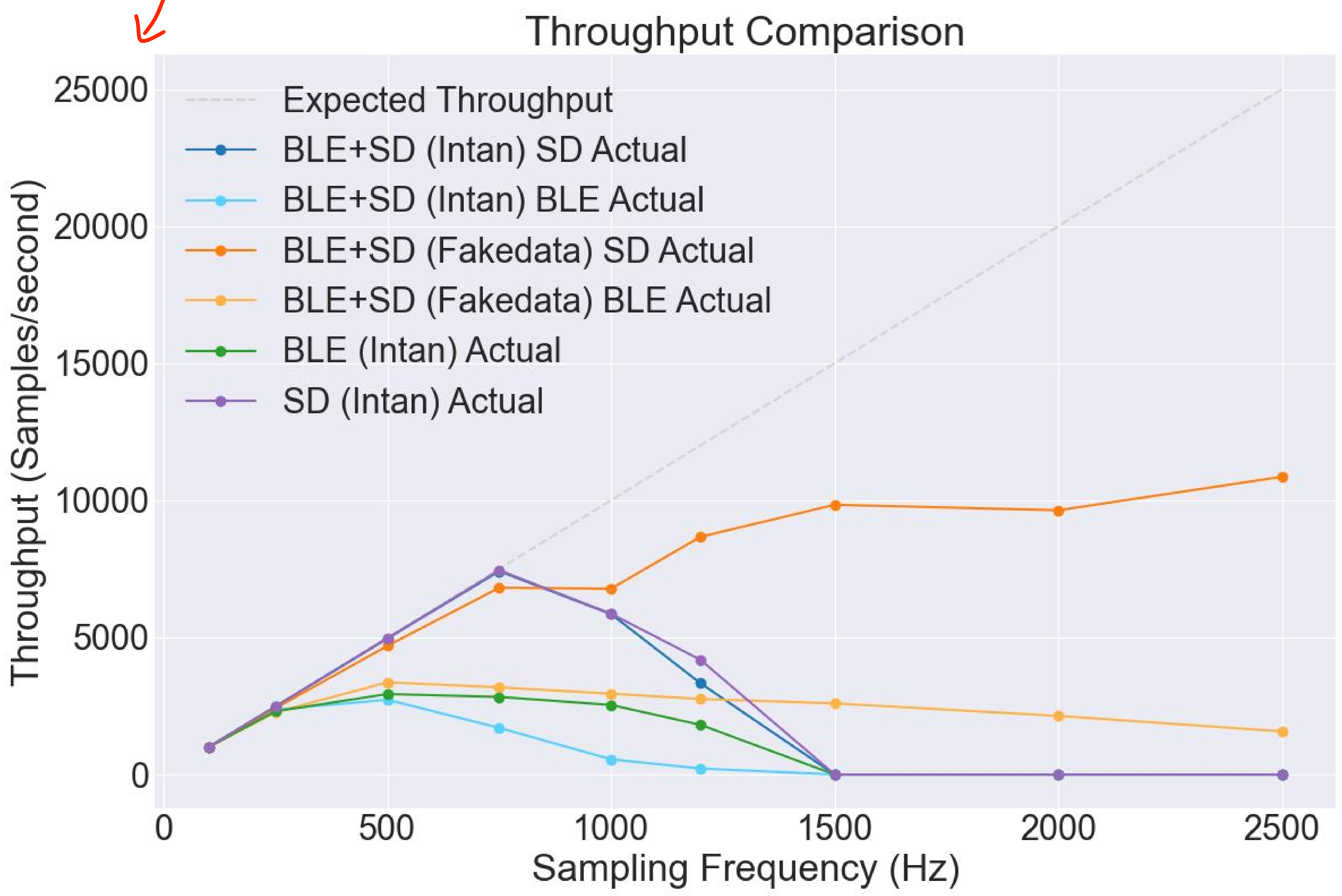
Li-Po Battery
On/Off Mechanical Switch
Voltage Regulator
SD Card
Regulated 3.3V Power Supply
Unregulated Power Supply
Regulated 3.3V Power Supply
Battery Connector Male
Battery Connector Female
BLE
ISP1807 (nRF52840)
SPI Bus
SPI Bus
RHD2132
Regulated 3.3V Power Supply
Voltage Divider
Battery Level
Programming/ Debug
SWD Programming Connector
Biosignals
Omnetics Connector
To Brain

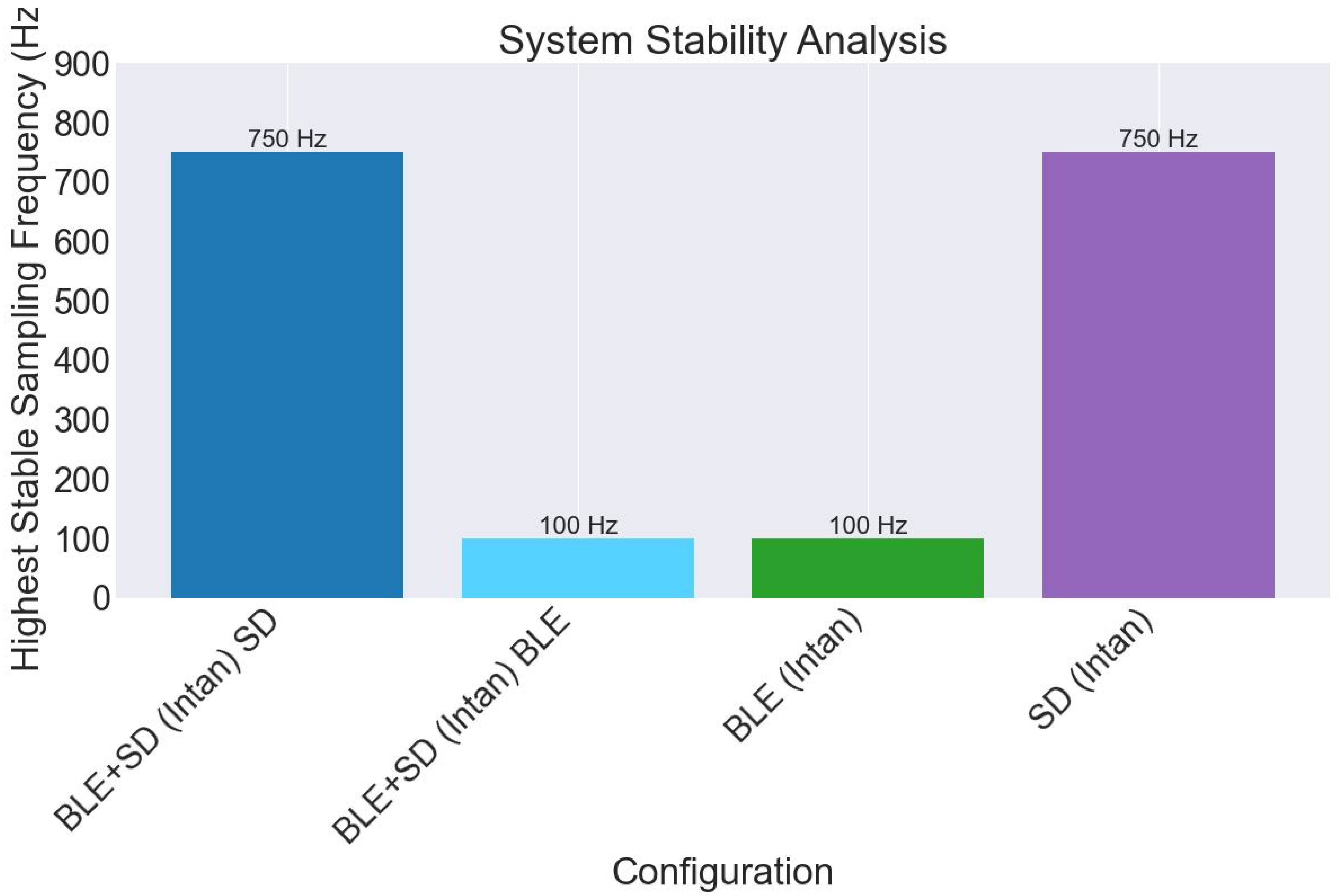

Iteration 1
Iteration 2
Iteration 3
Crown V0
Crown V1
Crown V2
Crown V3

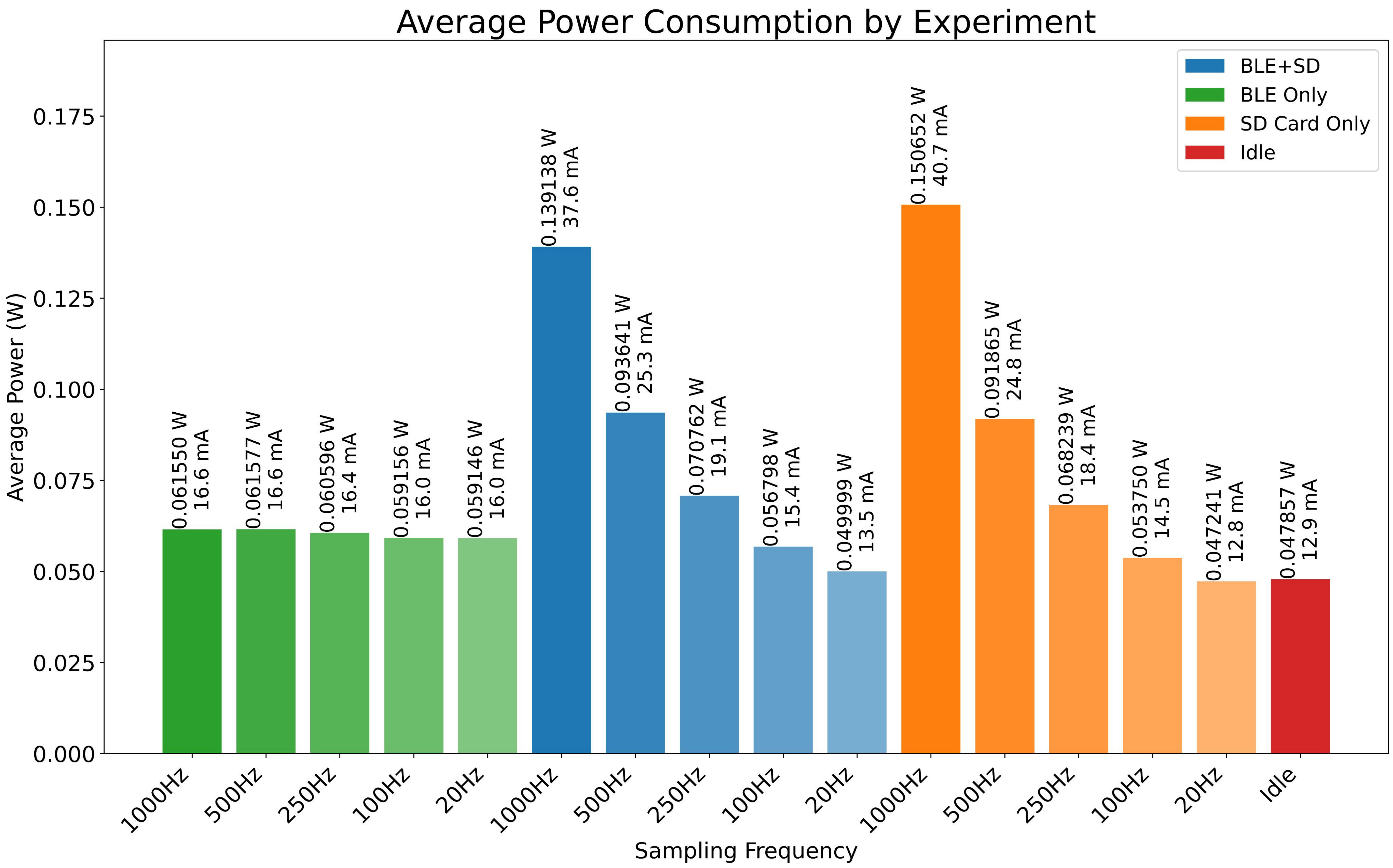




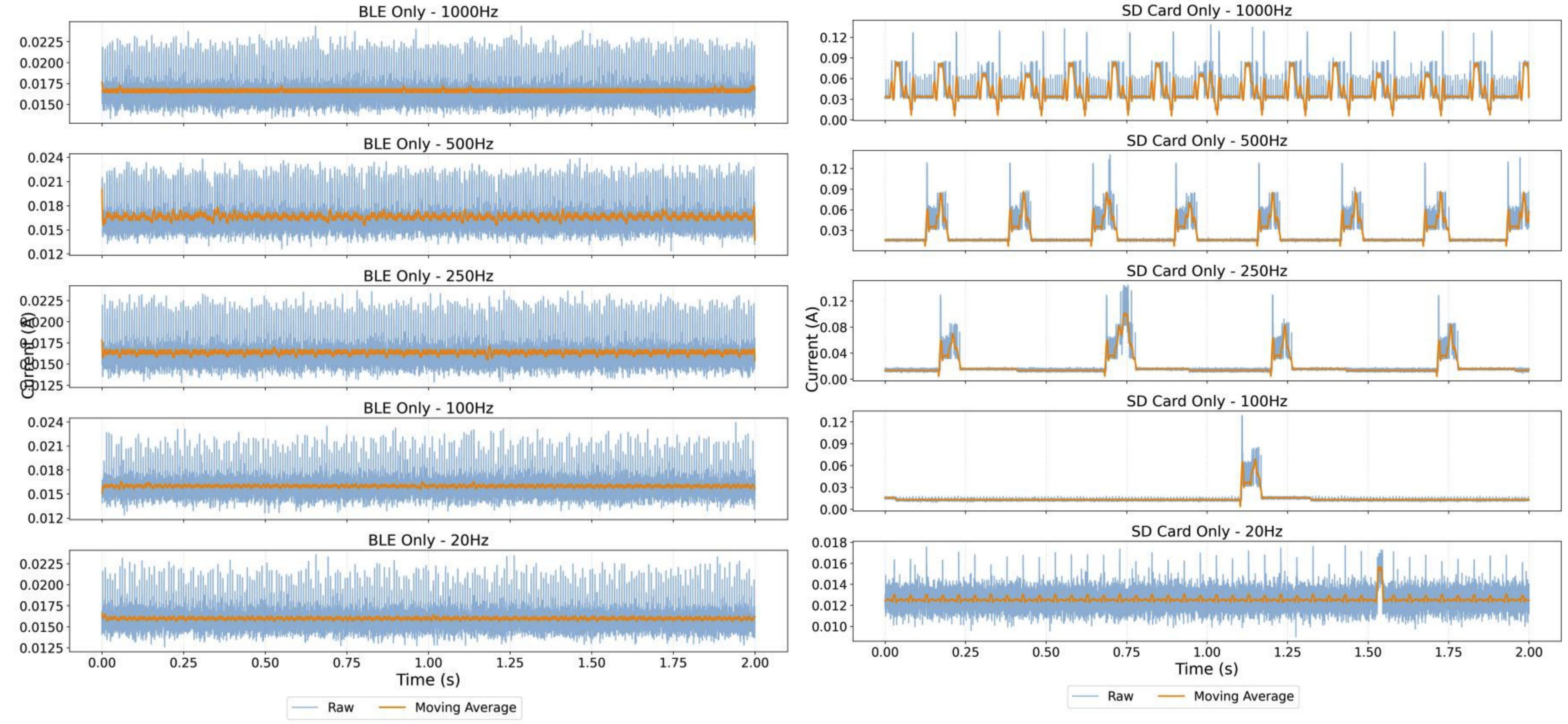
ERRATUM:
y-axis needs to be divided by 10

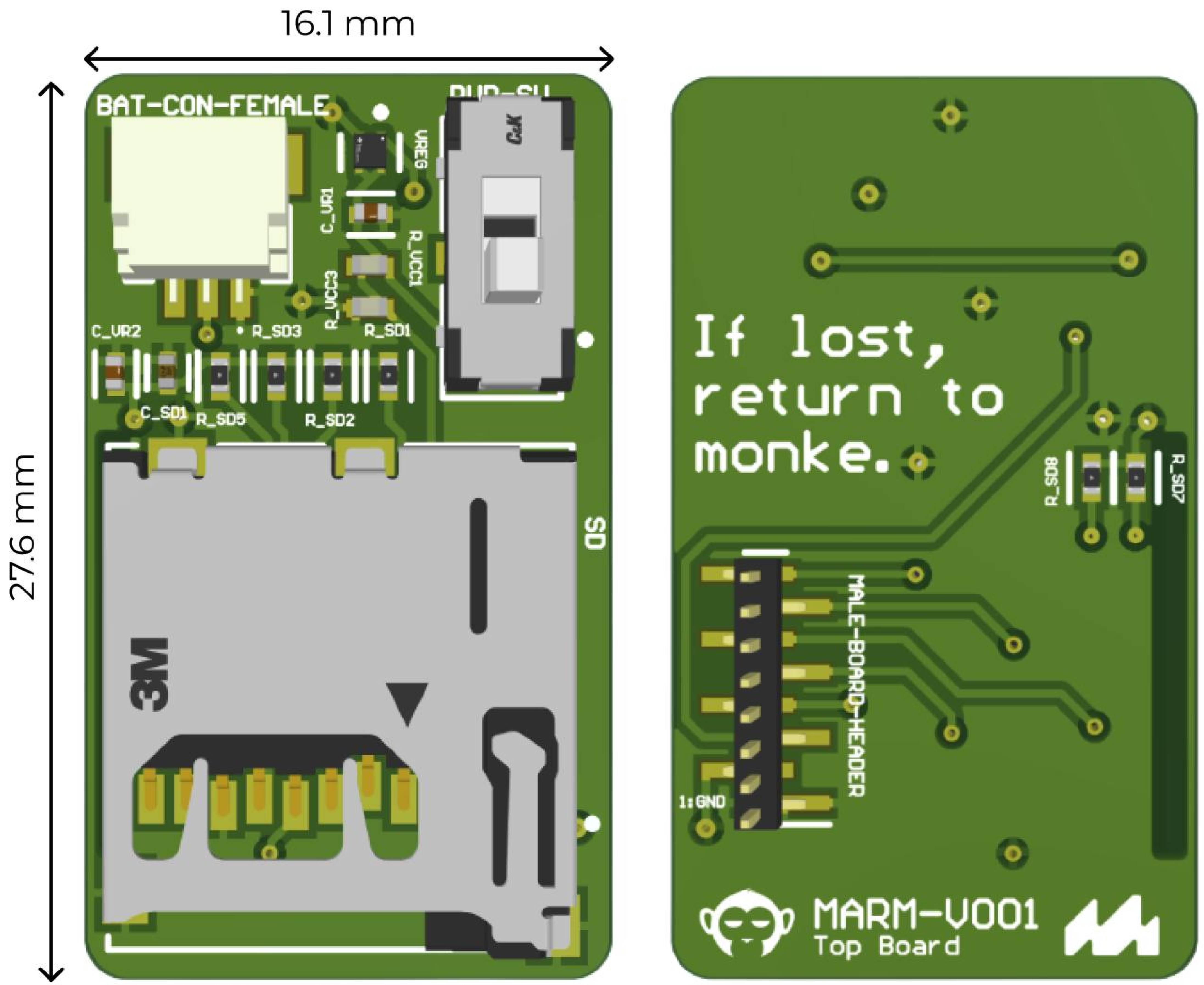




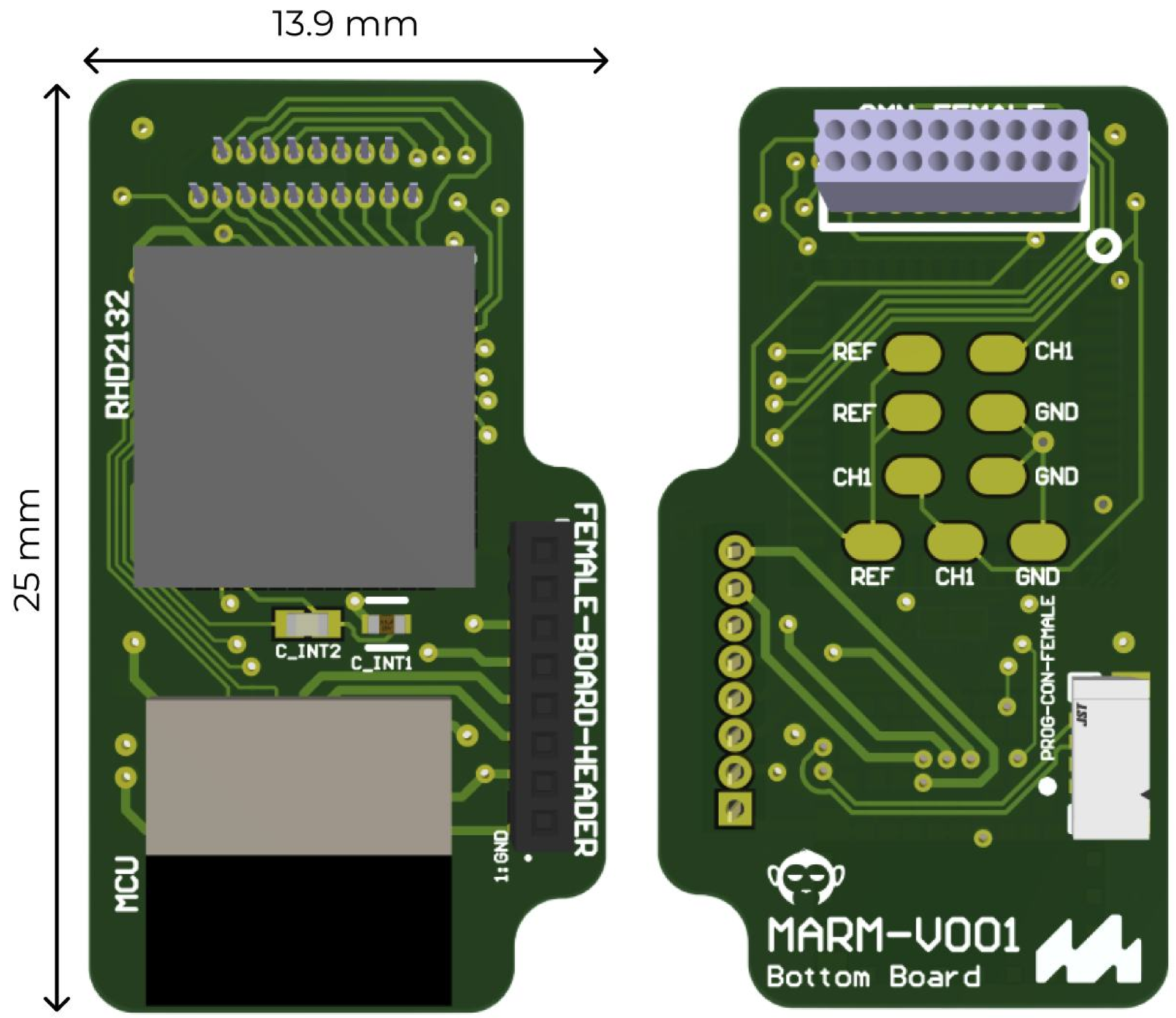


Average Power Consumption by Experiment
BLE+SD
BLE Only
SD Card Only
Idle
Average Power (W)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.061550 W
16.6 mA
0.061577 W
16.6 mA
0.060596 W
16.4 mA
0.059156 W
16.0 mA
0.059146 W
16.0 mA
0.139138 W
37.6 mA
0.093641 W
25.3 mA
0.070762 W
19.1 mA
0.056798 W
15.4 mA
0.049999 W
13.5 mA
0.150652 W
40.7 mA
0.091865 W
24.8 mA
0.068239 W
18.4 mA
0.053750 W
14.5 mA
0.047241 W
12.8 mA
0.047857 W
12.9 mA
1000Hz
500Hz
250Hz
100Hz
20Hz
1000Hz
500Hz
250Hz
100Hz
20Hz
1000Hz
500Hz
250Hz
100Hz
20Hz
Idle
Sampling Frequency

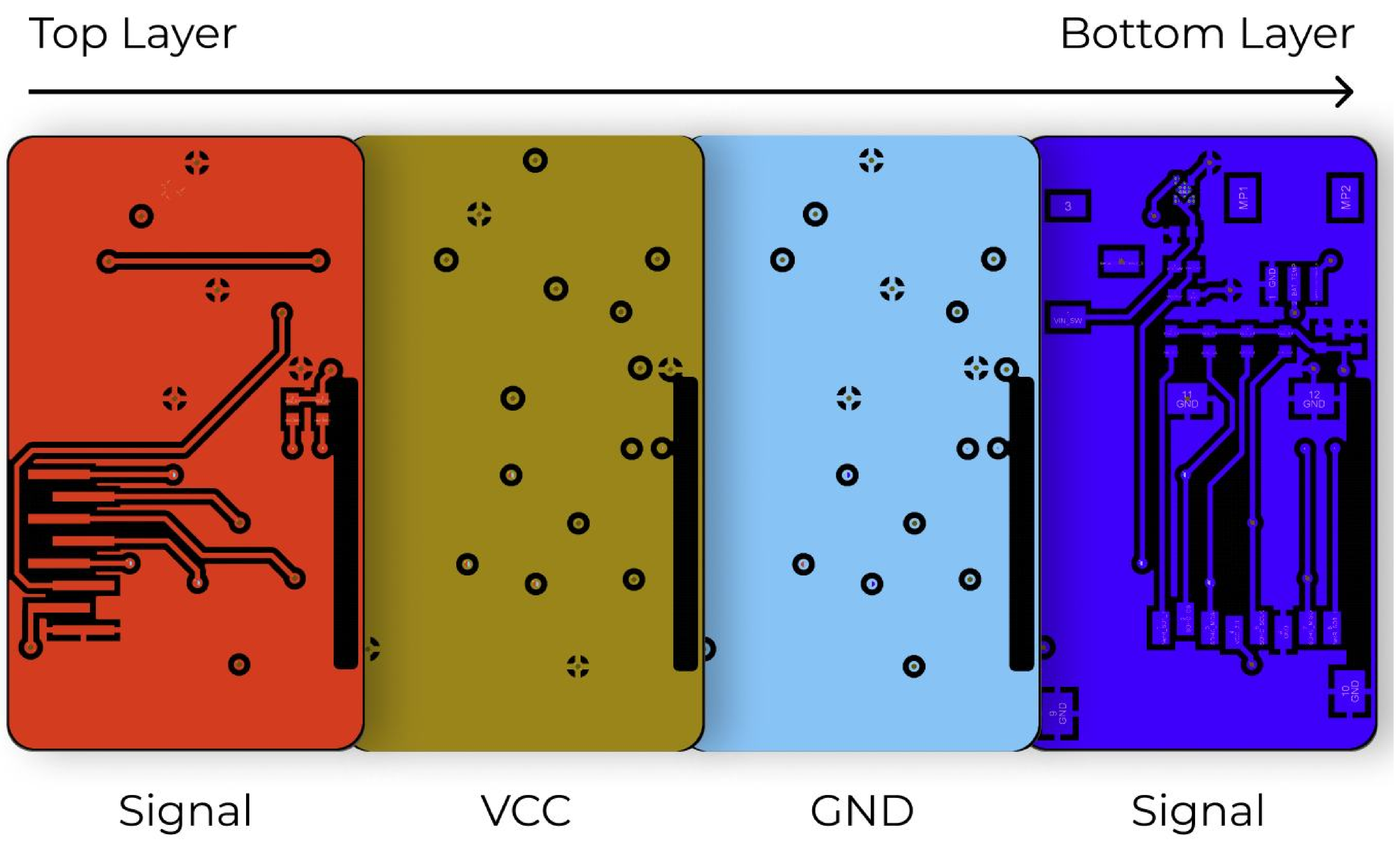

BLE Only - 1000Hz
BLE Only - 500Hz
BLE Only - 250Hz
BLE Only - 100Hz
BLE Only - 20Hz
Current (A)
Time (s)
Raw
Moving Average
SD Card Only - 1000Hz
SD Card Only - 500Hz
SD Card Only - 250Hz
SD Card Only - 100Hz
SD Card Only - 20Hz
Current (A)
Time (s)
Raw
Moving Average

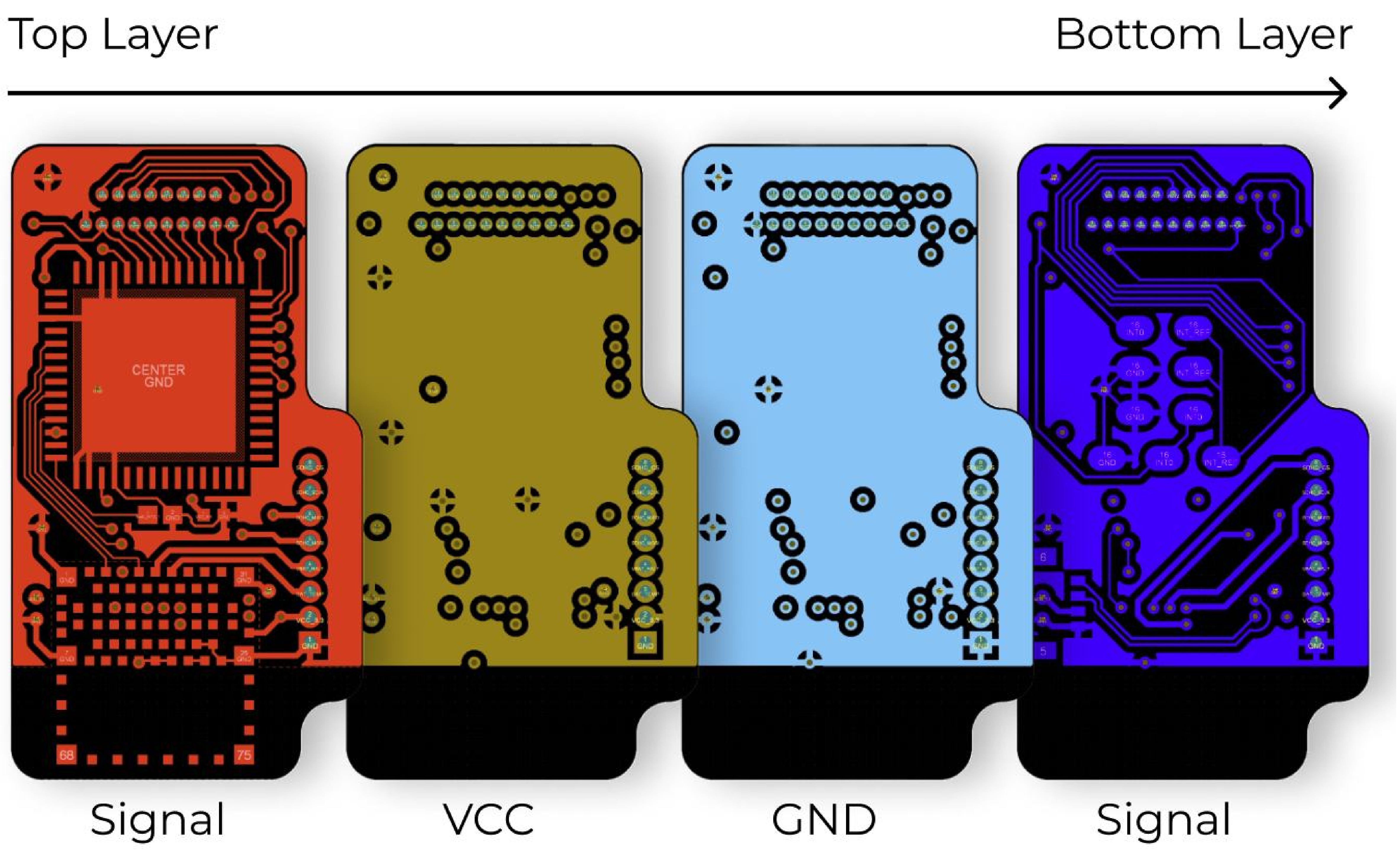


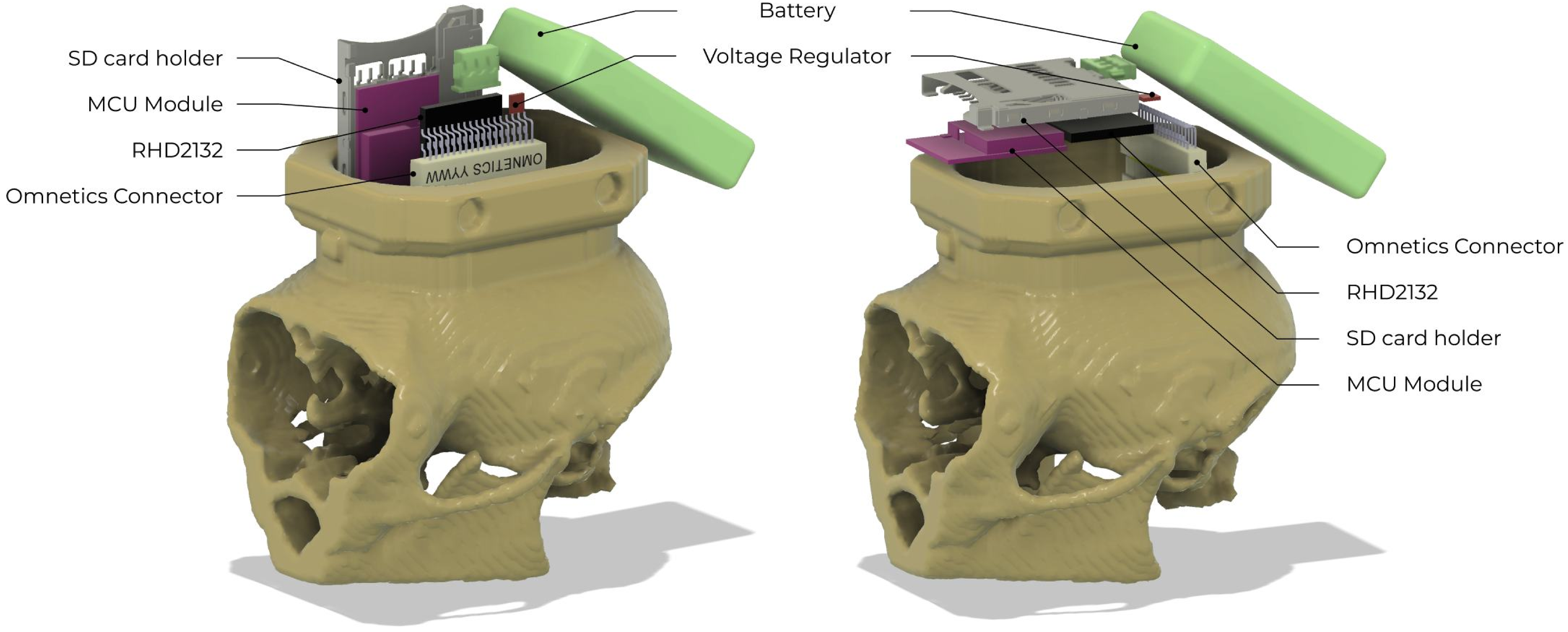
Top Board



Bottom Board

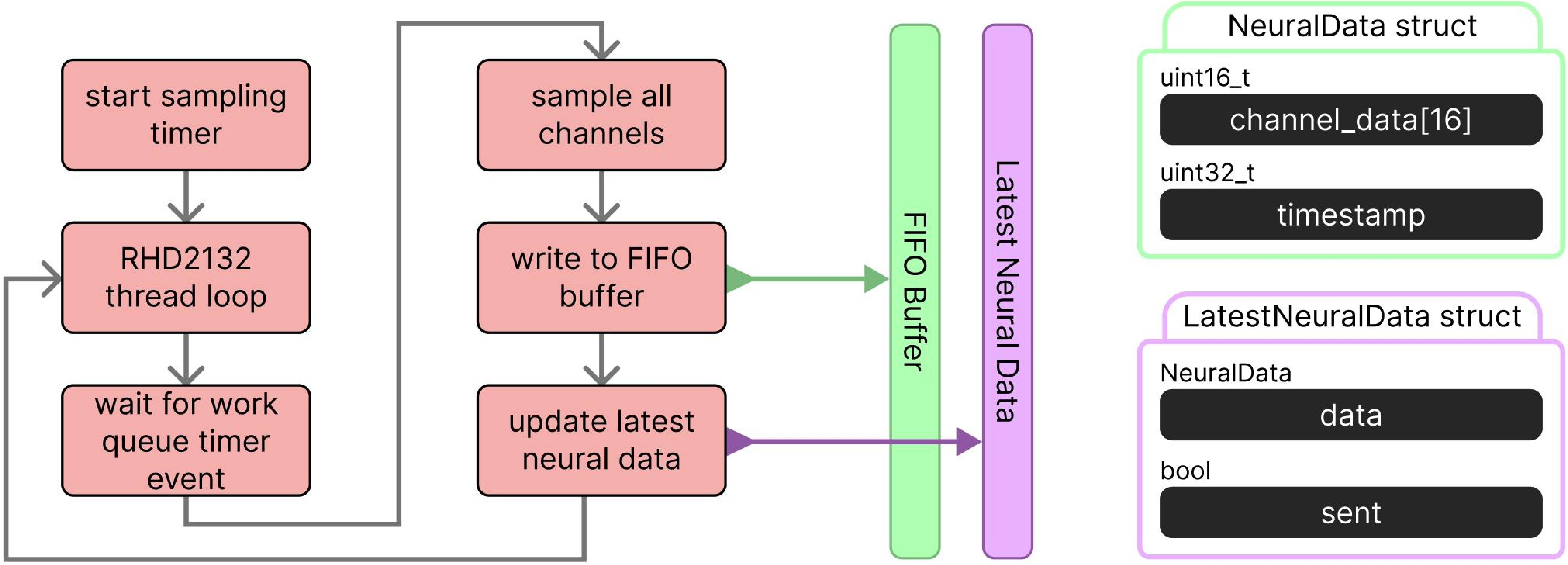

Top Layer
Bottom Layer
Signal
VCC
GND
Signal

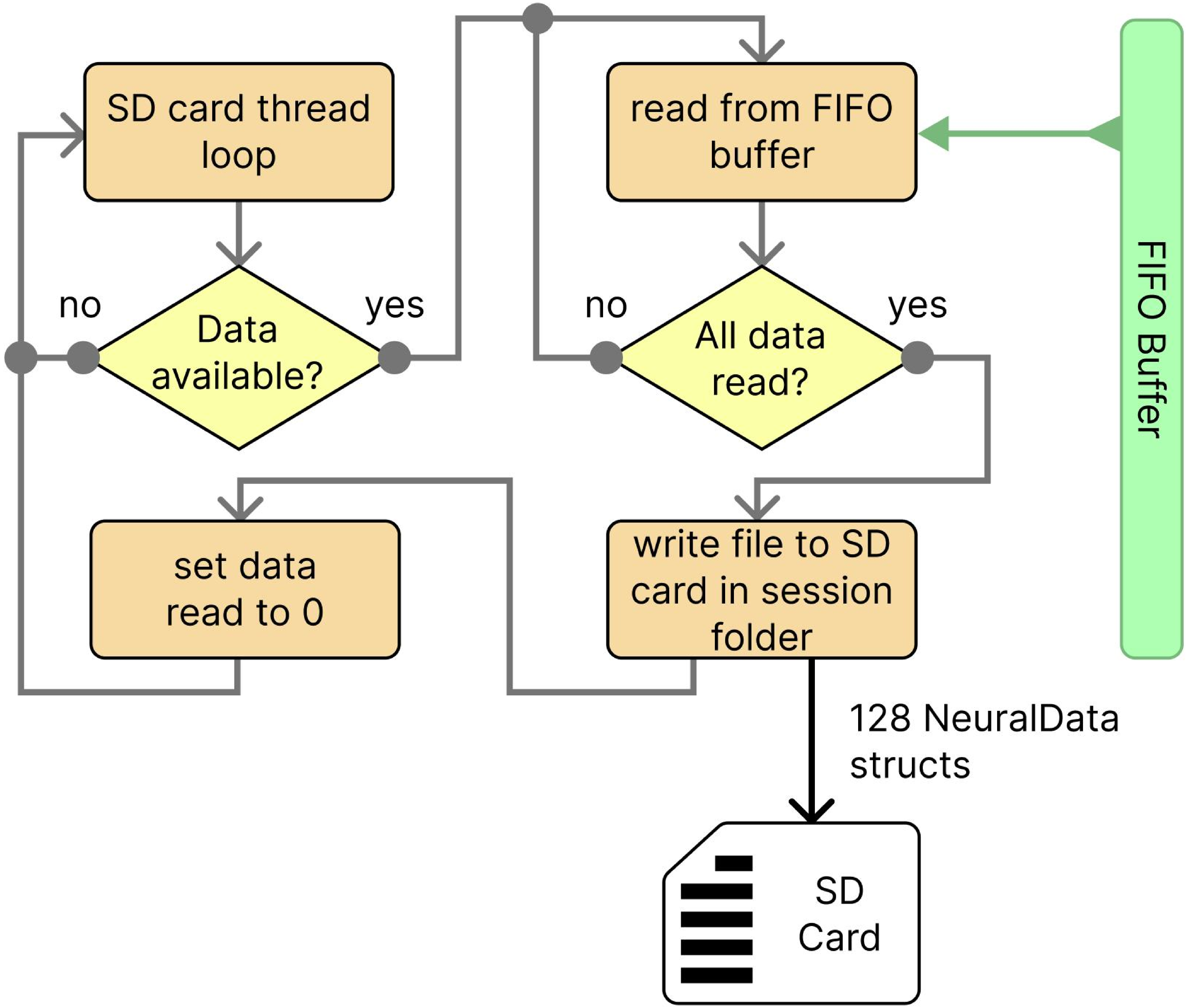

Top Layer
Bottom Layer
Signal
VCC
GND
Signal

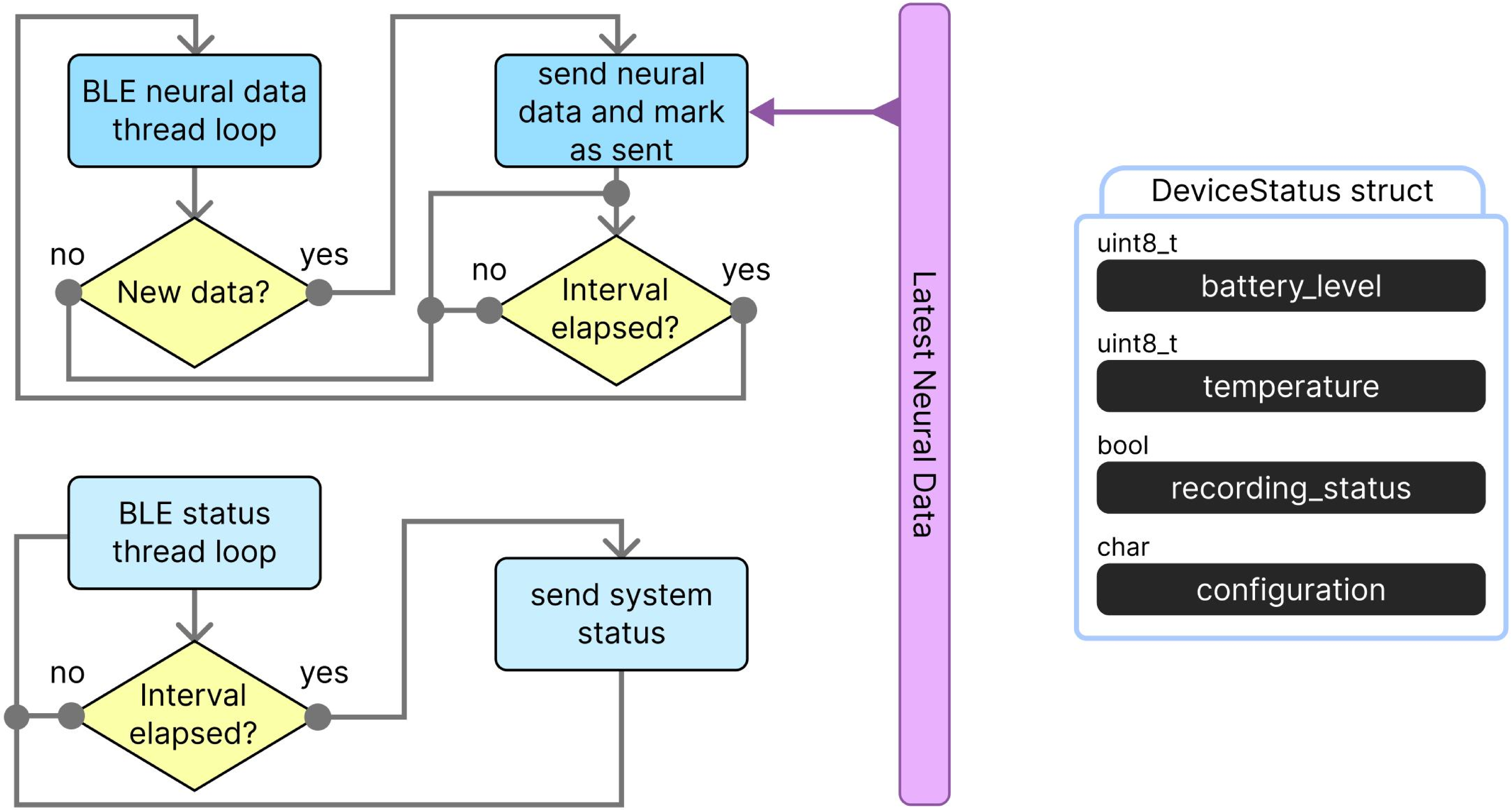


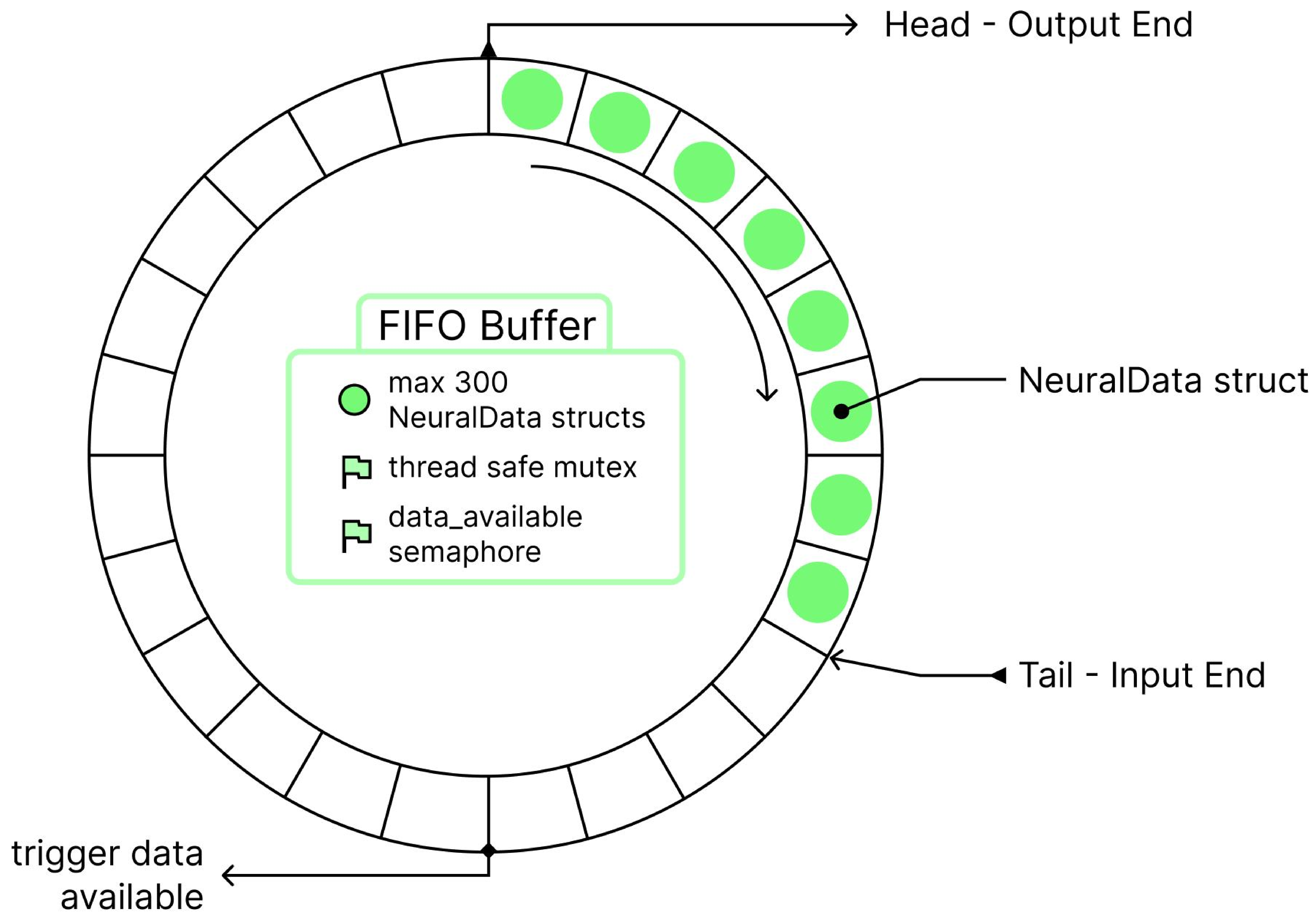
Vertical Layout

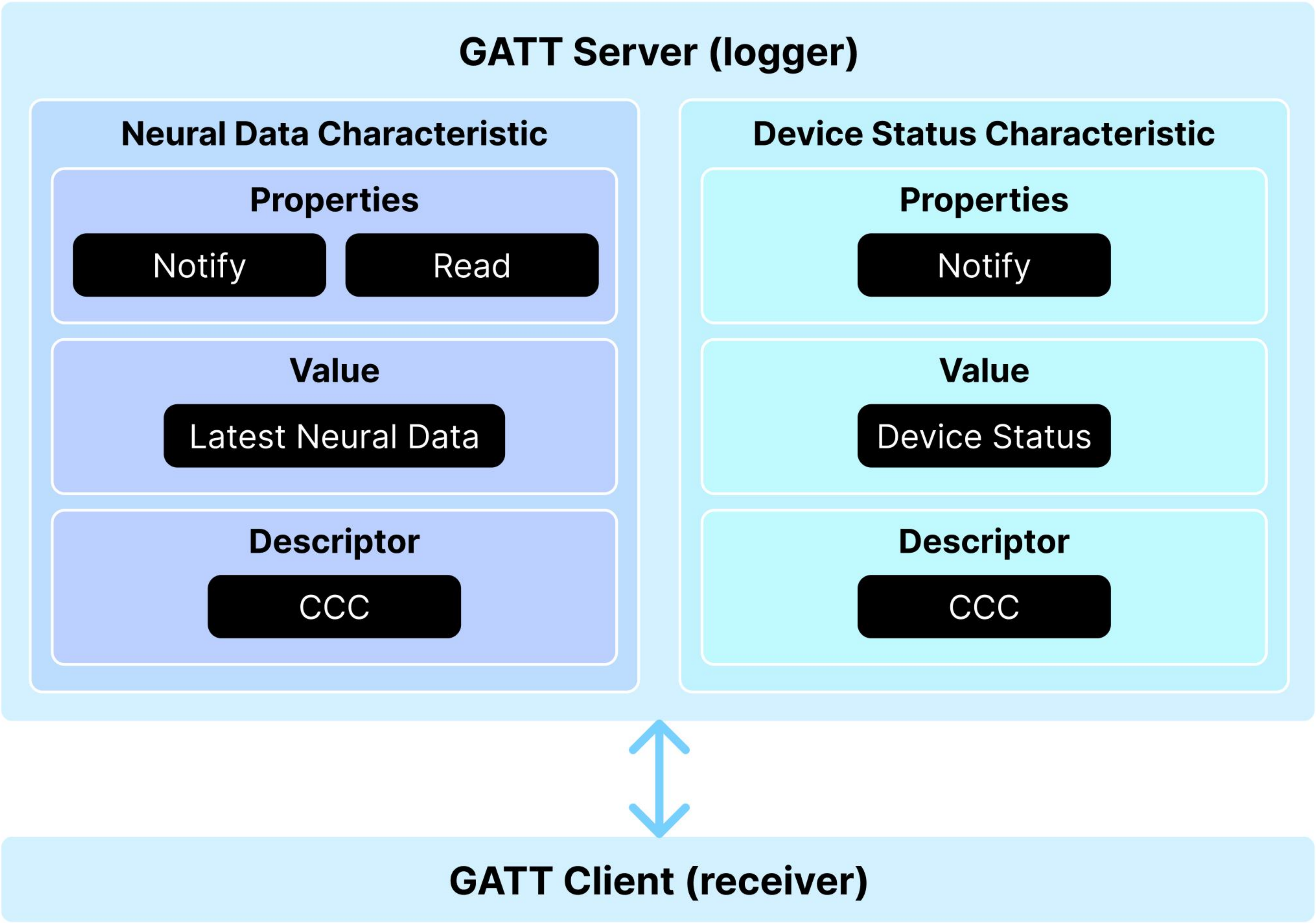
Horizontal Layout
(final)

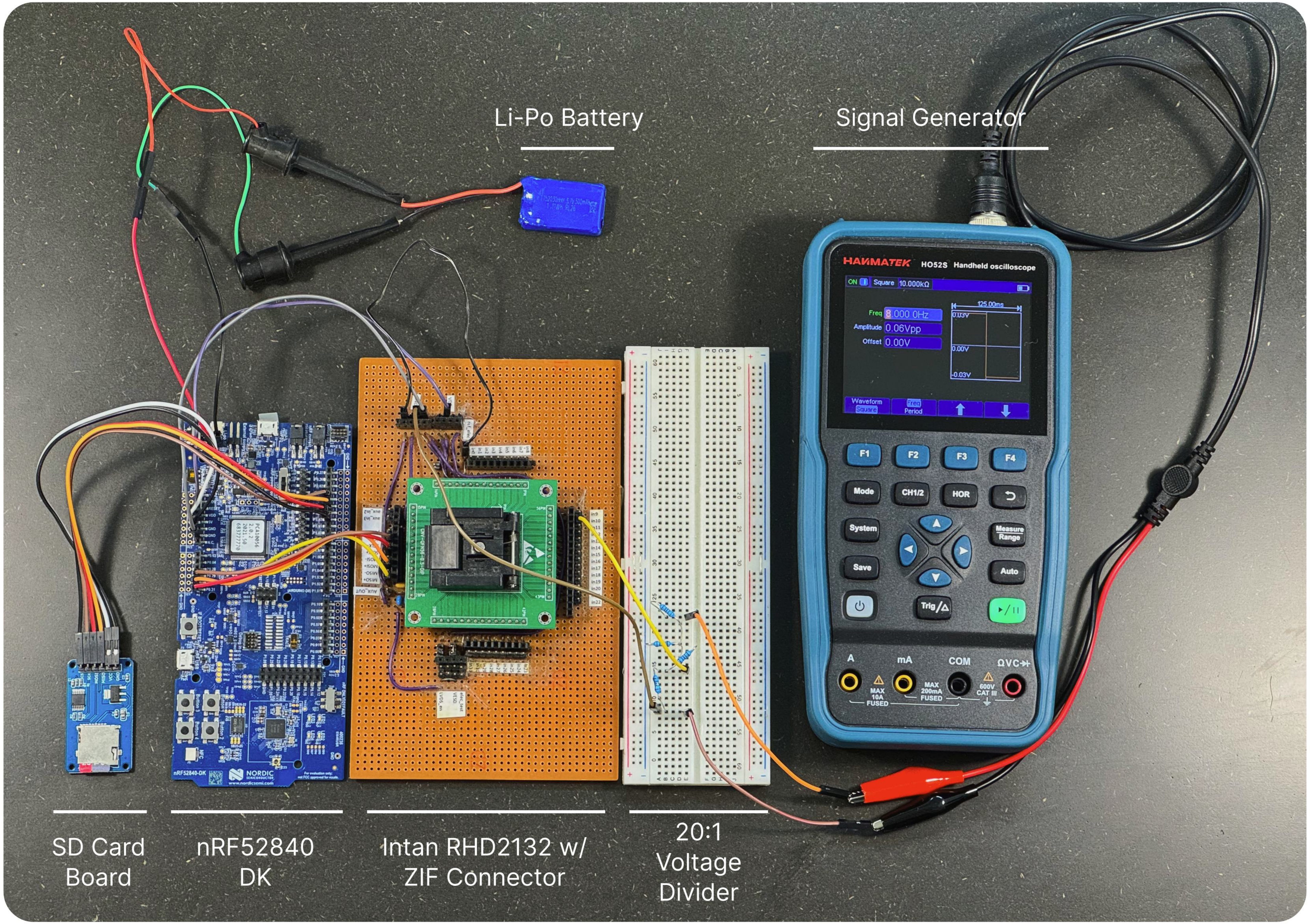

start sampling timer
RHD2132 thread loop
wait for work queue timer event
sample all channels
write to FIFO buffer
update latest neural data
FIFO Buffer
Latest Neural Data
NeuralData struct
uint16_t
channel_data[16]
uint32_t
timestamp
LatestNeuralData struct
NeuralData
data
bool
sent


SD card thread loop
Data available?
no
yes
read from FIFO buffer
All data read?
no
yes
FIFO Buffer
set data read to 0
write file to SD card in session folder
128 NeuralData structs
SD Card


BLE neural data thread loop
New data?
no
yes
send neural data and mark as sent
Interval elapsed?
no
yes
Latest Neural Data
BLE status thread loop
Interval elapsed?
no
yes
send system status
DeviceStatus struct
uint8_t
battery_level
uint8_t
temperature
bool
recording_status
char
configuration


Head - Output End
FIFO Buffer
max 300
NeuralData structs
thread safe mutex
data_available
semaphore
NeuralData struct
Tail - Input End
trigger data
available


GATT Server (logger)
Neural Data Characteristic
Properties
Notify
Read
Value
Latest Neural Data
Descriptor
CCC
Device Status Characteristic
Properties
Notify
Value
Device Status
Descriptor
CCC
GATT Client (receiver)


Li-Po Battery
Signal Generator
HO52S Handheld oscilloscope
SD Card Board
nRF52840 DK
Intan RHD2132 w/ ZIF Connector
20:1 Voltage Divider