

IMPERIAL



Marmoset Neural Logger Project

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

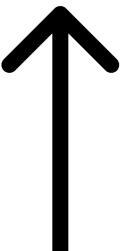
Student: **Martin Lombard**

Supervisors: **Tim Constandinou, Ian Williams**

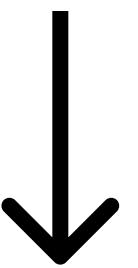




Newcastle University



Collaboration



IMPERIAL

Neuroscience Study



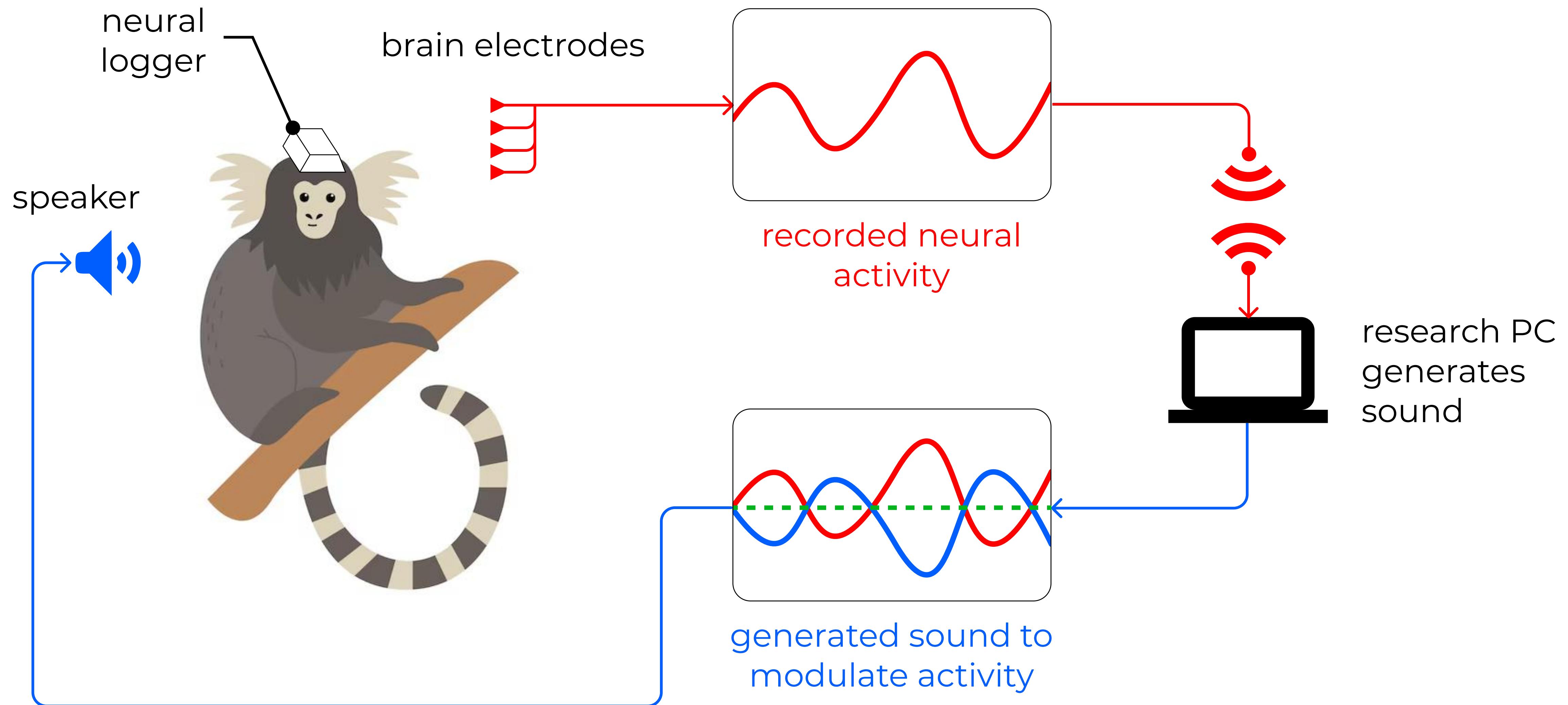
Device Development

```
1 // Define WRITE_BUFFER_SIZE (64 * 1024) // 64 KB write buffer
2
3 #define K_THREAD_STACK_DEFINE(sd_card_stack, SD_CARD_THREAD_STACK)
4 struct k_thread sd_card_thread_data; // Declare the thread stack
5
6 > int sd_card_list_files(char const *const path, char *buf,
7     size_t buf_size);
8 static char abs_path_name[PATH_MAX_LEN + 1];
9 static struct fs_file_t f_entry;
10
11 int sd_card_open_write_close(char const *const filename,
12     int flags);
13
14 int ret;
15
16 LOG_INF("Entering sd_card_open_write_close");
17
18 ret = k_sem_take(&m_sem_sd_oper_ongoing, K_MSEC(K_SEM_WAIT));
19 if (ret)
20 {
21     LOG_ERR("Sem take failed. Ret: %d", ret);
22     return ret;
23 }
24
25 if (!sd_init_success)
26 {
27     k_sem_give(&m_sem_sd_oper_ongoing);
28     return -ENODEV;
29 }
30
31 // Construct the absolute path
32 if (snprintfabs_path_name, sizeof(abs_path_name), "%s",
33     LOG_ERR("Filename is too long");
34     k_sem_give(&m_sem_sd_oper_ongoing);
```

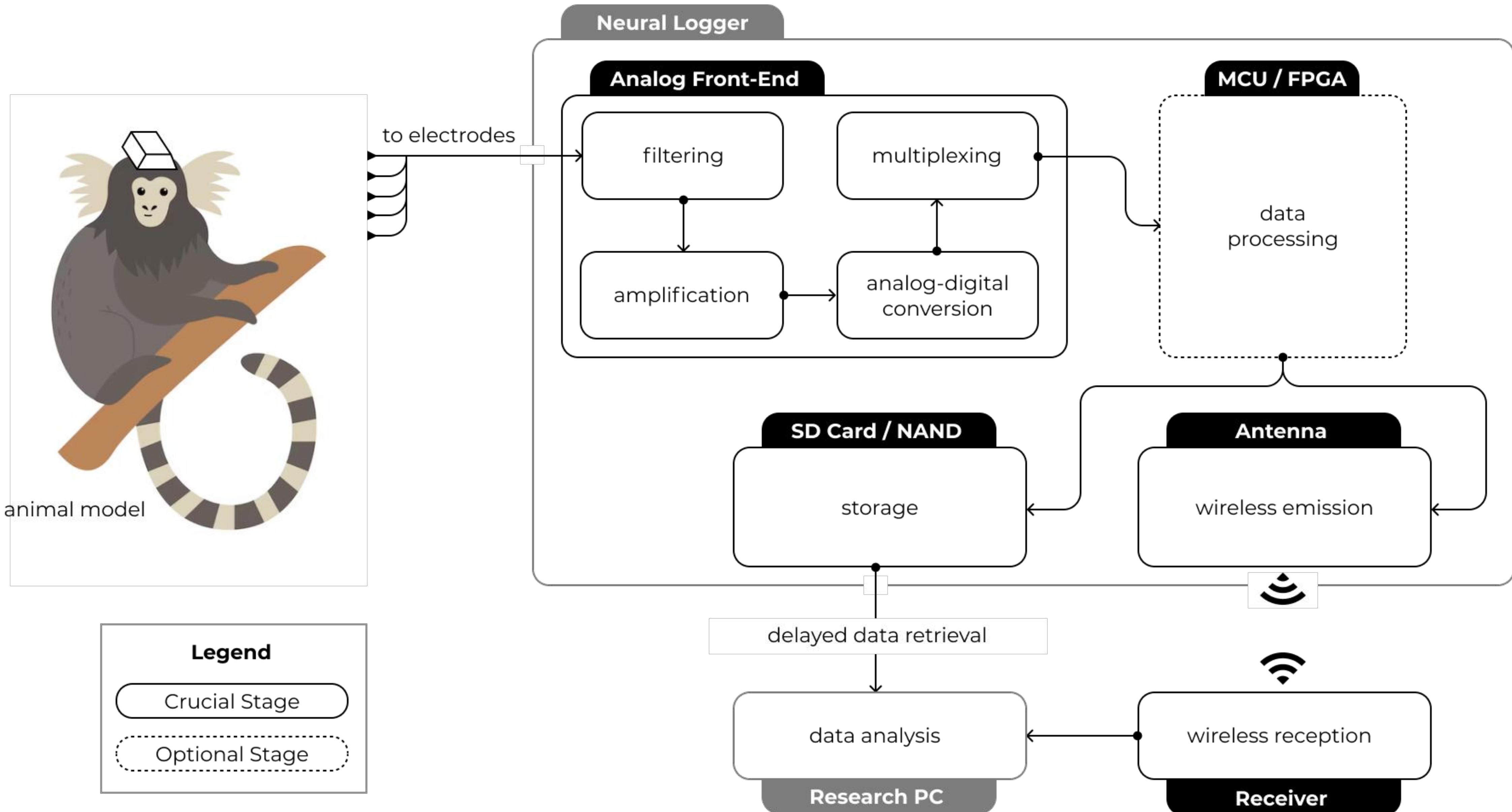


Full
System

CLAS - Closed Loop Auditory Stimulation



Neural Loggers



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. Huxter², Stuart A. Bowyer^{1,4}, Anthony J. Blockeel², James Butler², Syed A. Imtiaz^{1,5}, Keith A. Wafford², Keith G. Phillips², Mark D. Tricklebank², Hugh M. Marston² & 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.

Recent advances in the development of transgenic mice have provided unprecedented insight into the mechanisms of mammalian brain function and human disease processes, and have led to a dramatic shift from rats to mice as the preferred preclinical model used in drug discovery. However, their small size makes neuronal recording in freely-moving mice challenging. The ability to make direct electrophysiological recordings from populations of neurons requires multiple parallel recording channels and high sampling rates (>10 KHz) in order to properly characterize action potentials^{1,2}. The circuitry required is consequently energy-intensive and traditionally requires a multi-wire tether to provide power and to carry the analogue signal to the recording equipment. While this is practical in larger rodents, it presents a serious burden for a mouse³. Recently developed wireless recording systems allow both greater freedom of movement and the possibility of entirely new experimental designs, such as recording from complex enclosed environments^{4,5}. However, there has always been a trade-off between the weight of the device and recording density or duration. Current off-the-shelf solutions are limited to less than 4 hours recording unless a harness is employed to support the additional battery weight, or provide longer recording only at reduced sample-rates which are suitable for recording local field potentials (LFP) or electroencephalograms (EEG), but not action potentials (APs). In either case, the devices are also still cumbersome and relatively heavy (4 g or more, Table 1). This represents >10% of the weight of an adult mouse - similar to a human subject carrying a 6 Kg weight on their head. To improve on existing wireless technology, the circuitry needed to be redesigned from the bottom-up, with an emphasis on improving the energy efficiency.

Here we test the performance of TaiNi - a novel wireless system based on a customized Application-Specific Integrated Circuit (ASIC) created using innovative low power design techniques. The circuit blocks, as shown in Fig. 1, incorporated in the ASIC include filters, amplifiers, analogue-to-digital converters, multiplexing and wireless transmission. This maximized efficiency and reduced total weight to 1.5 g. This system represents a significant advance in scalable recording systems for small rodents, and provides a robust foundation for additional designs.

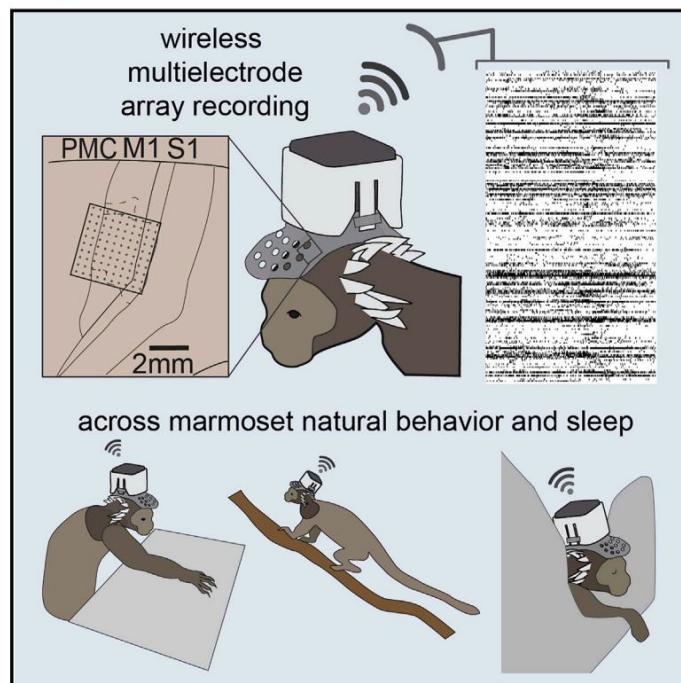
¹Department of Electrical and Electronic Engineering, Imperial College London, London, UK. ²Eli Lilly and Company Limited, Windlesham, UK. ³Department of Neuroimaging Sciences, Institute of Psychiatry, Kings College London, London, UK. ⁴TainTec Ltd., Barking Road, London, UK. Correspondence and requests for materials should be addressed to J.R.H. (email: huxter_john@network.lilly.com) or E.R.-V. (email: e.rodriguez@imperial.ac.uk)

Cell Reports

Resource

Chronic wireless neural population recordings with common marmosets

Graphical abstract



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

CellPress

Neural Logger Literature



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,*}

^aINL, UMR5270 CNRS, INSA Lyon, Université de Lyon, Villeurbanne, F-69621, France

^bCRNI, SLEEP Team, UMR 5292 CNRS/UJF/INSEMM, Université Claude Bernard Lyon 1, Lyon, F-69372, France

^cMax Planck Institute for Ornithology, Avian Sleep Group, 82319, Seewiesen, Germany

ABSTRACT

Background: Sleep is an inactive state of reduced environmental awareness shared by all animals. When compared to wakefulness, sleep behavior is associated with changes in physiology and brain activity. The nature of these changes varies considerably across species, and therefore is a rich resource for gaining insight into the evolution and functions of sleep. A major obstacle to capitalizing on this resource is the lack of a small device capable of recording multiple biological parameters for extended periods of time both in the laboratory and the field.

New method: ONEIROS is a new tool designed for conducting sleep research on small, freely moving animals. The miniature, standalone system is capable of recording up to 26 electrophysiological signals (electroencephalogram, electromyogram, electrooculogram, electrocardiogram), metabolic (3 temperature channels) and behavior via an accelerometer for several days. In addition, the device is equipped with a vibrating motor which can be used to assess arousal thresholds and to disrupt sleep. The system is available in telemetric or data-logger configuration useable in the field.

Results: To demonstrate the efficacy of this tool, we simultaneously recorded for the first time, electroencephalogram, hippocampal local field potential, electromyogram, electrooculogram, brain, body and ambient temperature, and 3D acceleration. We also deprived rats of paradoxical sleep by triggering the vibrating motor after online recognition of the state. Finally, by successfully recording a pigeon in an 8 m² aviary in a social context with the device in the logger configuration, we demonstrate the feasibility of using the device in the field.

1. Introduction

Sleep is a vital and complex behavioral state that competes with the time allocated to foraging, courtship, parental care, and vigilance (Lesku et al., 2012; Rattenborg et al., 2016, 1999). From a behavioral standpoint, sleep is traditionally defined as an inactive state with reduced responsiveness to environmental stimuli (i.e. elevated arousal threshold) that is rapidly reversible in response to sufficient stimulation. In many species, sleep occurs in a species-specific posture and at specific times of the day (Fig. 1). The duration and intensity of sleep increases following sleep deprivation, indicating that it is homeostatically regulated (Campbell and Tobler, 1984; Pieron, 1913). Initially identified in mammals, two electrophysiological sleep states can

be defined during behavioral sleep: paradoxical sleep (PS) or rapid eye movement sleep (REM sleep) (Aserinsky and Kleitman, 1953; Jouvet et al., 1959).

SWS is distinguished from wakefulness and PS by the presence of high amplitude, low frequency waves in the electroencephalogram (EEG), reduced heart and respiratory rate, reduced brain and body temperature, reduced muscle tone (compared to wakefulness), and the scarcity of eye movements. Environmental awareness is lower compare to resting wakefulness (Fig. 1). During PS, the EEG exhibits a desynchronized (low-amplitude, high-frequency) wake-like pattern. In contrast to wakefulness, PS is associated with tonic skeletal muscle atonia (Jouvet et al., 1959). This atonia is physically interrupted by rapid eye movements (Aserinsky and Kleitman, 1953) and other forms of

* Corresponding author.
E-mail address: pa.libourel@univ-lyon1.fr (P.-A. Libourel).

The graphical abstract illustrates the experimental setup for chronic wireless neural population recordings in common marmosets. It shows a marmoset wearing a head-mounted recording device connected to a base station via a cable. The device is shown in three different natural behaviors: sitting at a table, climbing a branch, and sleeping in a nest. A inset shows a brain slice labeled 'PMC M1 S1' with a 2mm scale bar, and a multi-electrode array being implanted. Another inset shows raw neural activity traces. The title 'wireless multielectrode array recording' is at the top left.

Cell Reports

Resource

Chronic wireless neural population recordings with common marmosets

Graphical abstract

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Marina Sundiang, Marek Niekrasz,
Jason N. MacLean,
Nicholas G. Hatsopoulos

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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>

Check for updates

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Neural Logger Literature

Newcastle University Needs



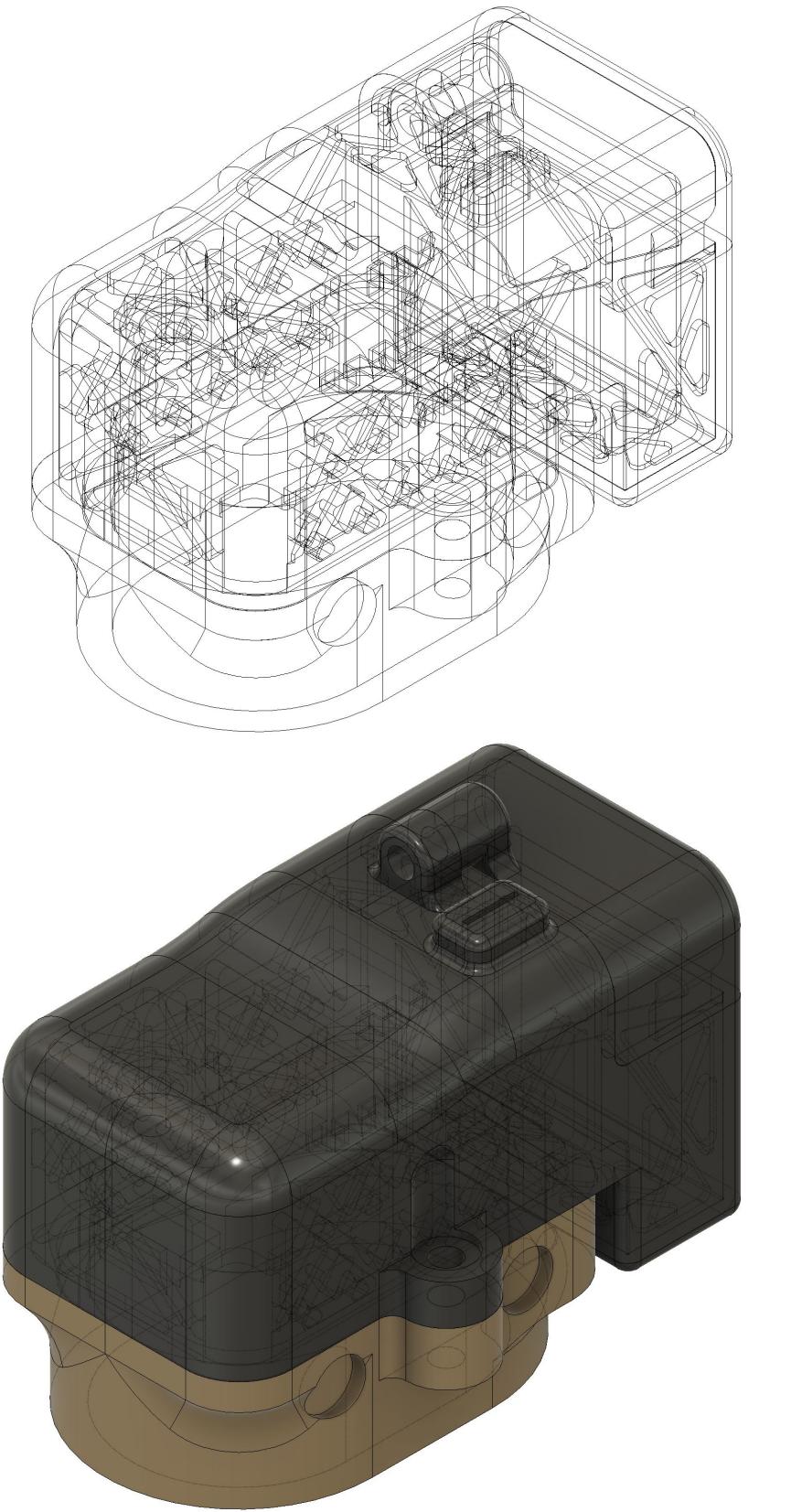
- 
 - 🔋 Autonomy
 - ⚡ Channel Count
 - 🧠 Sampling Rate
 - ⚙️ Dimensions
 - 💫 Plug-&-Play
 - 👤 Remote Operation

Target Specs

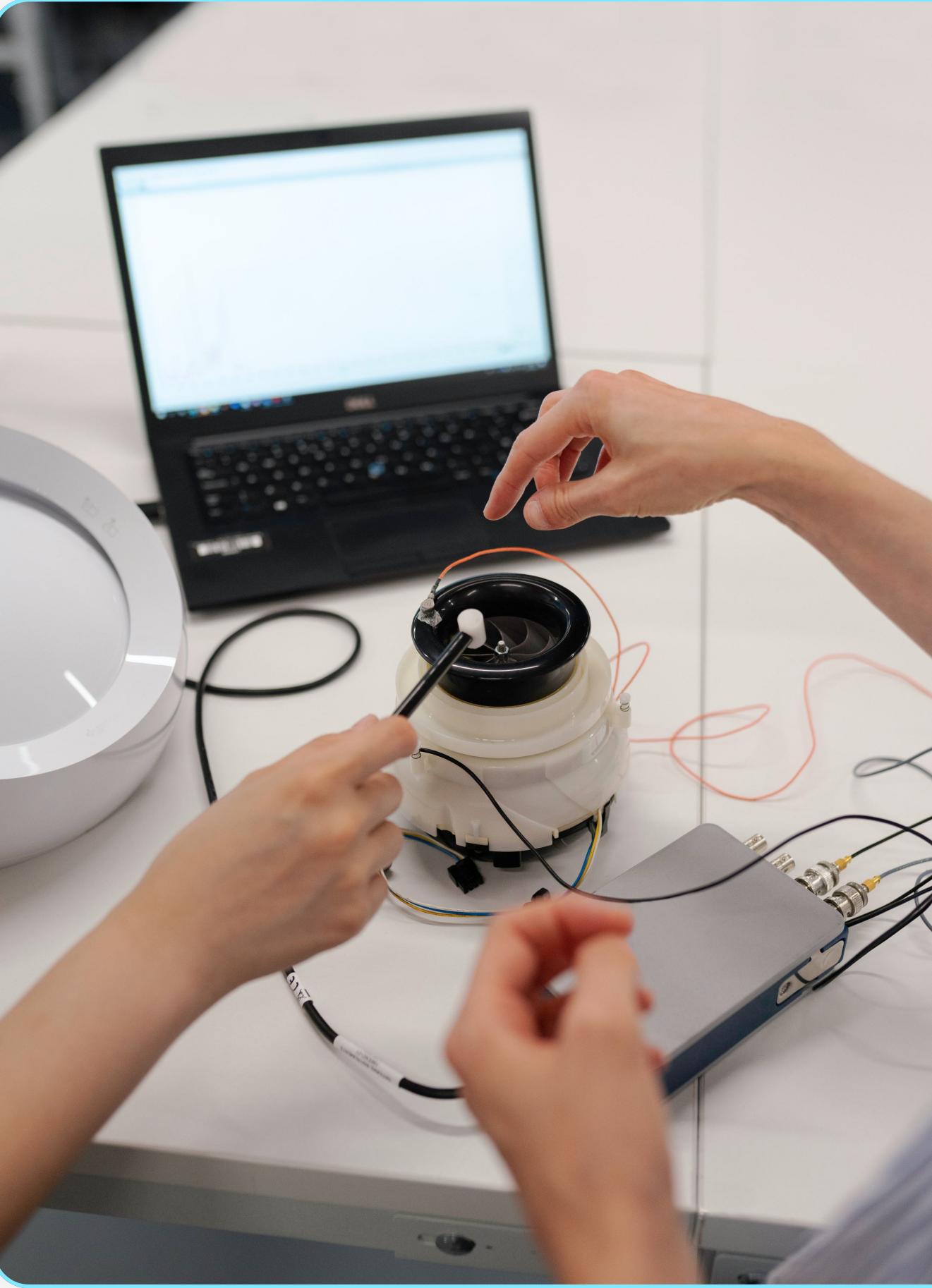
Code	Name	Value
E1	Autonomy	≥ 2 hrs
E2	Channel Count	≥ 16
E3	Sampling Rate	≥ 100 Hz/channel
M1	Dimensions	$40 \times 70 \times 40$ mm
M2	Weight	40-12 g
M3	Durability	High

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

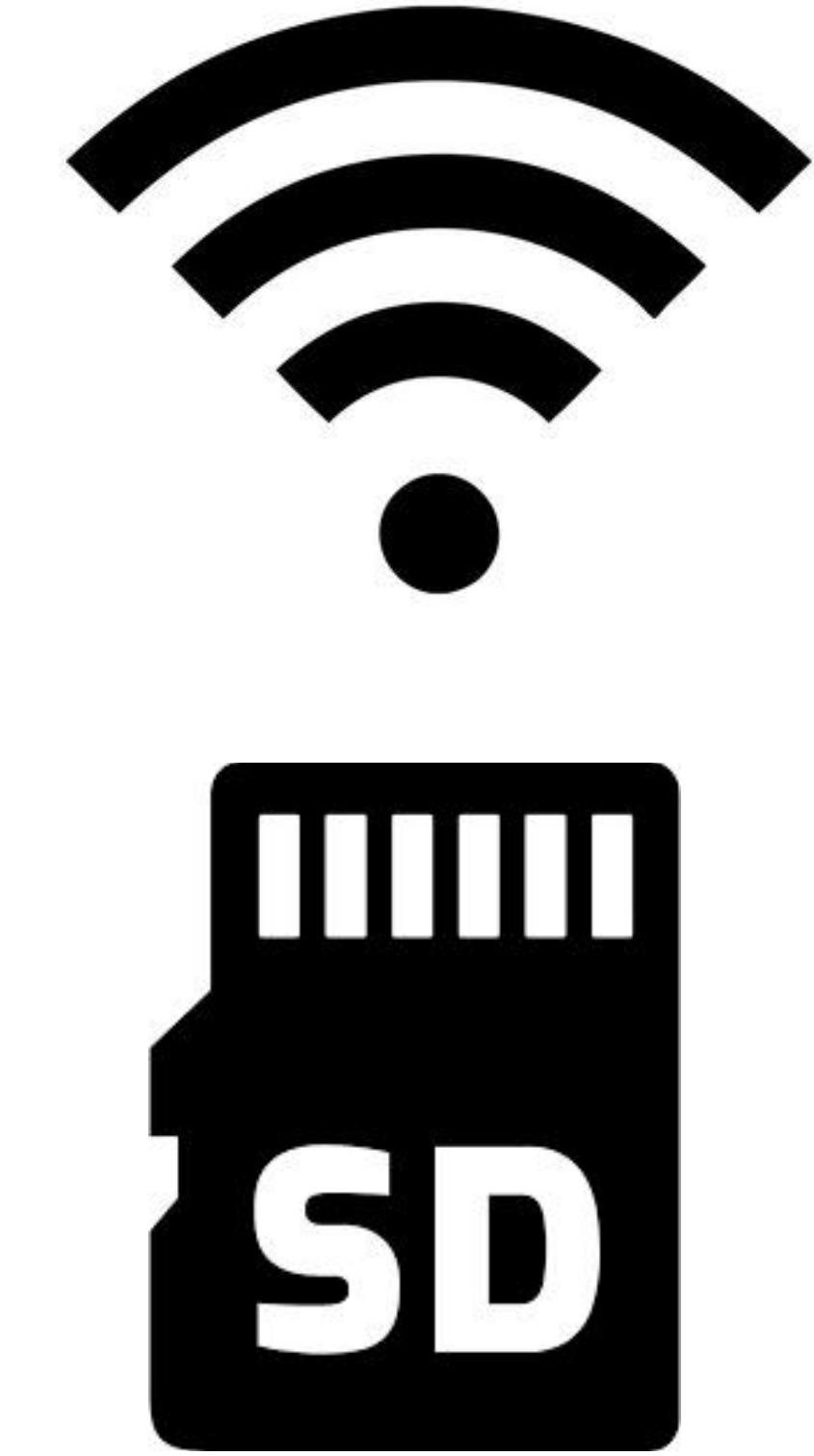
Innovative Angles



Mechanical Focus



Ease of Use

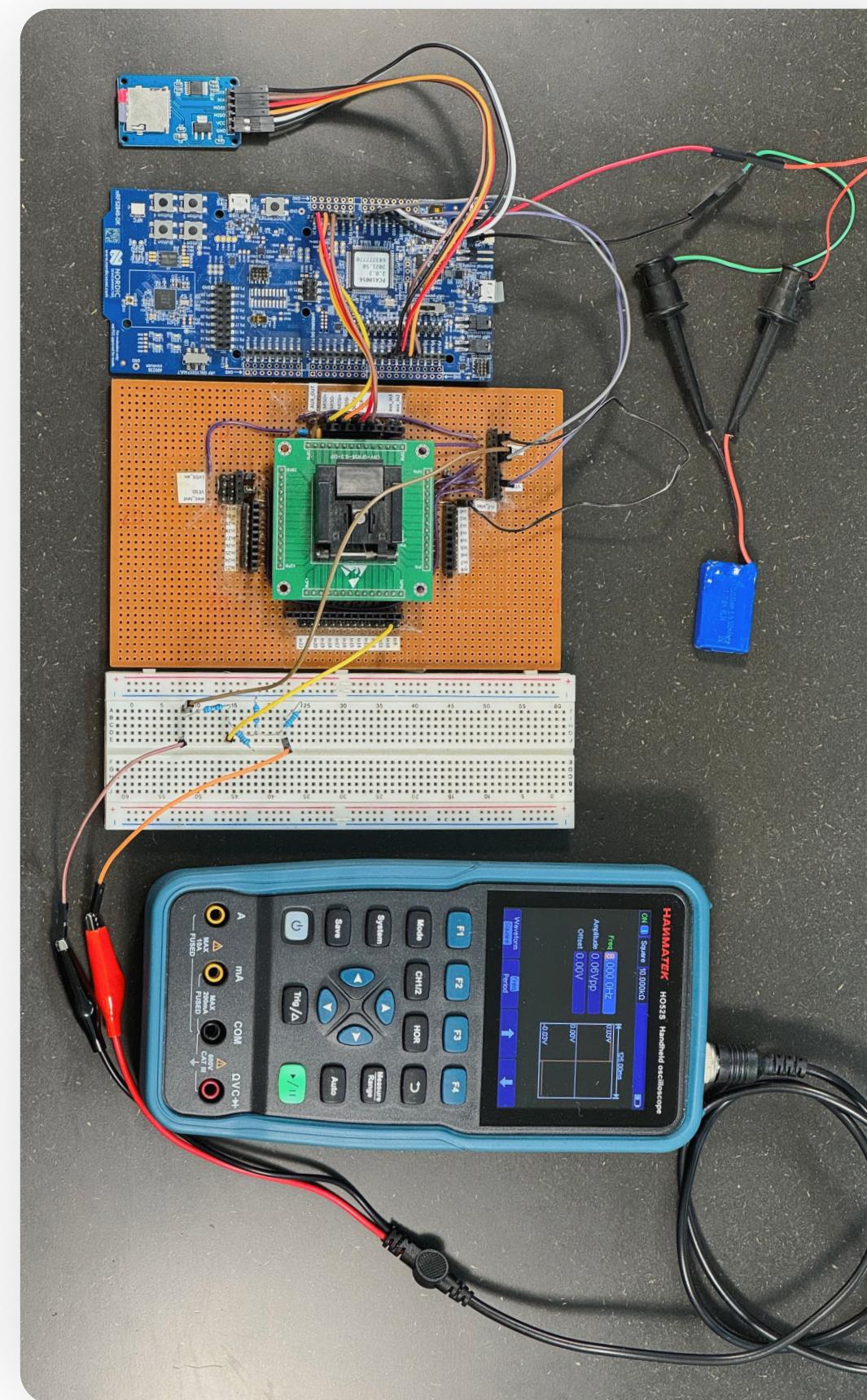


Simultaneous Wireless & Local Storage

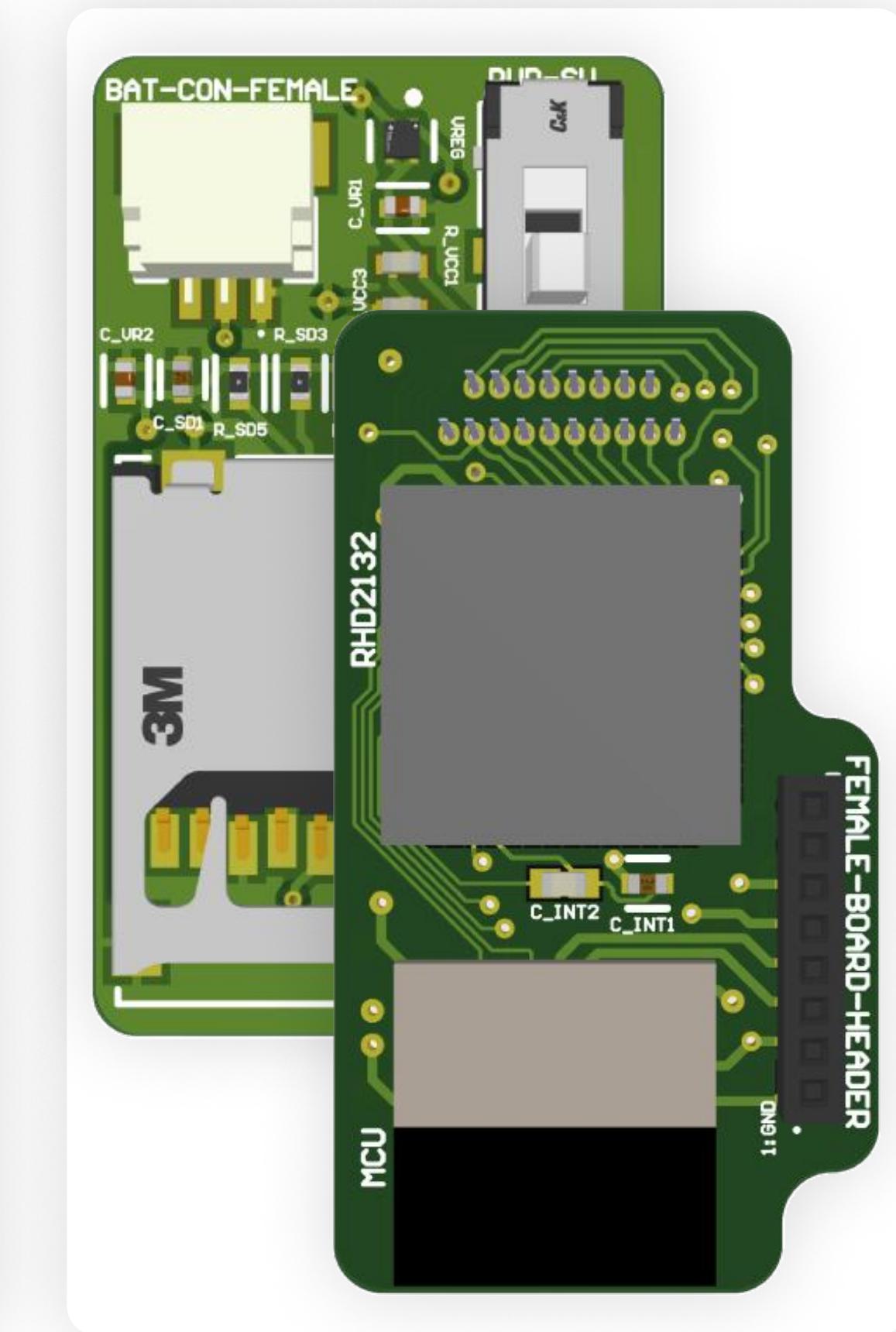
✓
**Full
Firmware v1**

```
41 #define WRITE_BUFFER_SIZE (64 * 1024) // 64 KB
42
43 K_THREAD_STACK_DEFINE(sd_card_stack, SD_CARD_TH
44 struct k_thread sd_card_thread_data; // Declare
45
46 > int sd_card_list_files(char const *const path,
47
48 static char abs_path_name[PATH_MAX_LEN + 1];
49 static struct fs_file_t f_entry;
50
51 int sd_card_open_write_close(char const *const
52 {
53     int ret;
54
55     LOG_INF("Entering sd_card_open_write_close");
56
57     ret = k_sem_take(&m_sem_sd_oper_ongoing, K_
58     if (ret)
59     {
56         LOG_ERR("Sem take failed. Ret: %d", ret);
57         return ret;
58     }
59
60     if (!sd_init_success)
61     {
62         k_sem_give(&m_sem_sd_oper_ongoing);
63         return -ENODEV;
64     }
65
66     // Construct the absolute path
67     if (snprintf(abs_path_name, sizeof(abs_path
68     {
69         LOG_ERR("Filename is too long");
70         k_sem_give(&m_sem_sd_oper_ongoing);
71     }
72
73     // Initialize the SD card stack
74     if (k_thread_start(&sd_card_thread_data, sd_c
75
76     // Return success
77     return 0;
78 }
```

✓
**Electronics
Prototype**



✓
**Stacked PCB
Design**

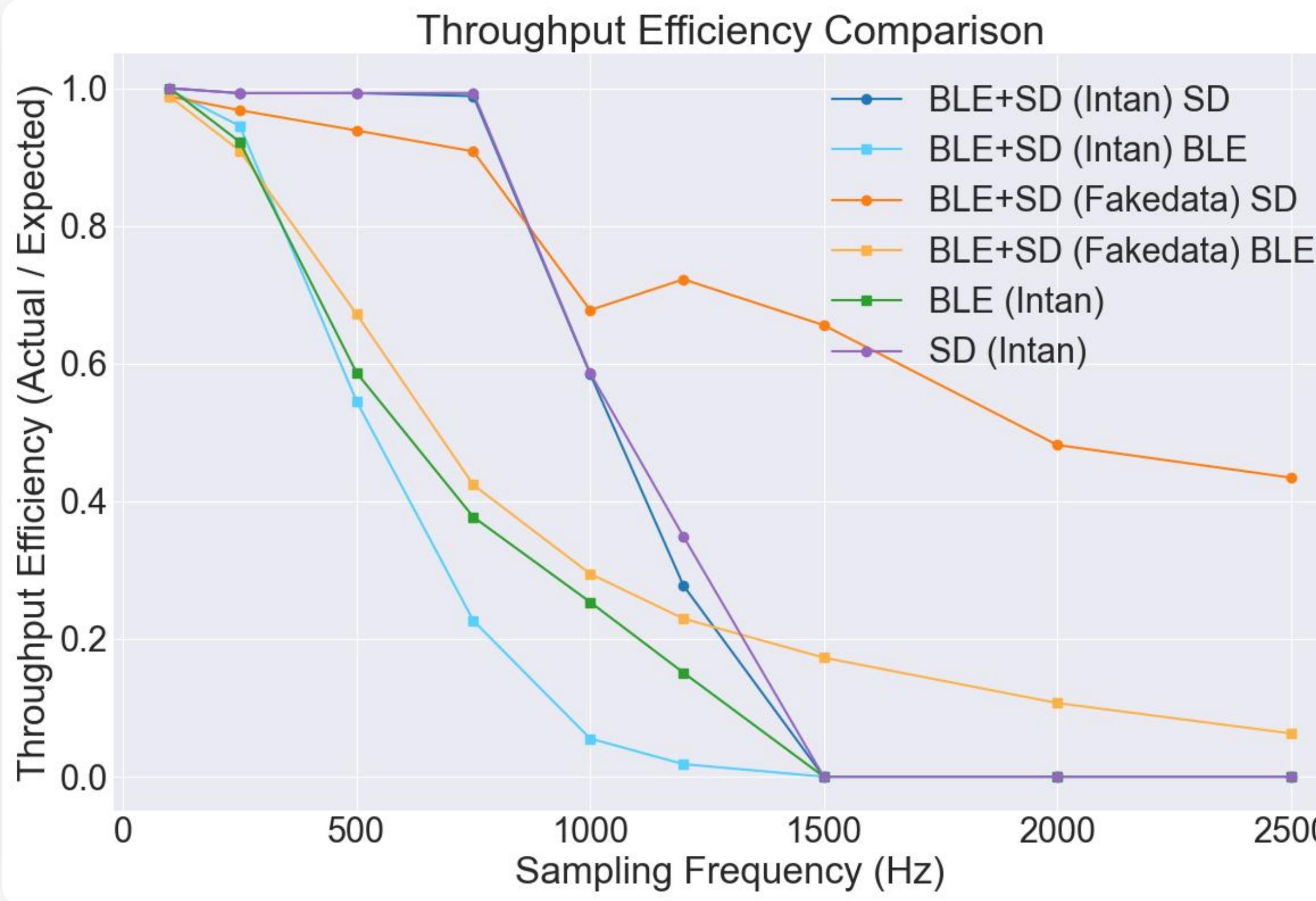


✓
**3x Mechanical
Iterations**

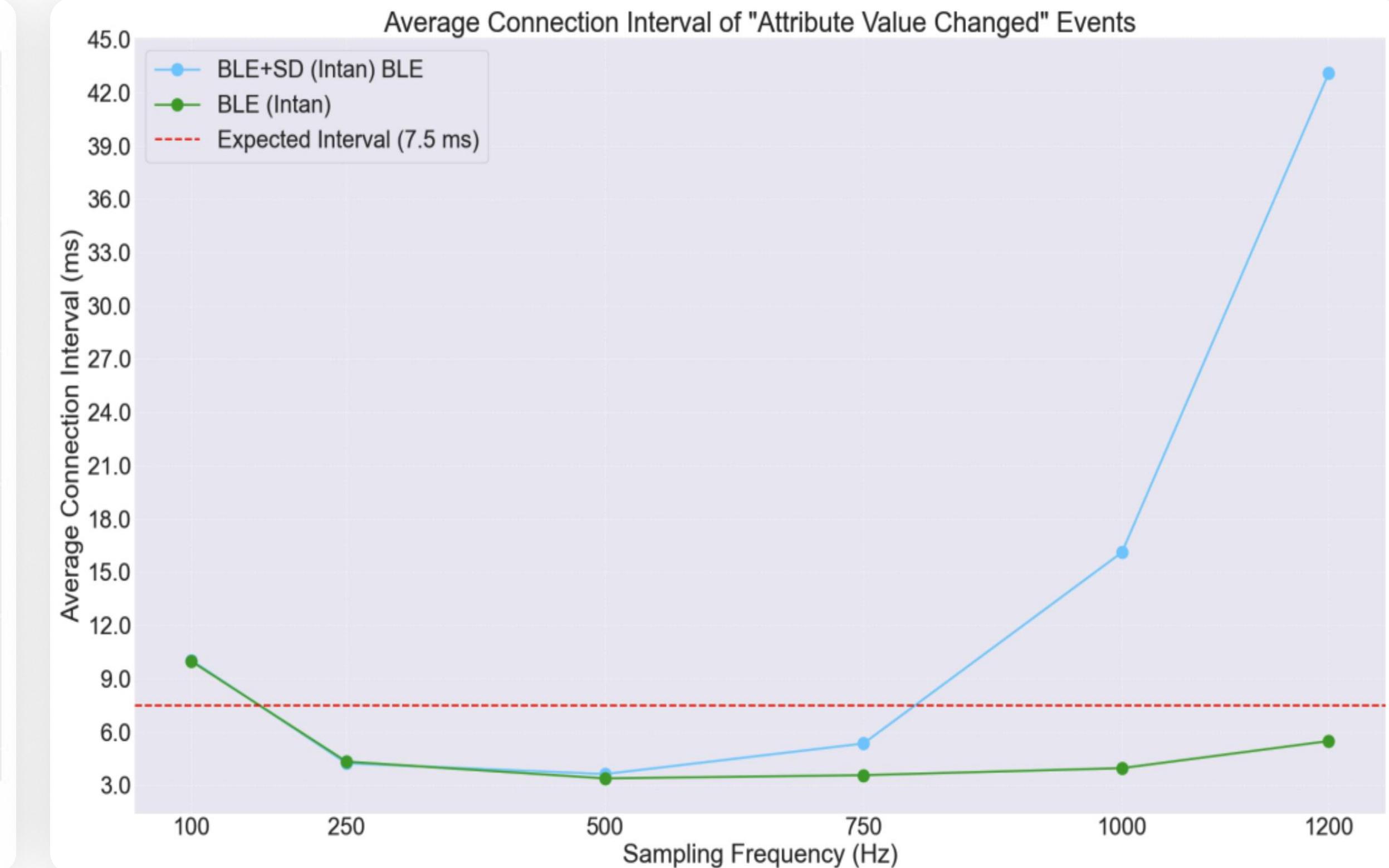


What I built!

Electronics & Firmware Results

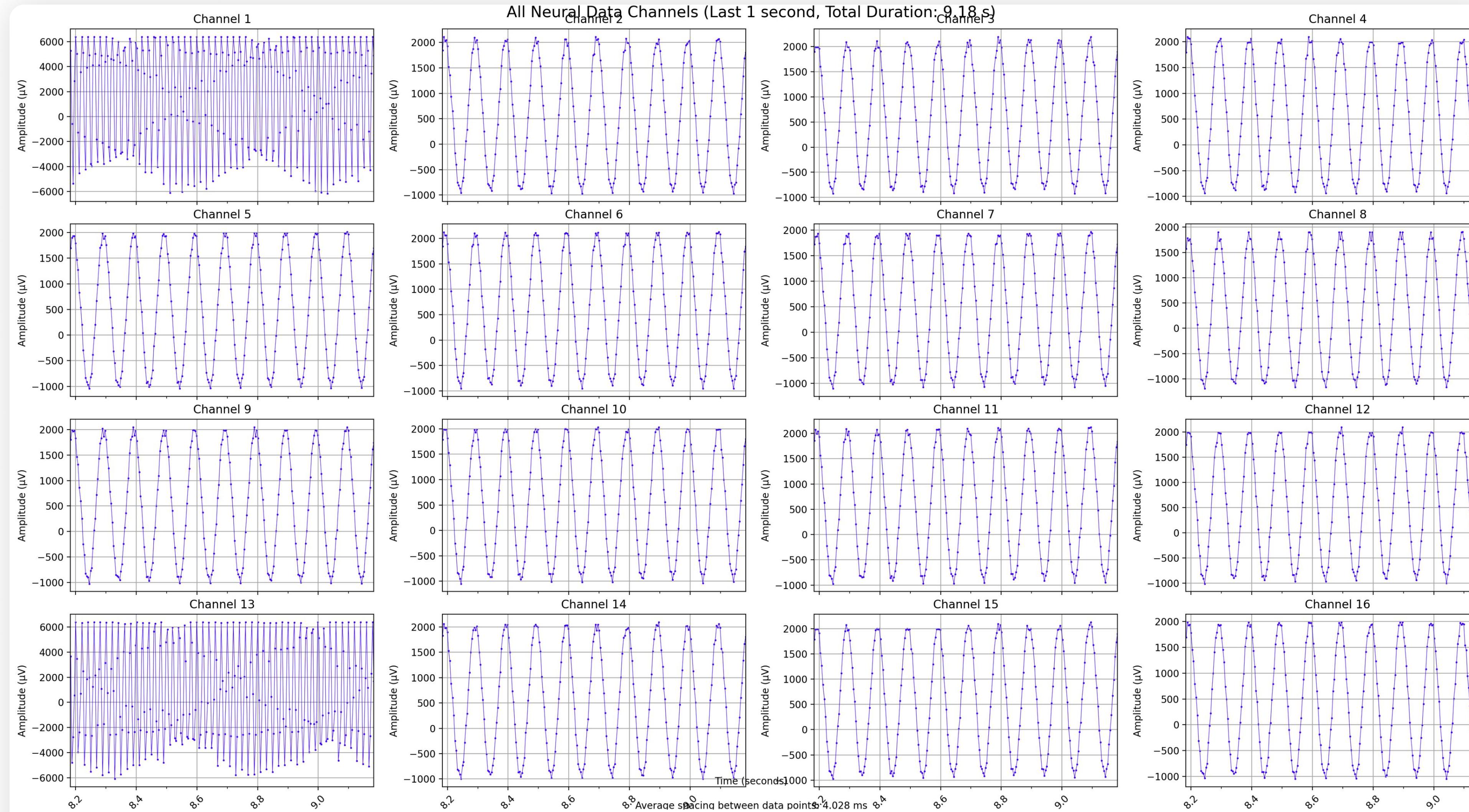


Highest stable recording frequency: **750 Hz**



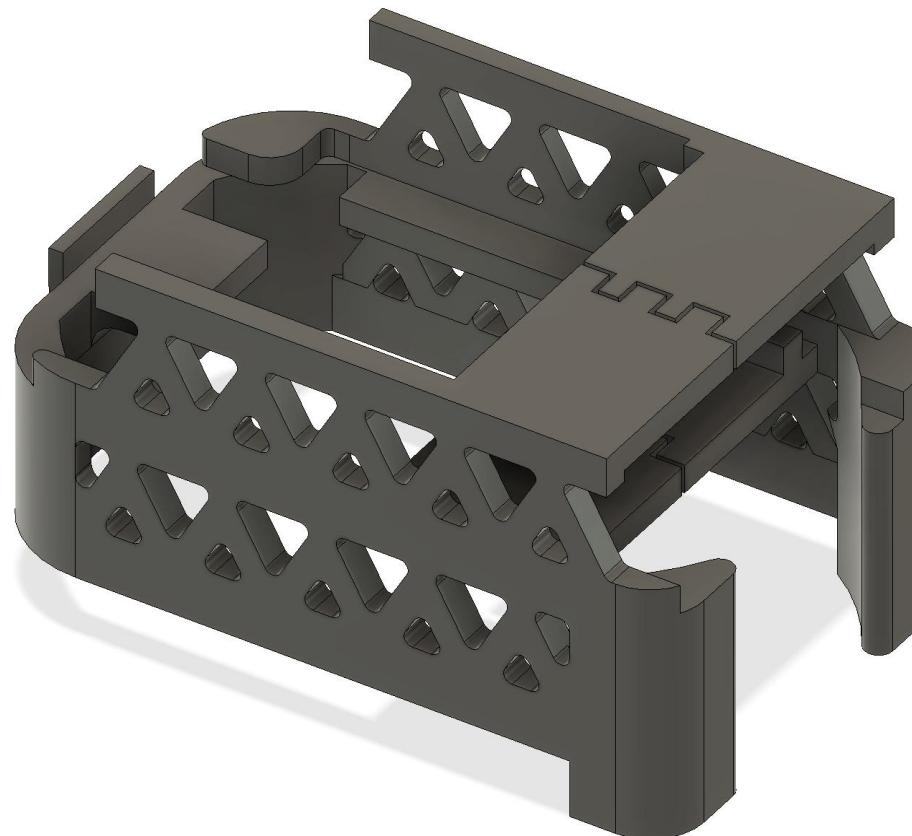
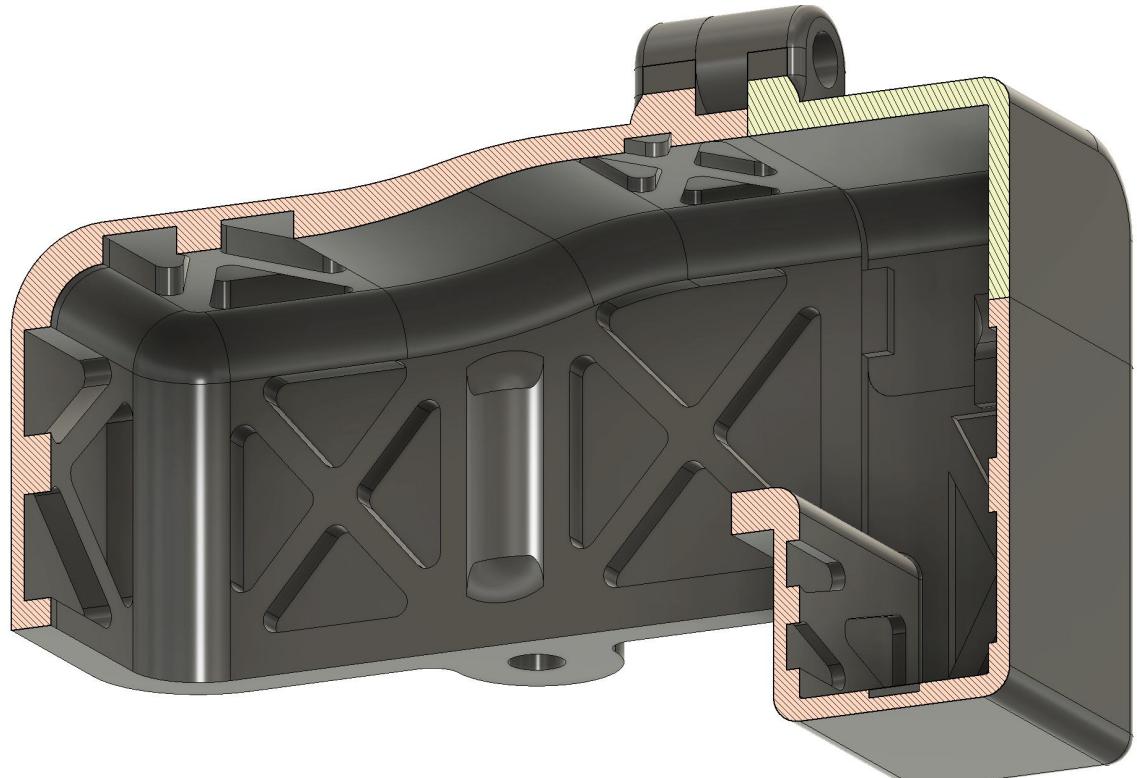
Highest recording frequency with appropriate BLE latency: **750 Hz**

Electronics & Firmware Results

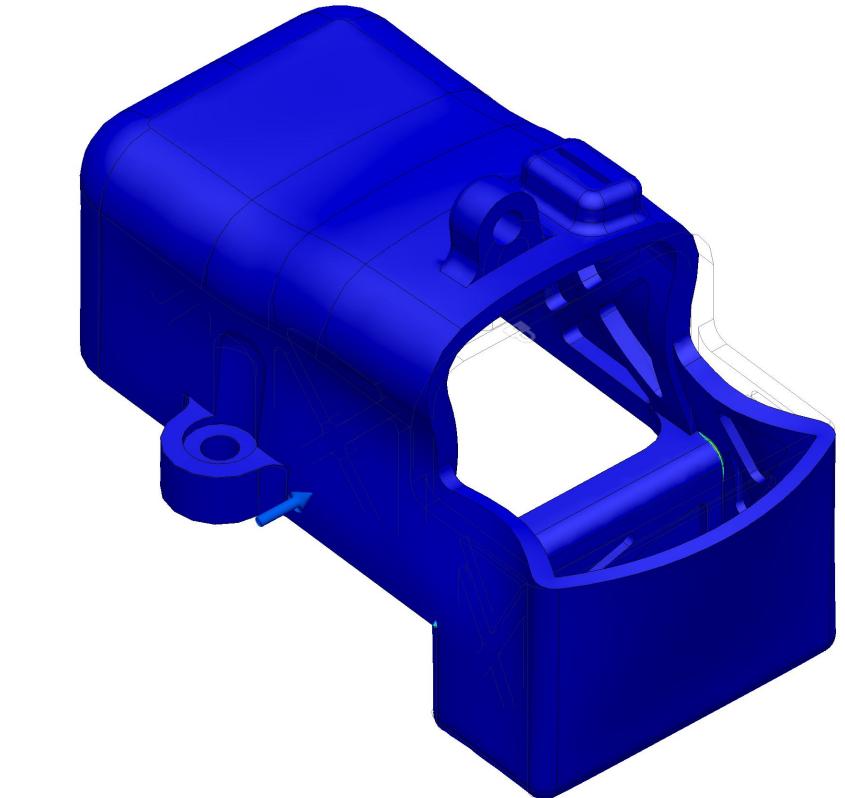
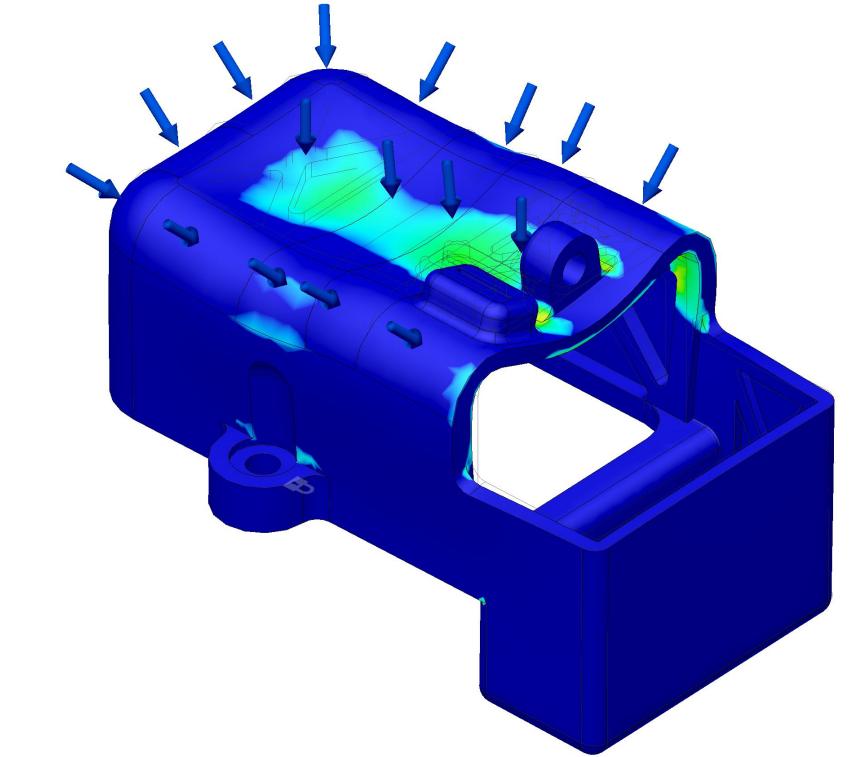
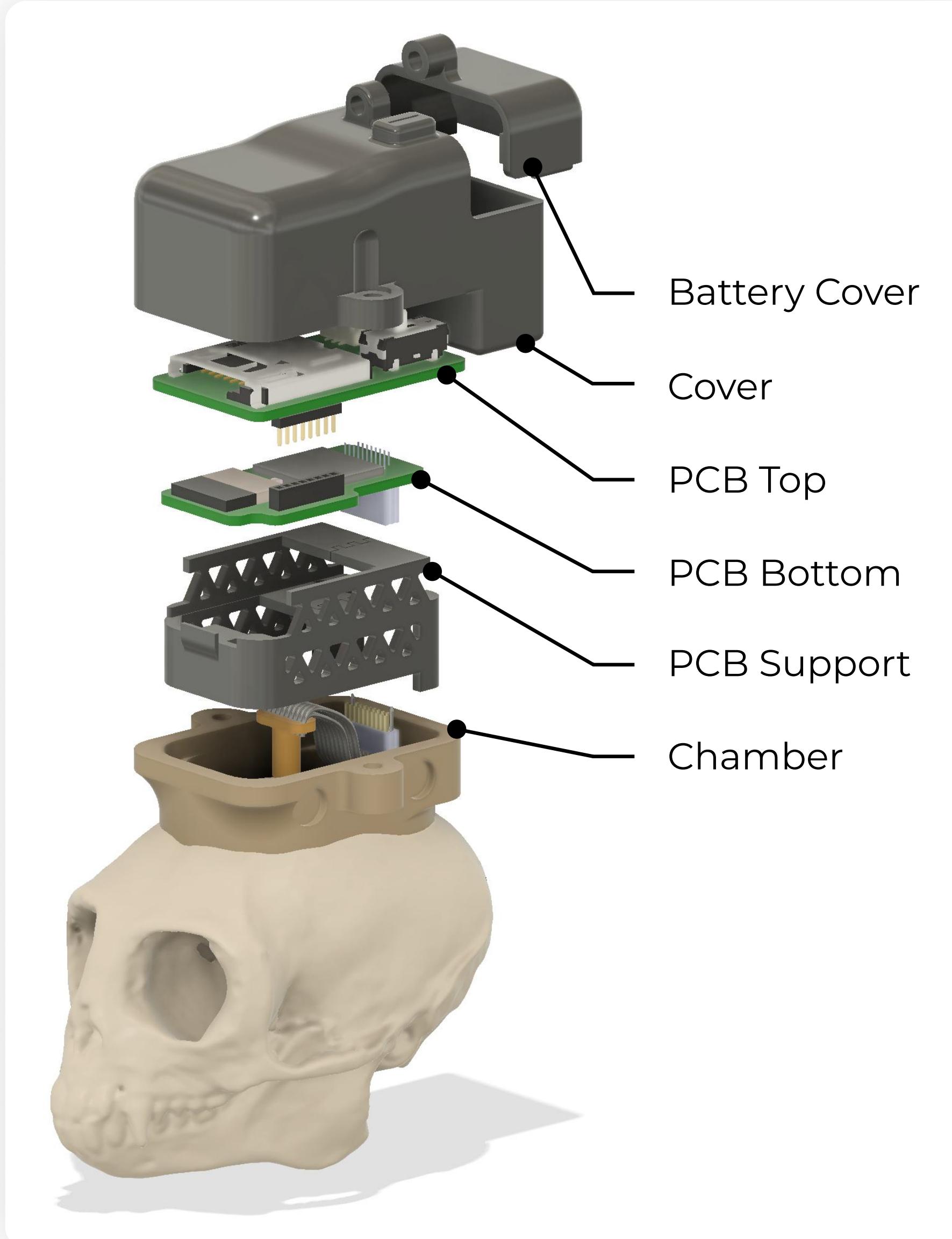


10 Hz sinusoidal signal recording

Mechanical Results



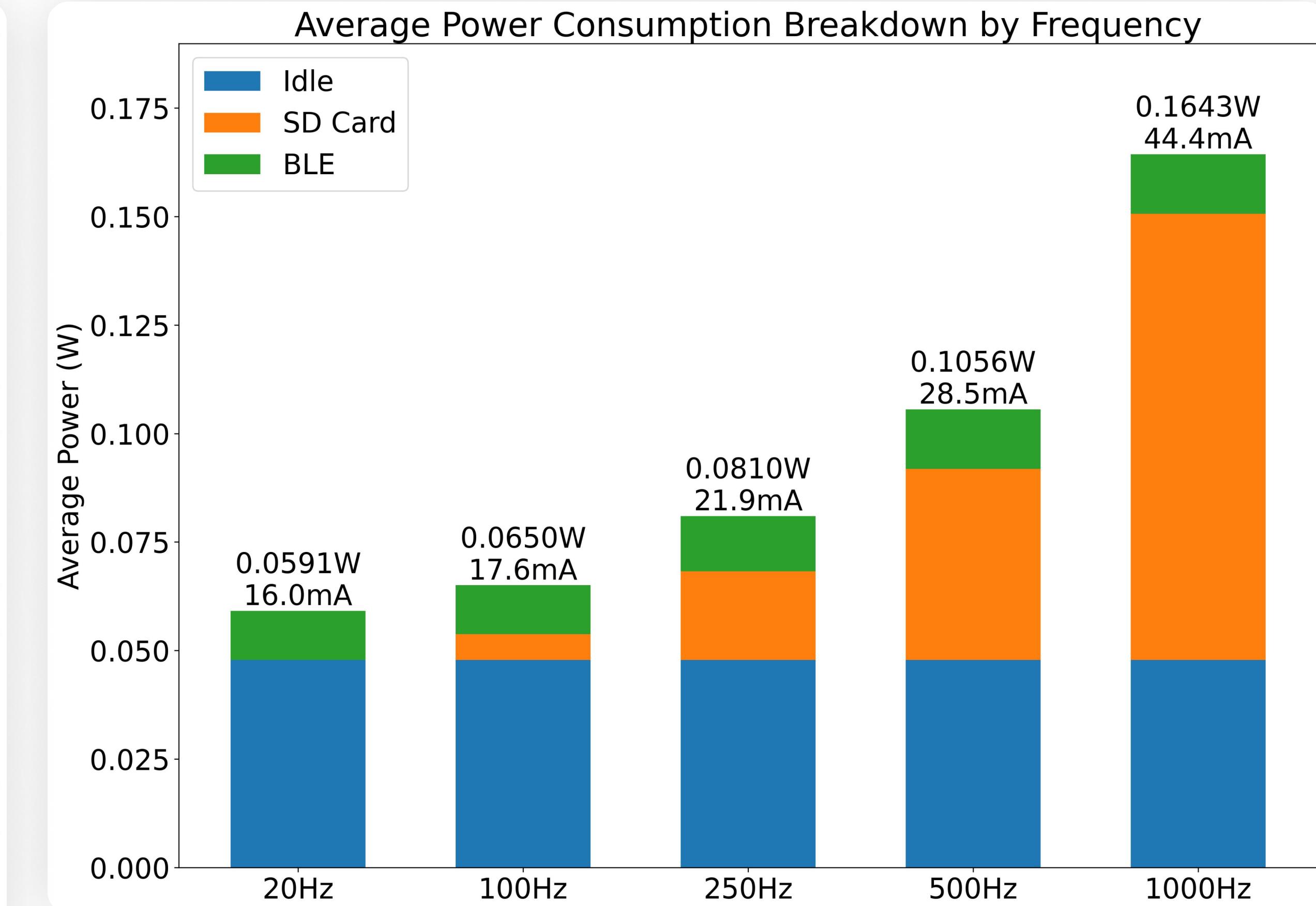
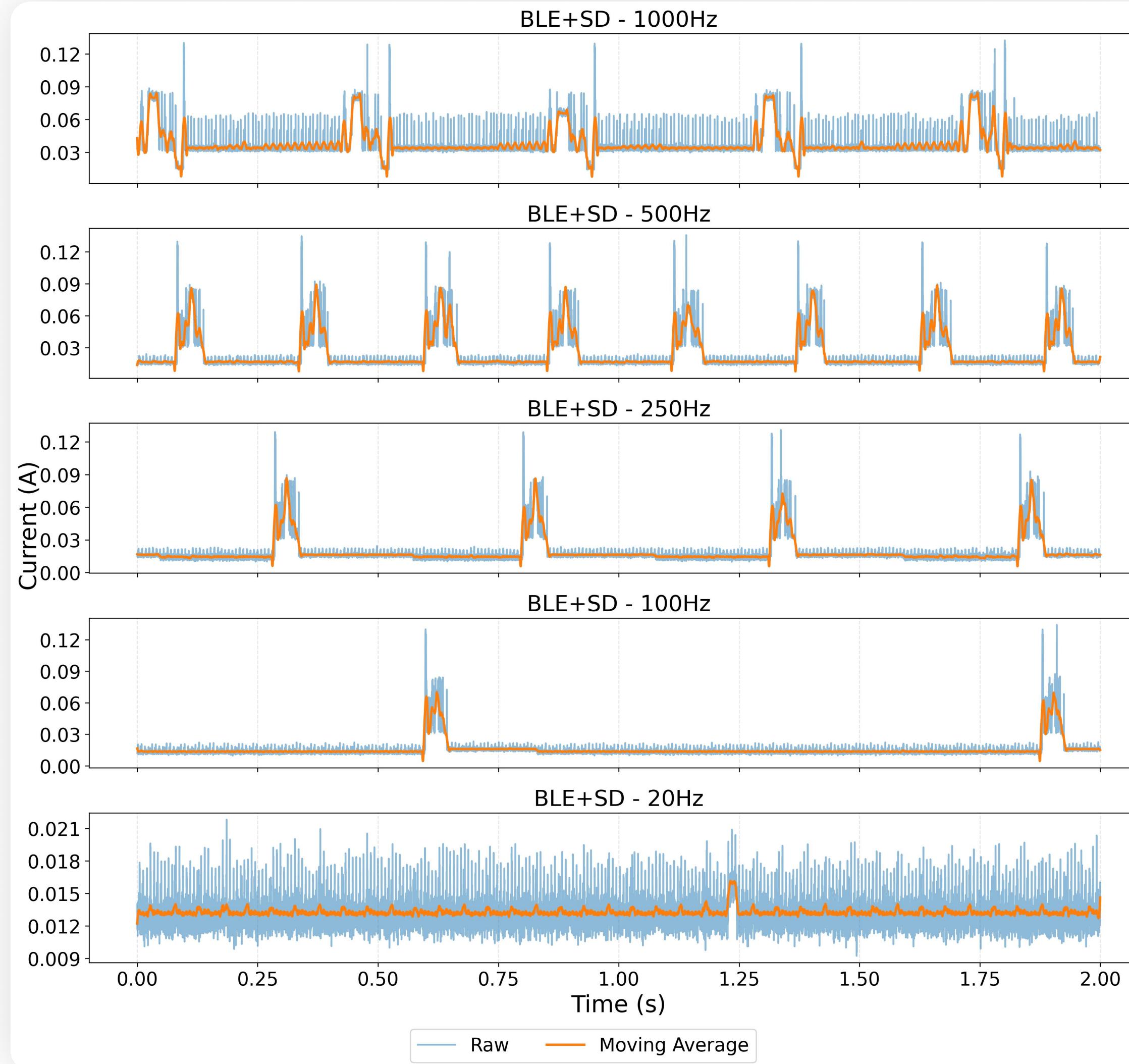
Weight Reduction Detail



FEA Housing Toughness

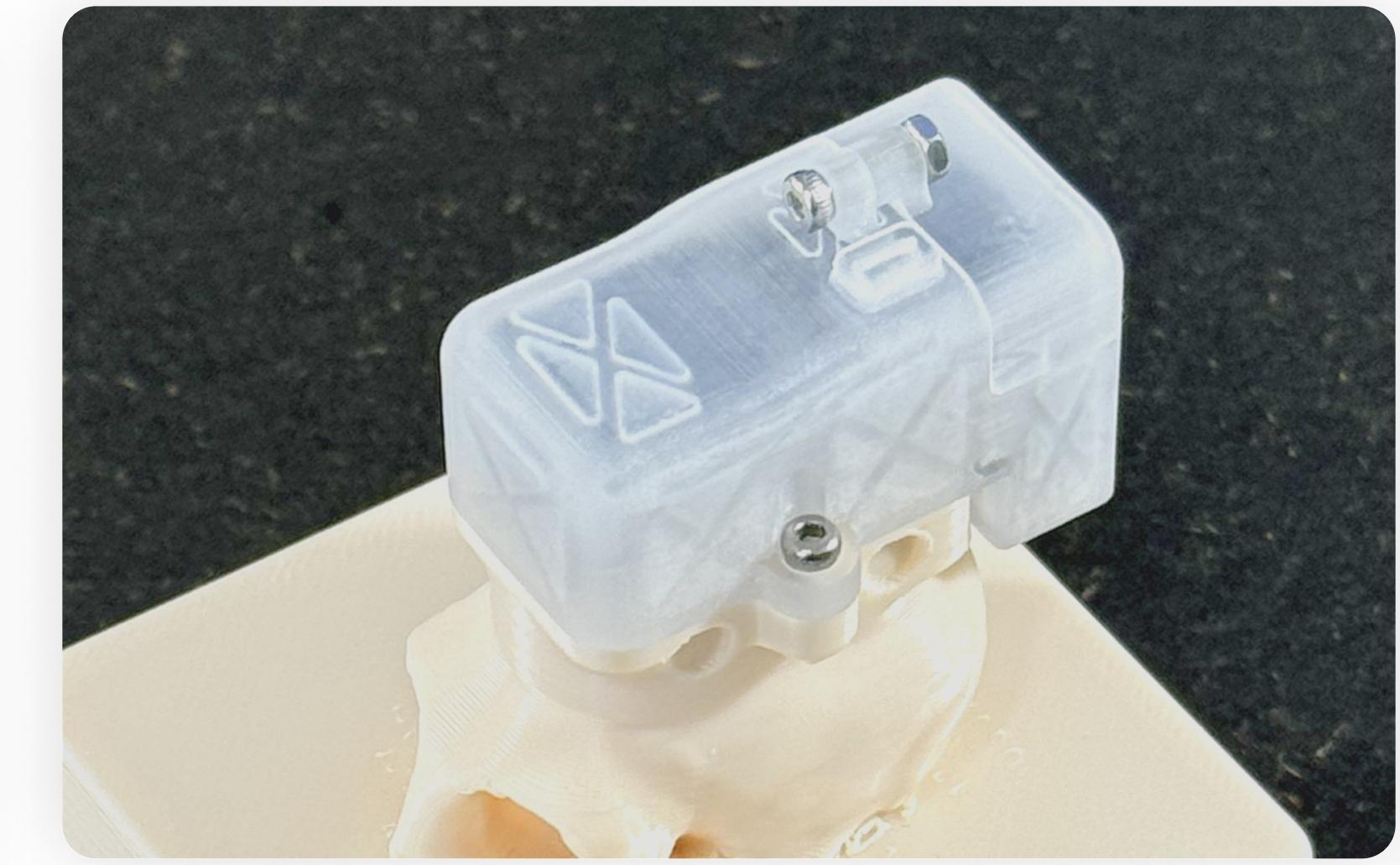
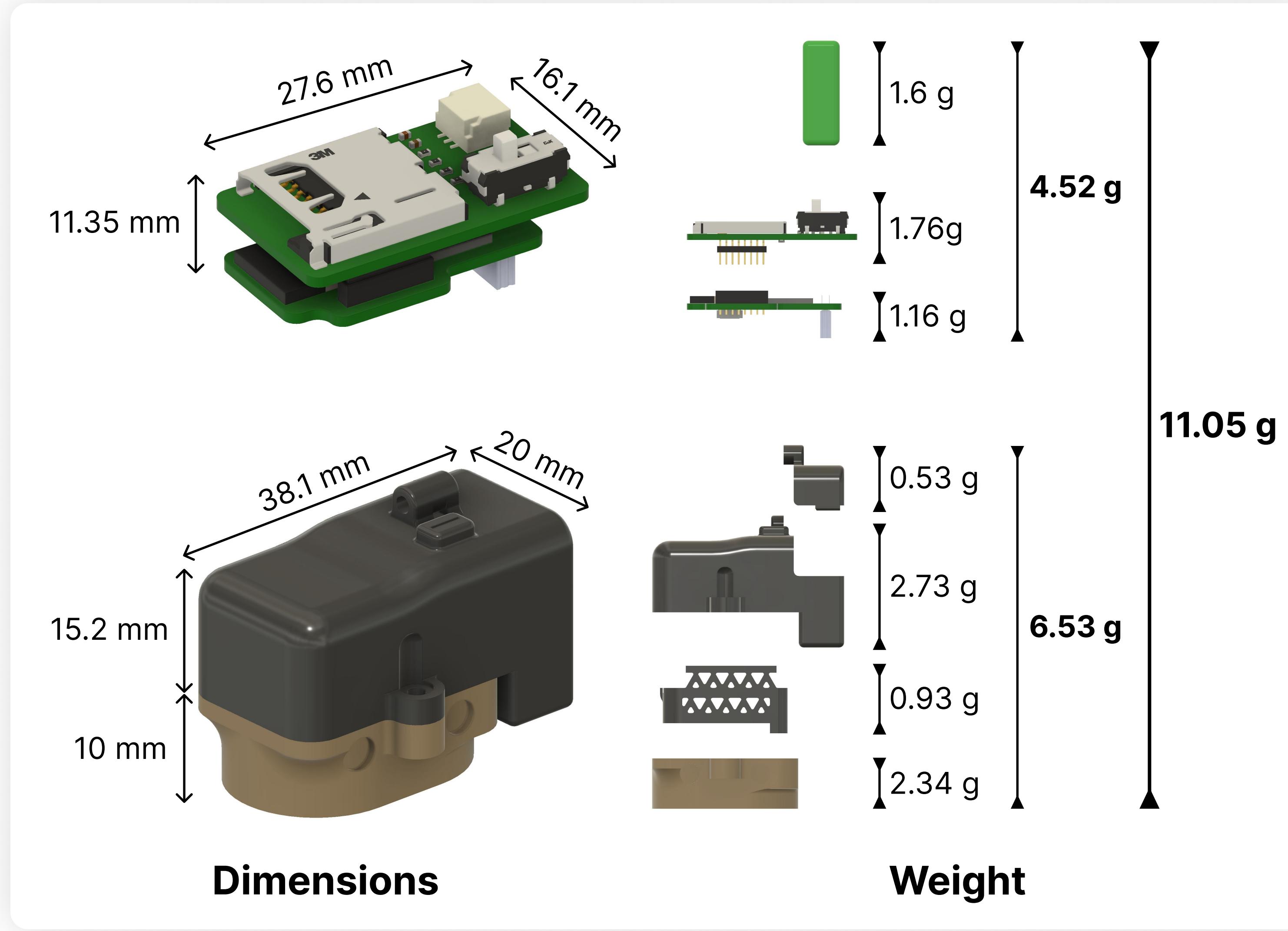
Housing **resists drops**, and monkey **inquisitiveness**.

Electronics & Firmware Results



Expected autonomy around 500 Hz: 2 hrs 40 min

Mechanical Results



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

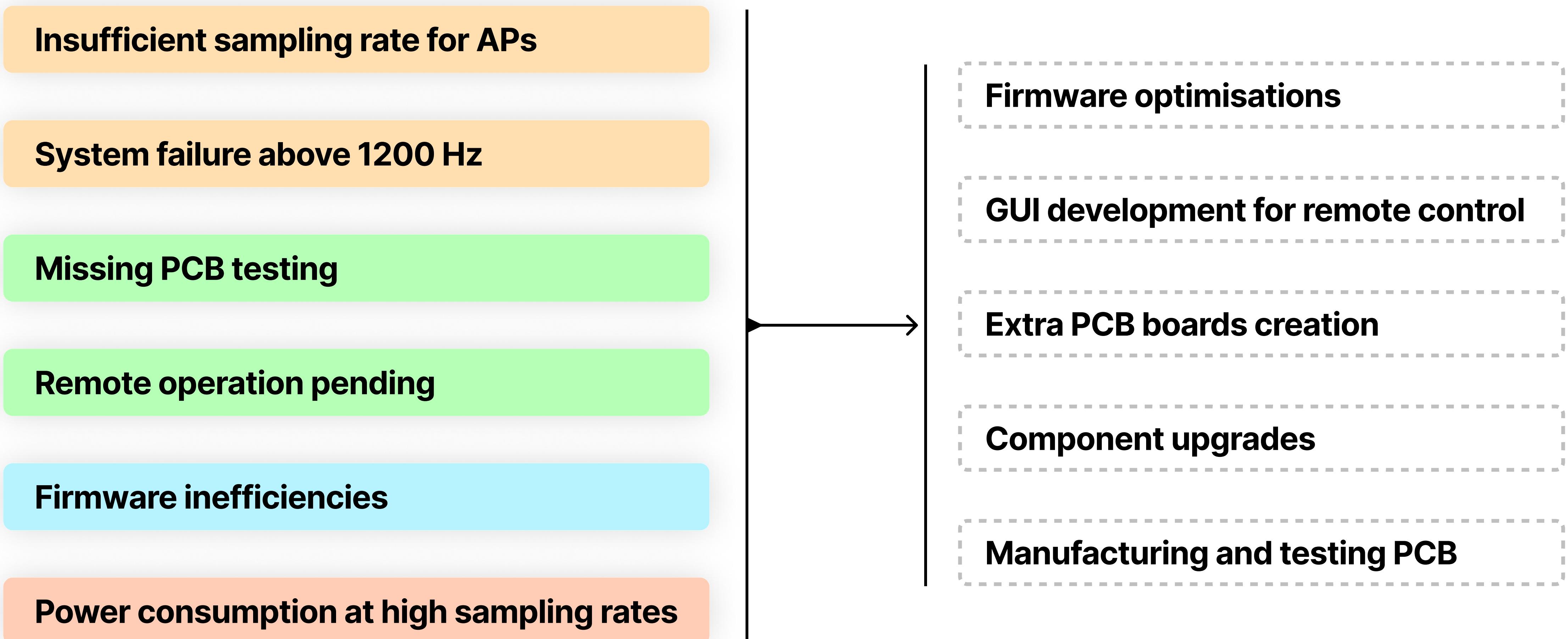
Results vs Initial Specifications

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

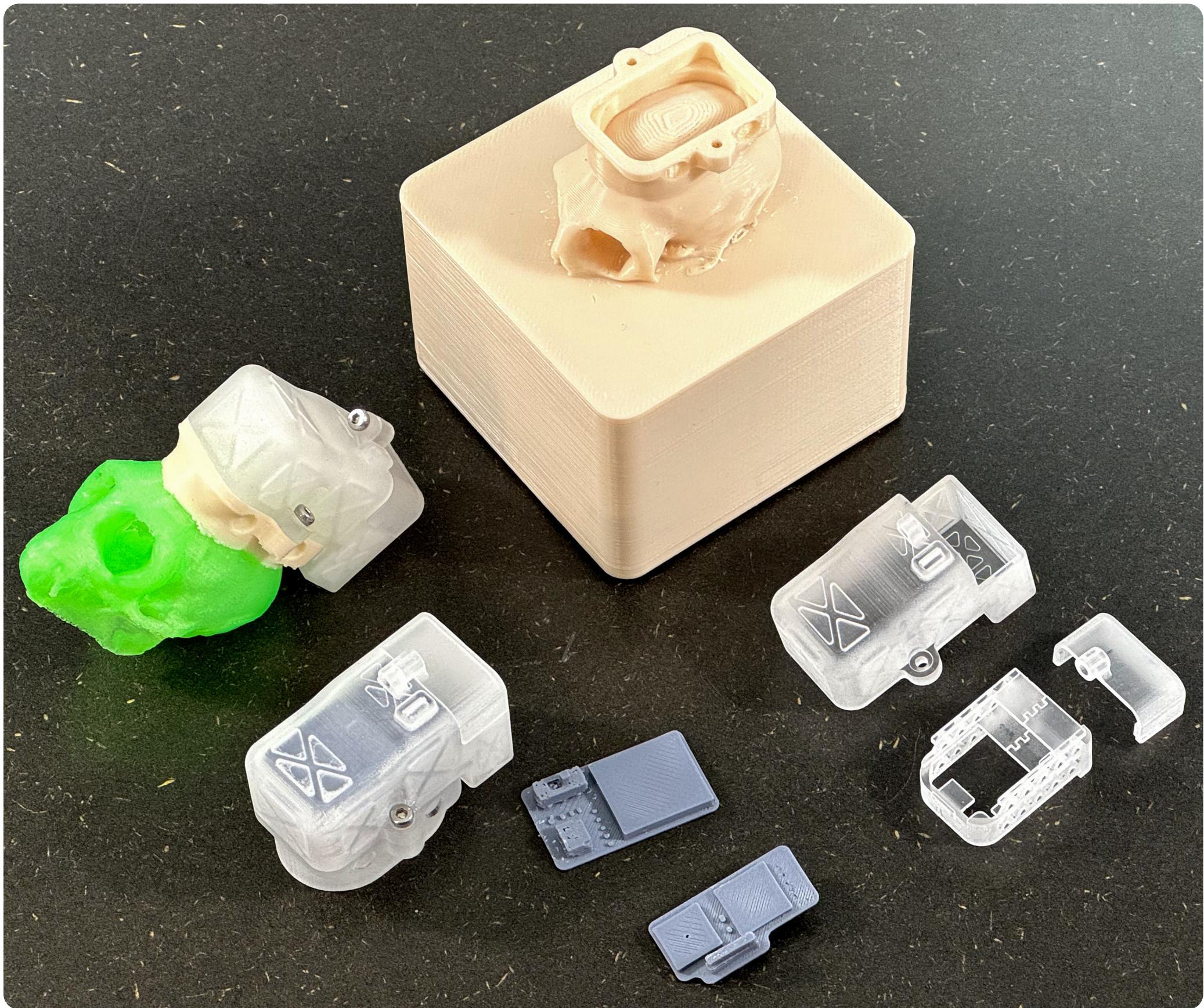
Code	Name	Target	Result
P1	Wireless Range	≥ 5 m	Not Tested
P2	Latency	< 10 ms	< 7.5 ms
P3	Local Storage & Wireless	Yes	Yes
D1	Plug-&-Play	Under 2 min	< 1.5 min
D2	Remote Operation	Yes	Not Achieved

Resulting Opportunities & Future Work



Thank you for listening :)

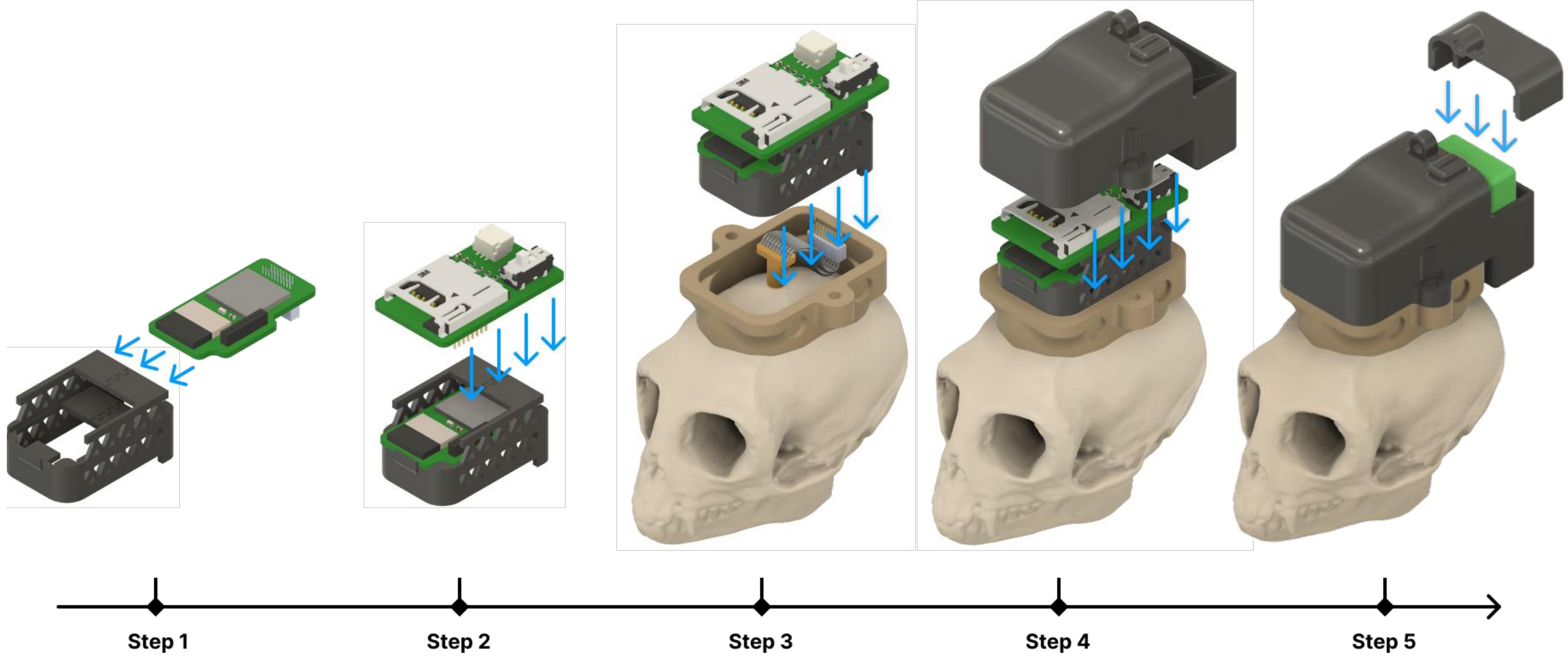




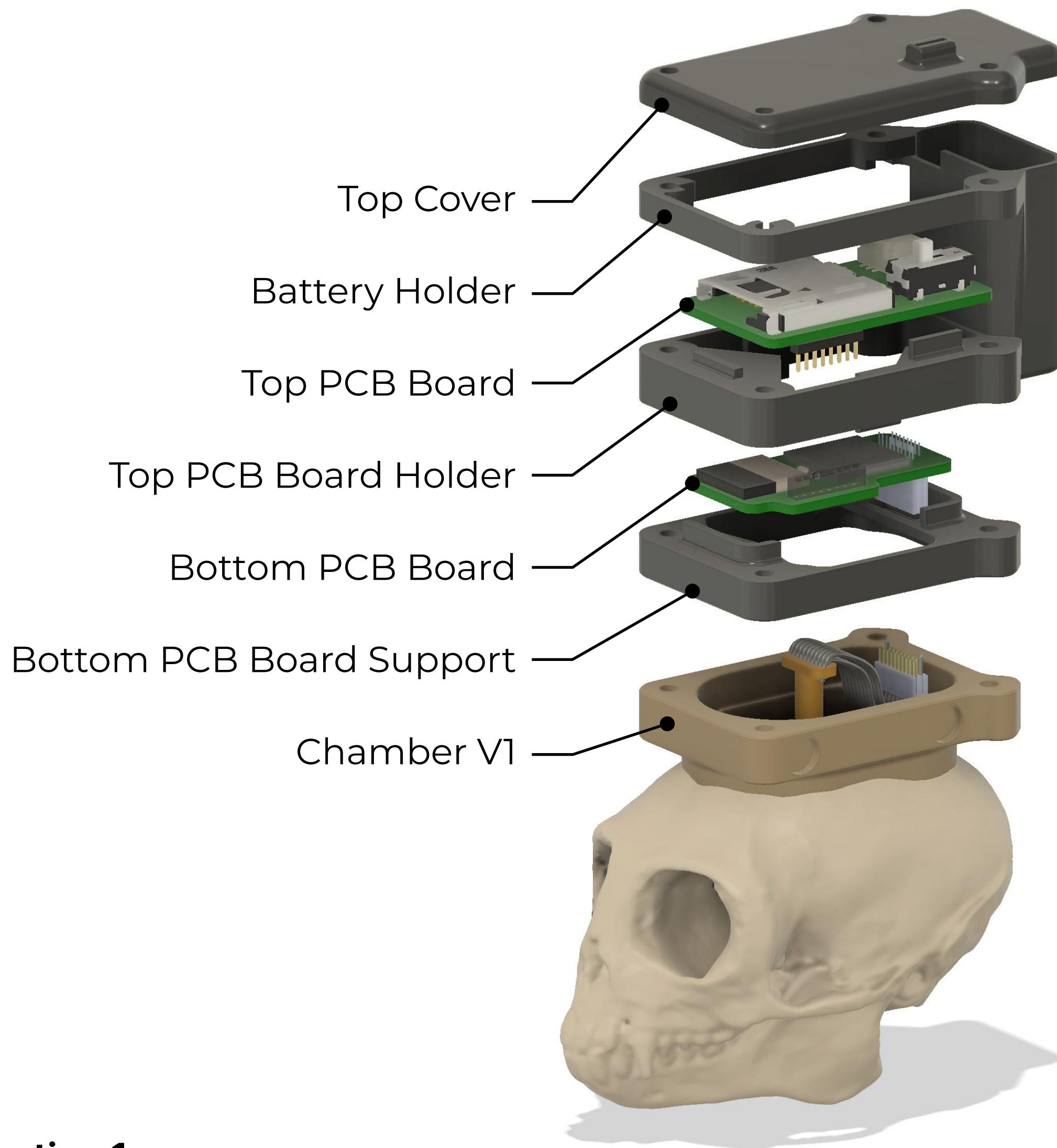
Assembly:
1m 27s

Full
Disassembly:
1m

Battery Swap:
30s



Assembly Process



Iteration 1

Parts number
(with screws):

8

Housing weight
(with crown):

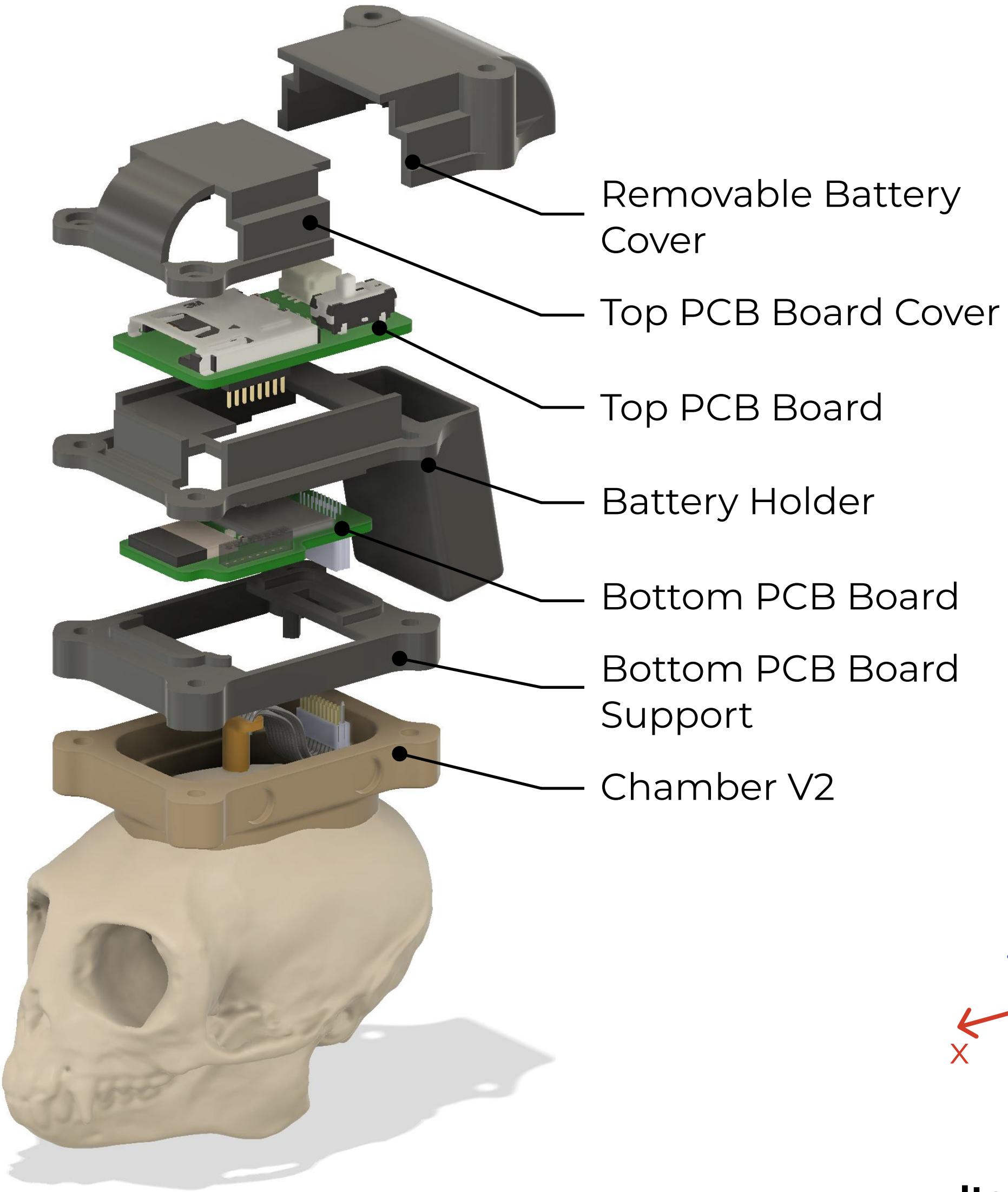
7.7g

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):

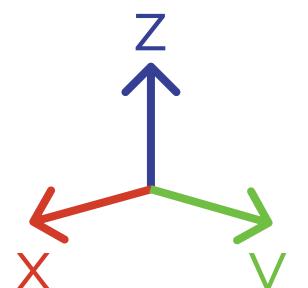
8.5g

Bounding Box
(with crown):

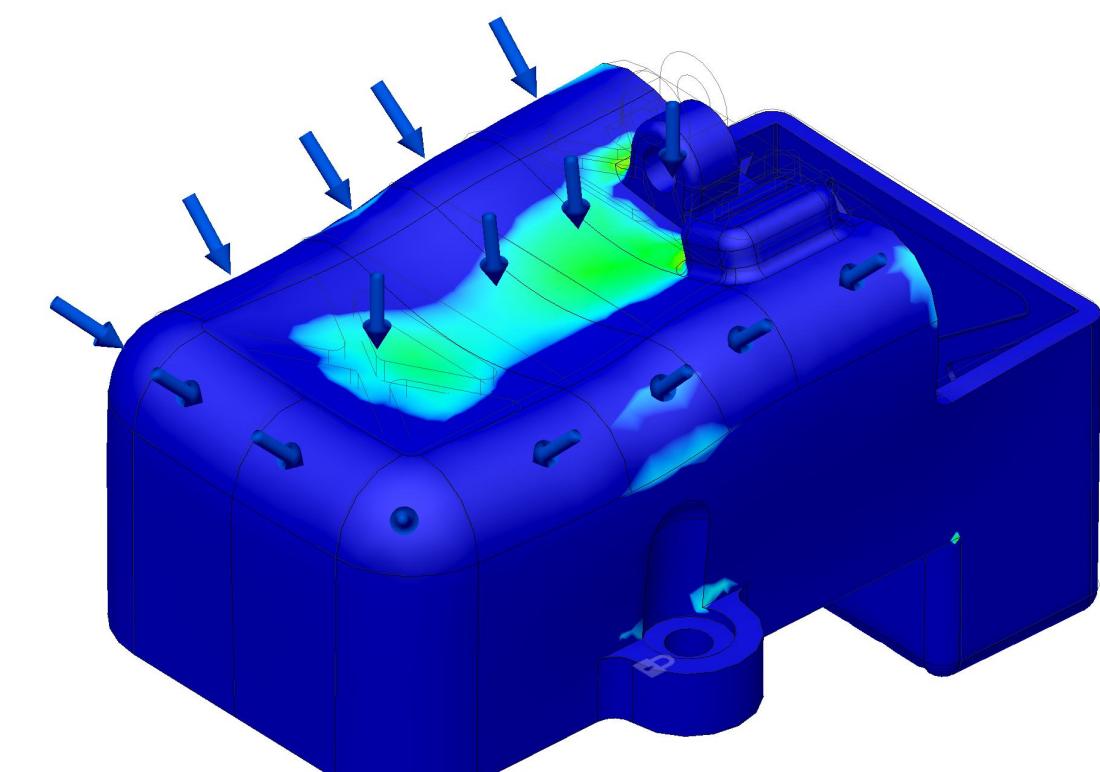
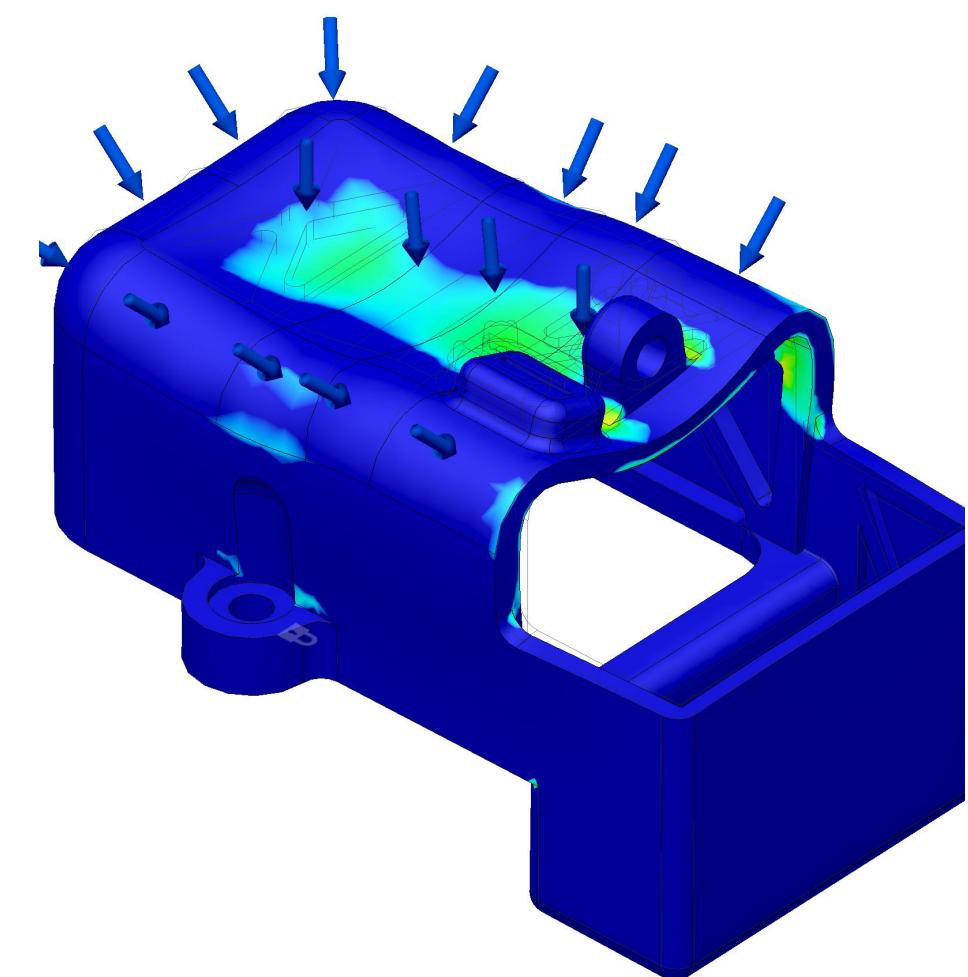
**25.6 x 45 x
31.4 mm**

Housing Material:

**Visijet M2S-
HT90**

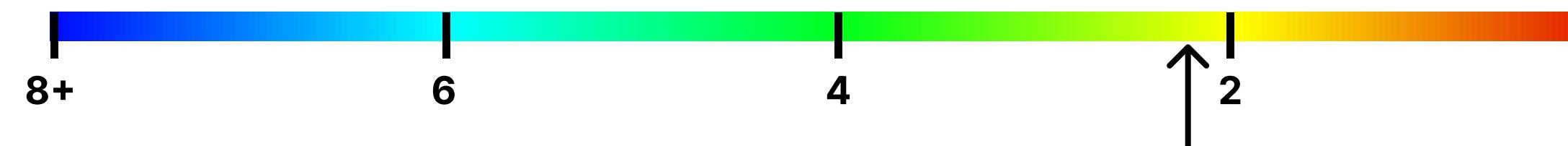


**Top Housing Safety Factor FEA
Simulated Fall Analysis**



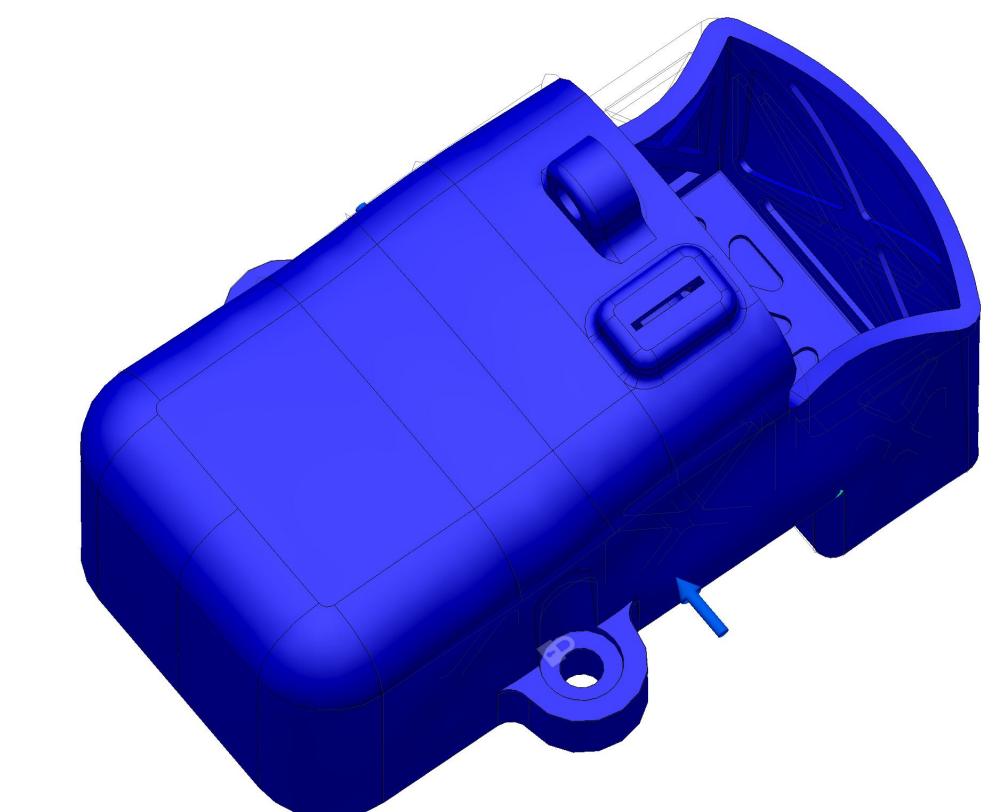
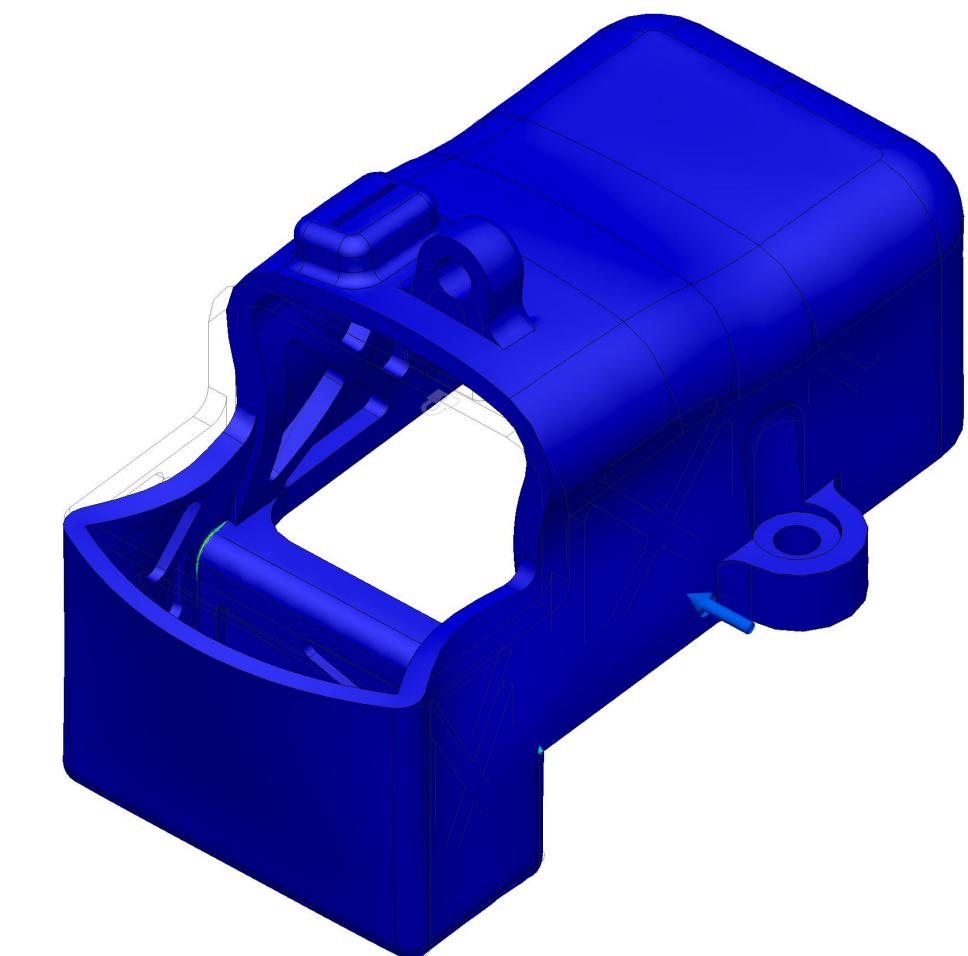
Safety Factor

2.151



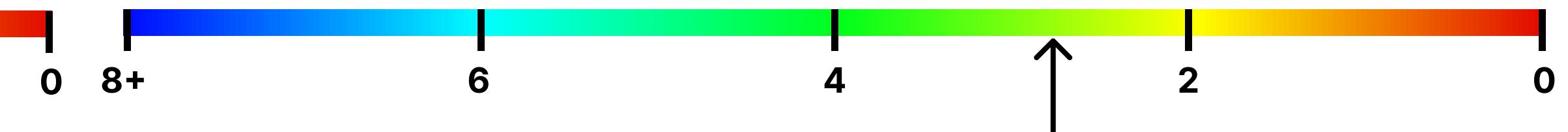
study
minimum

**Top Housing Safety Factor FEA
Simulated Monkey Force**

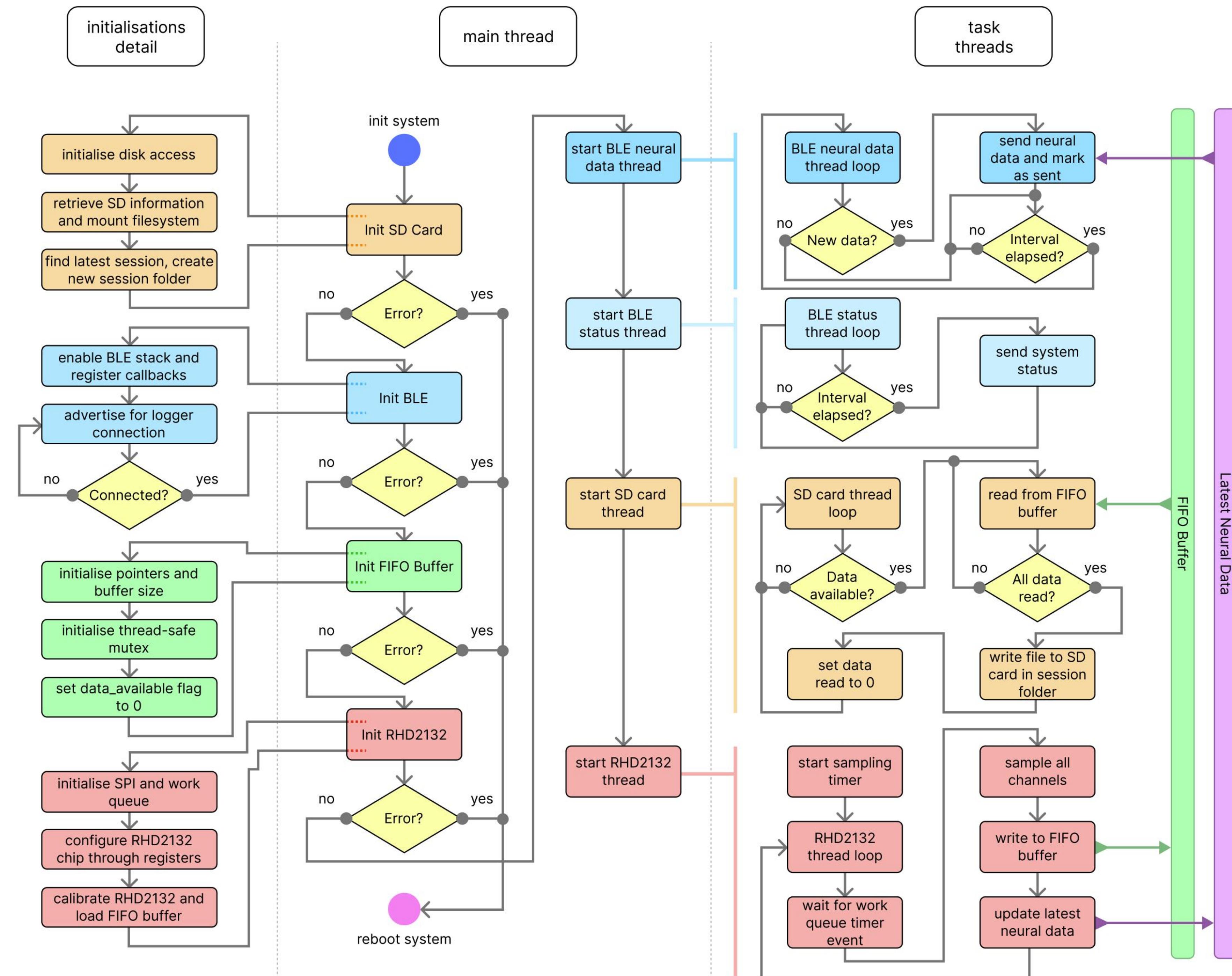


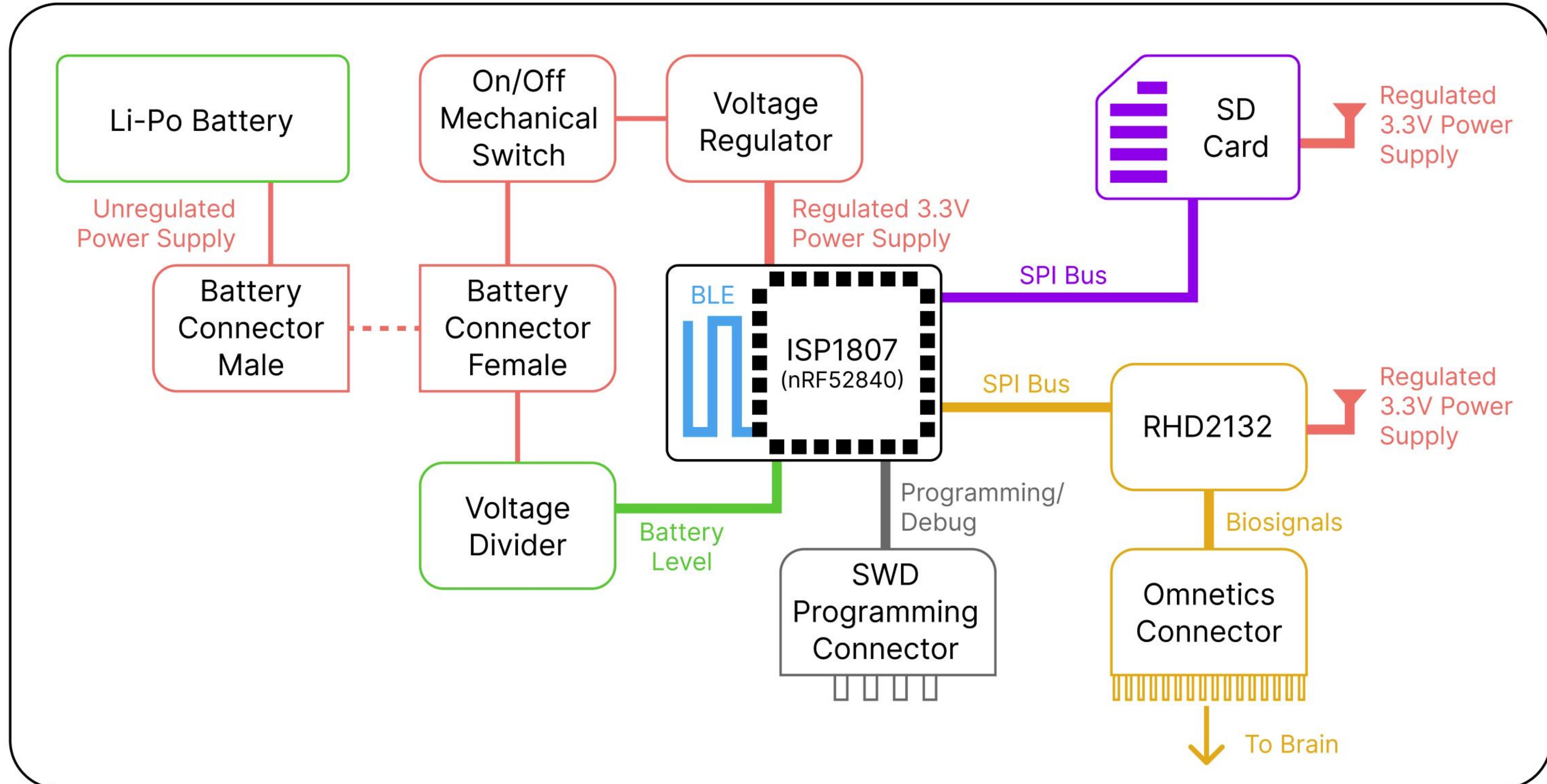
Safety Factor

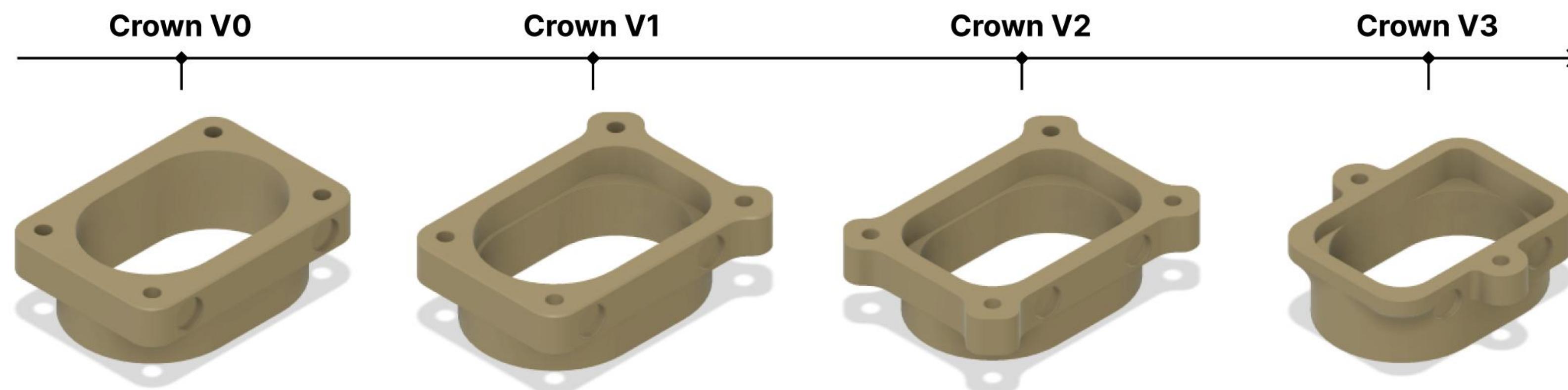
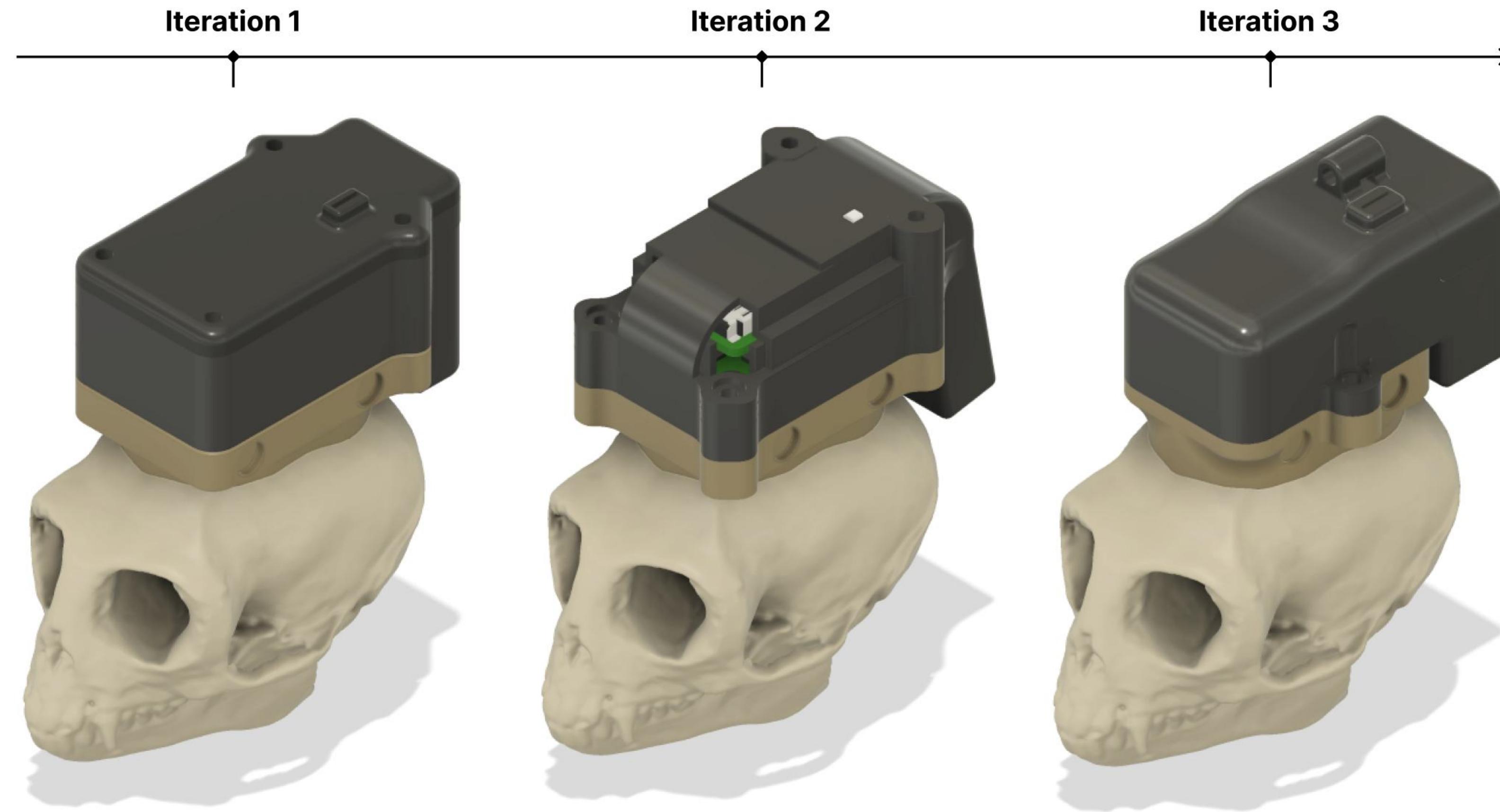
2.63

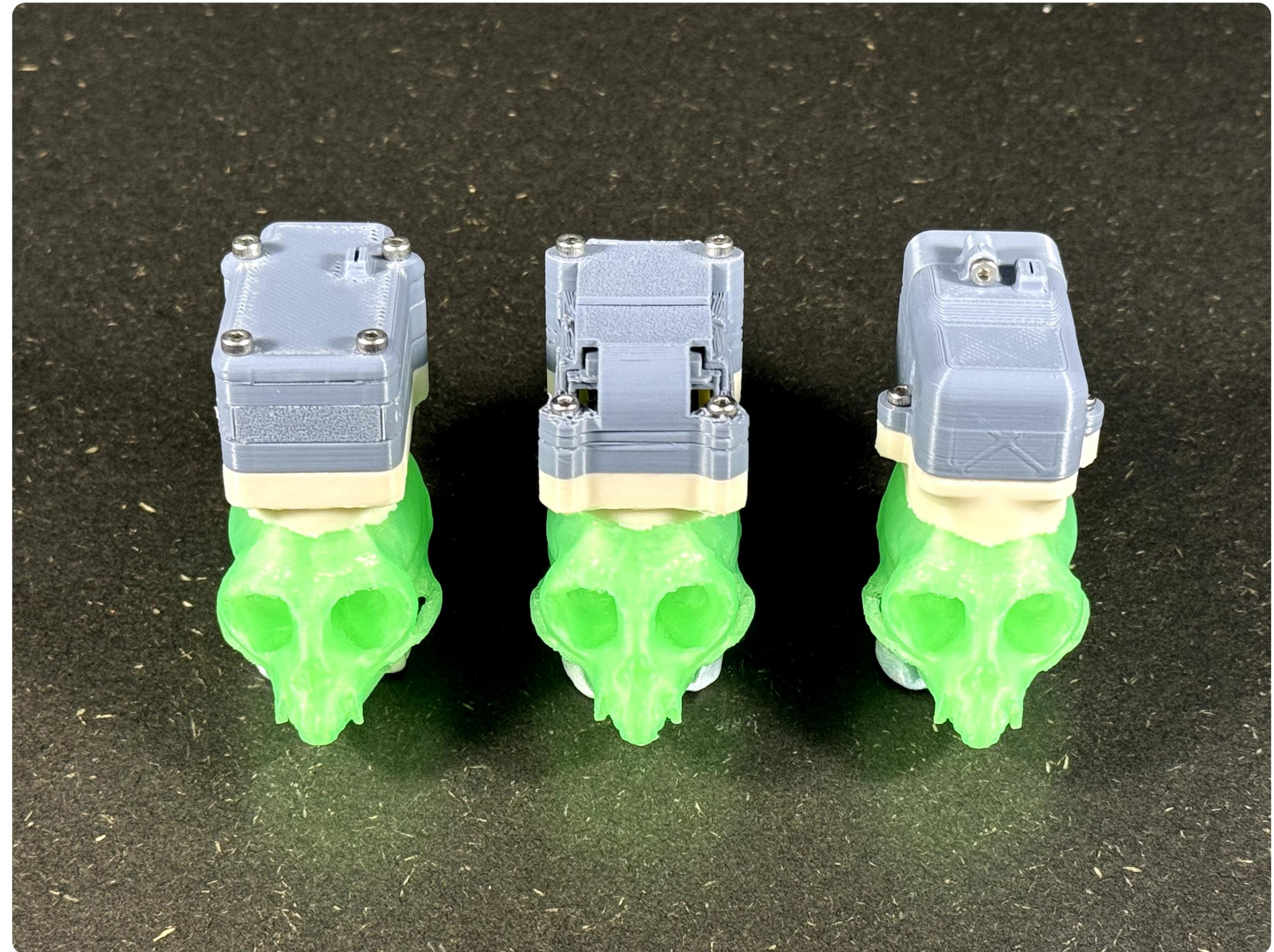
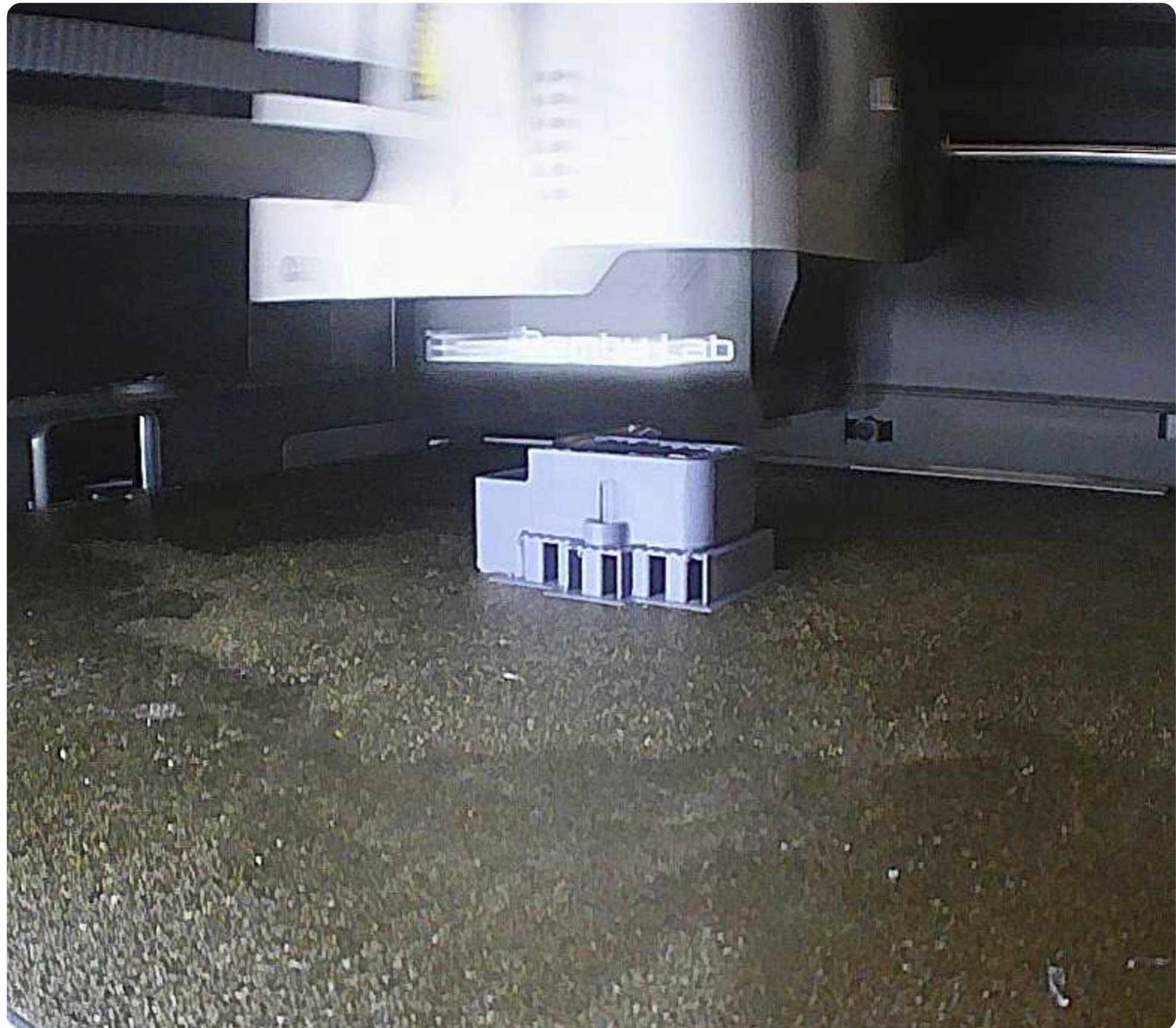


study
minimum



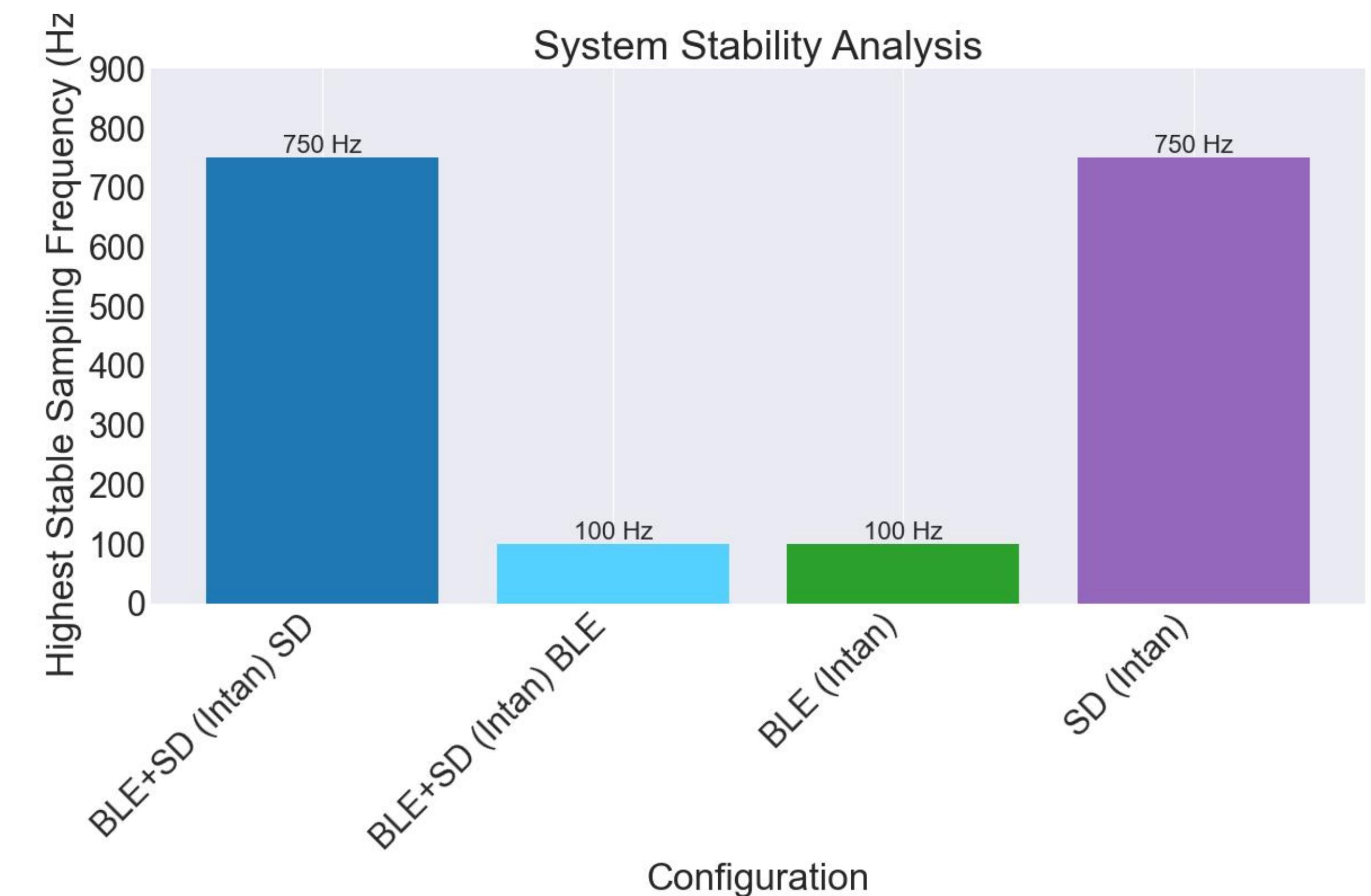
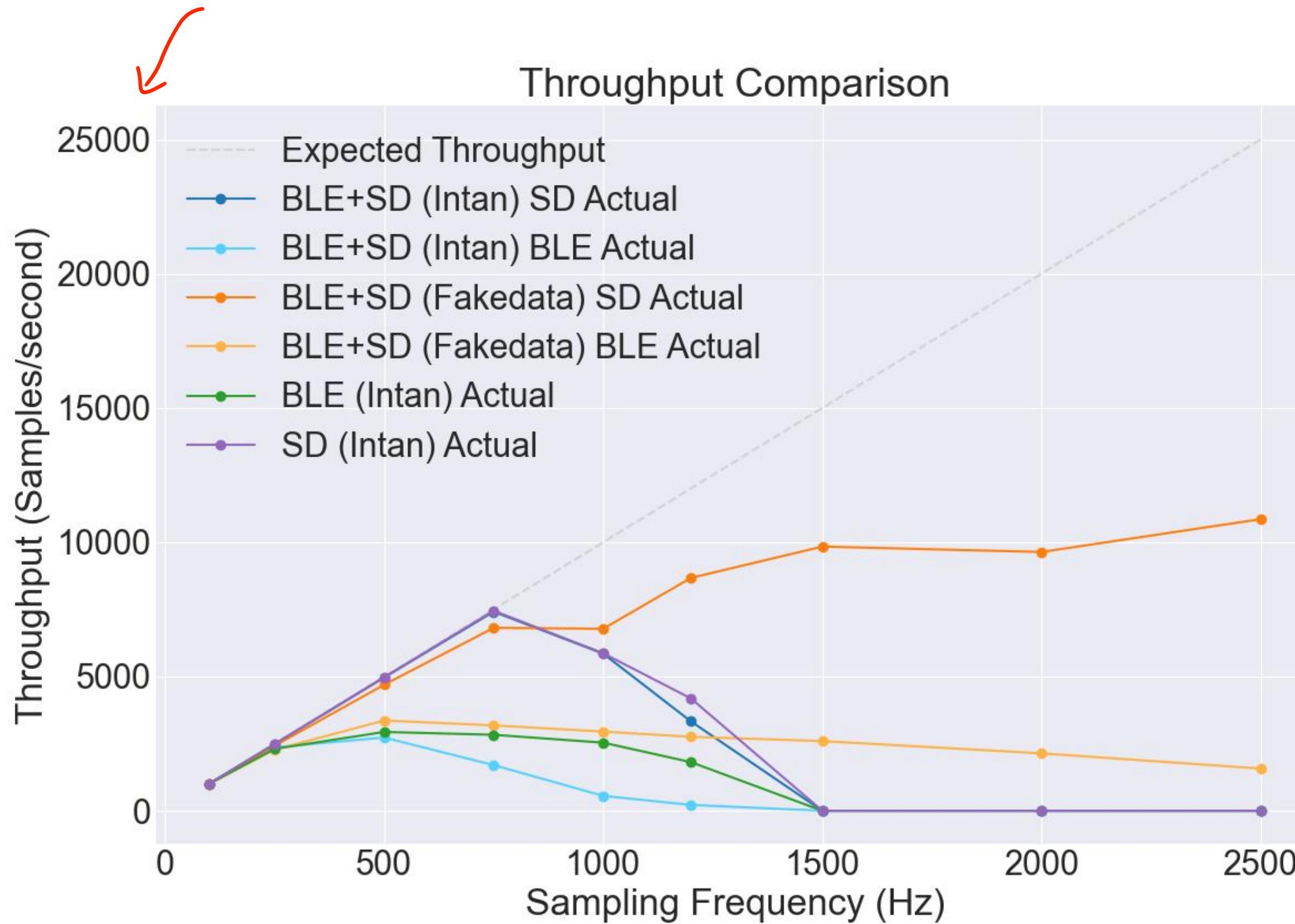




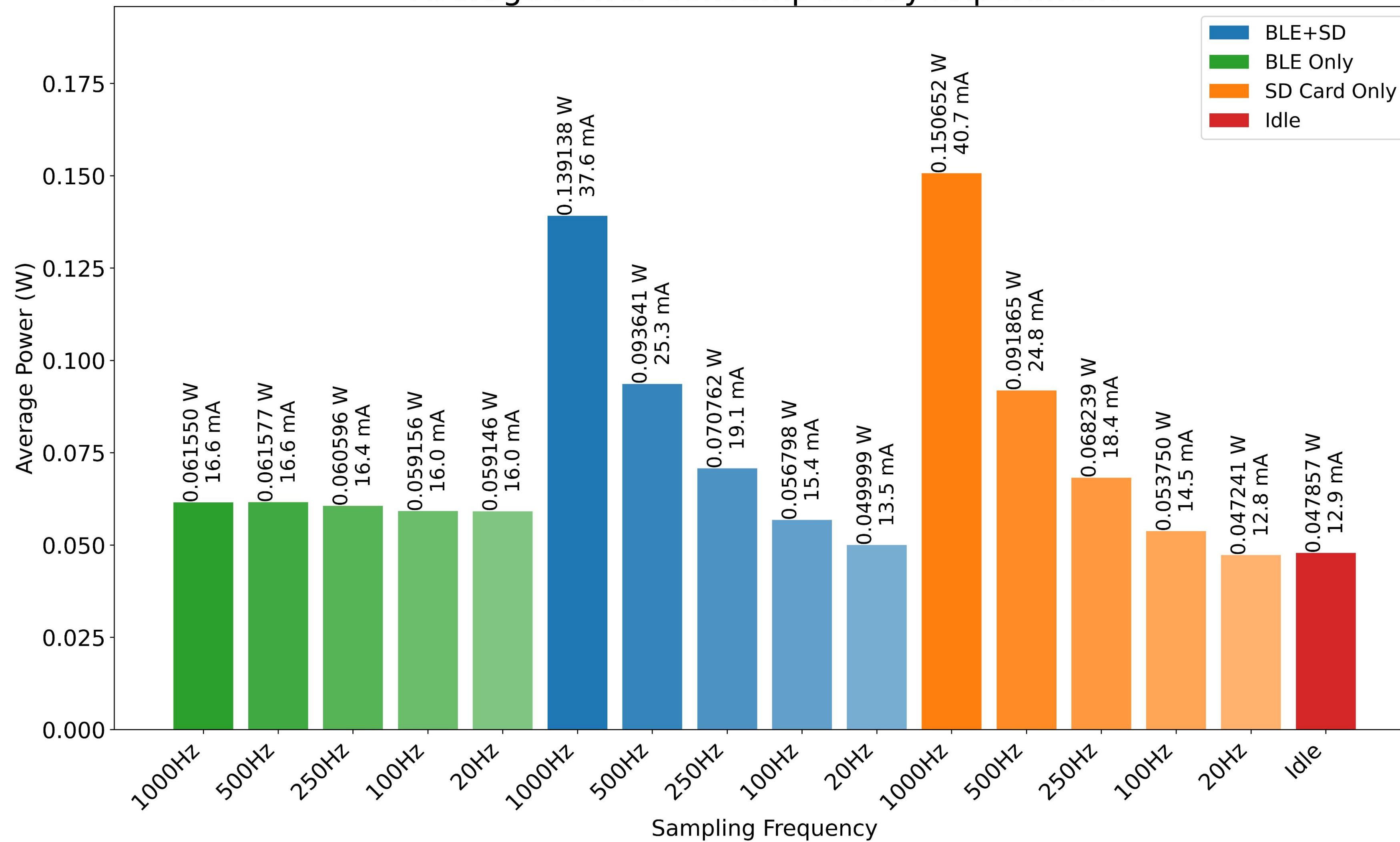


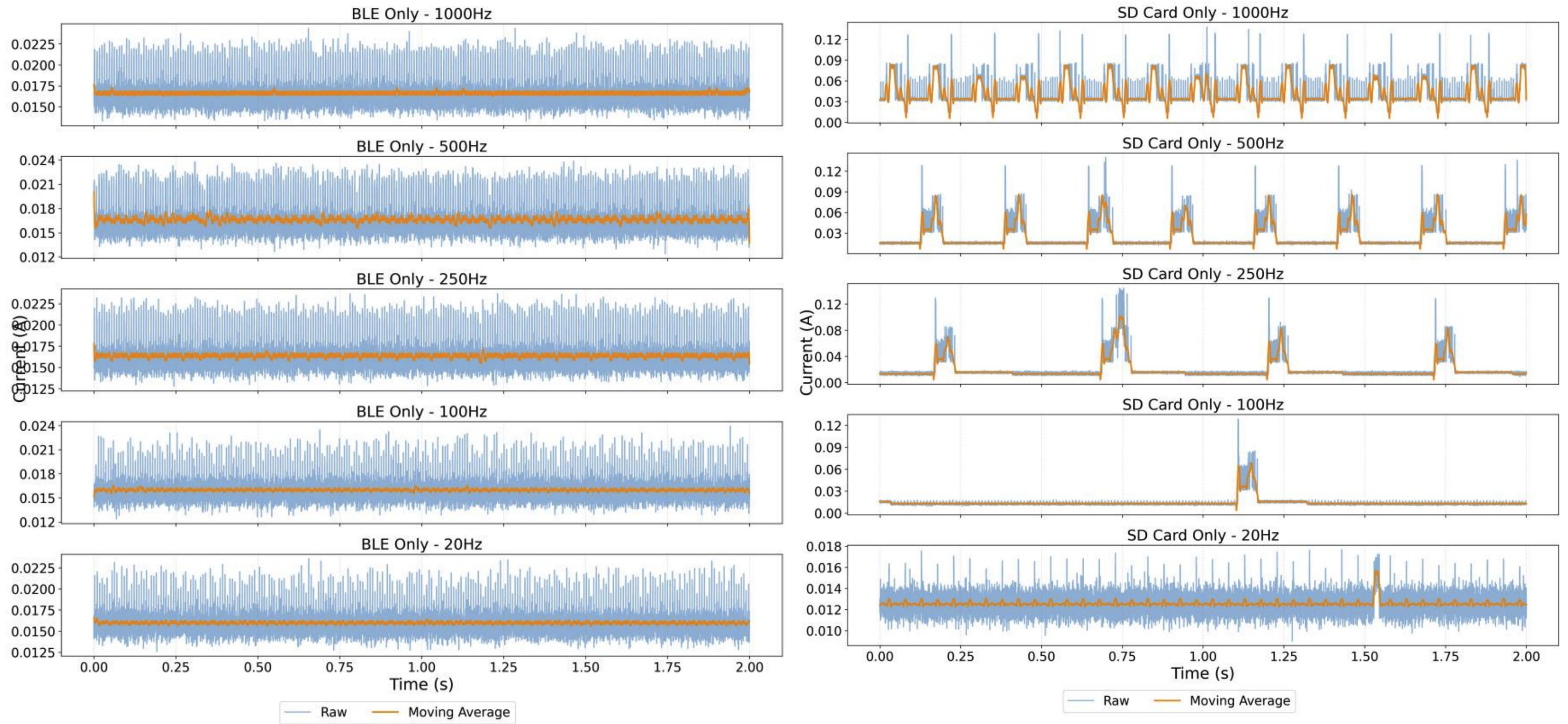
ERRATUM:

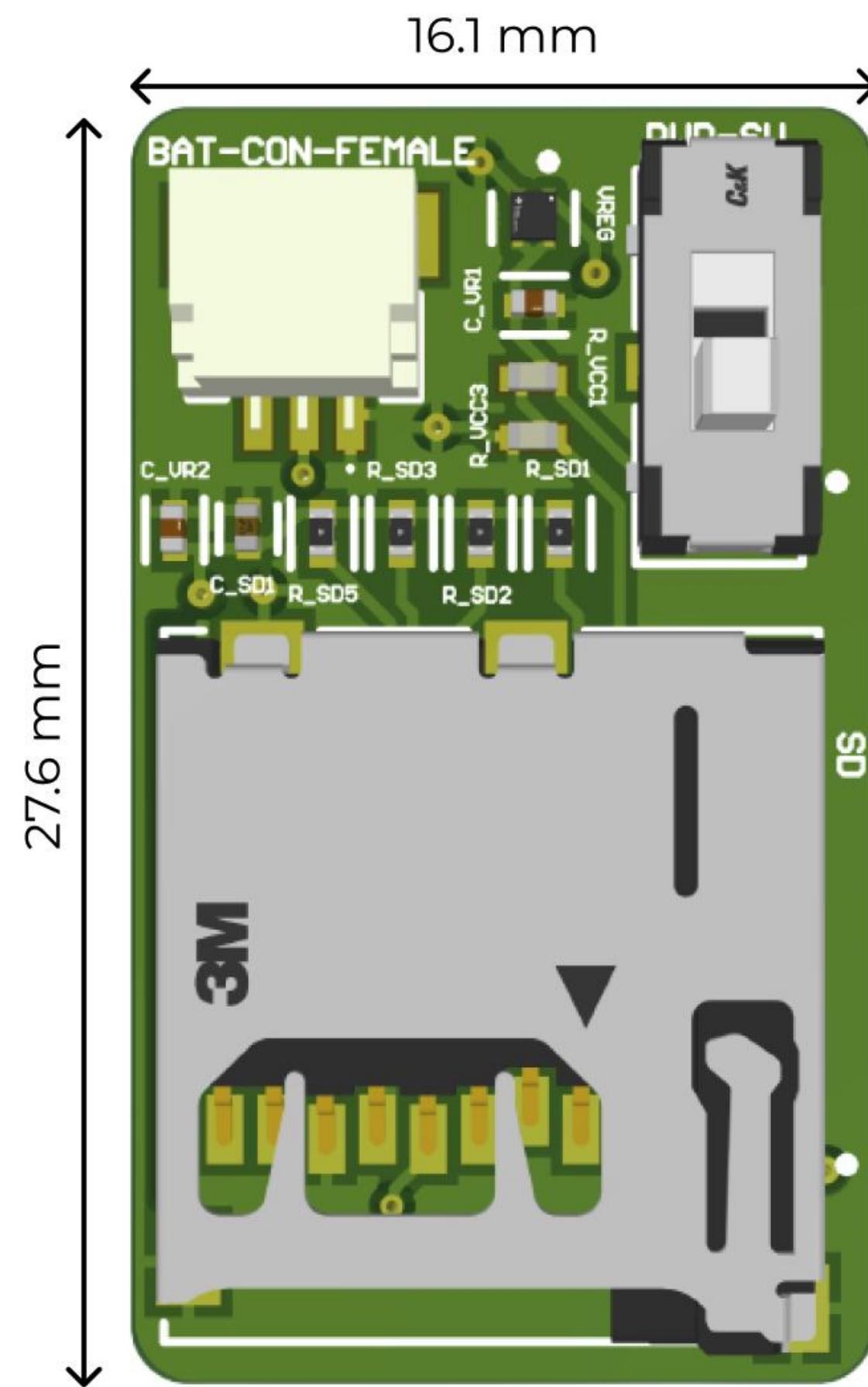
y-axis needs to be divided by 10



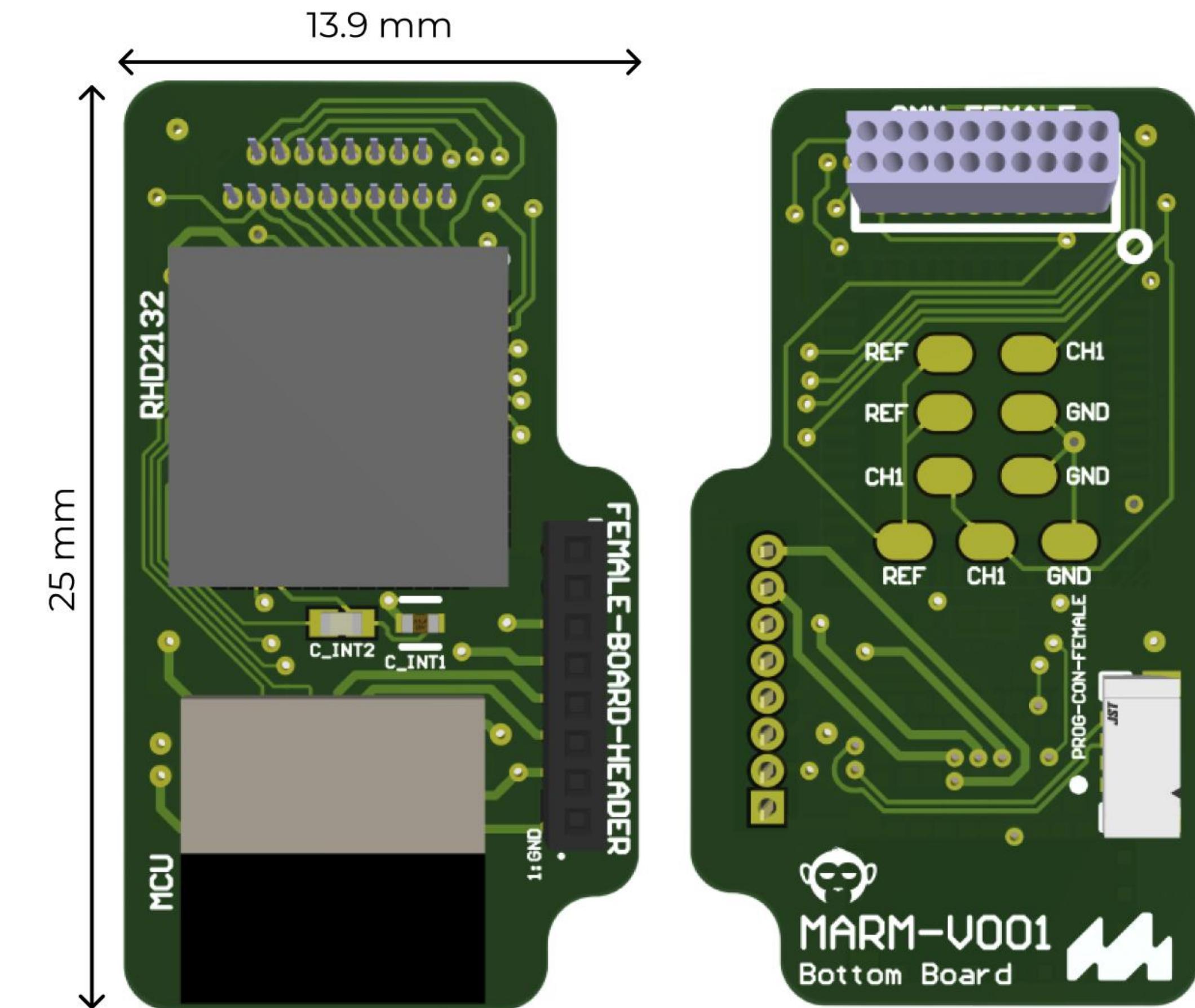
Average Power Consumption by Experiment





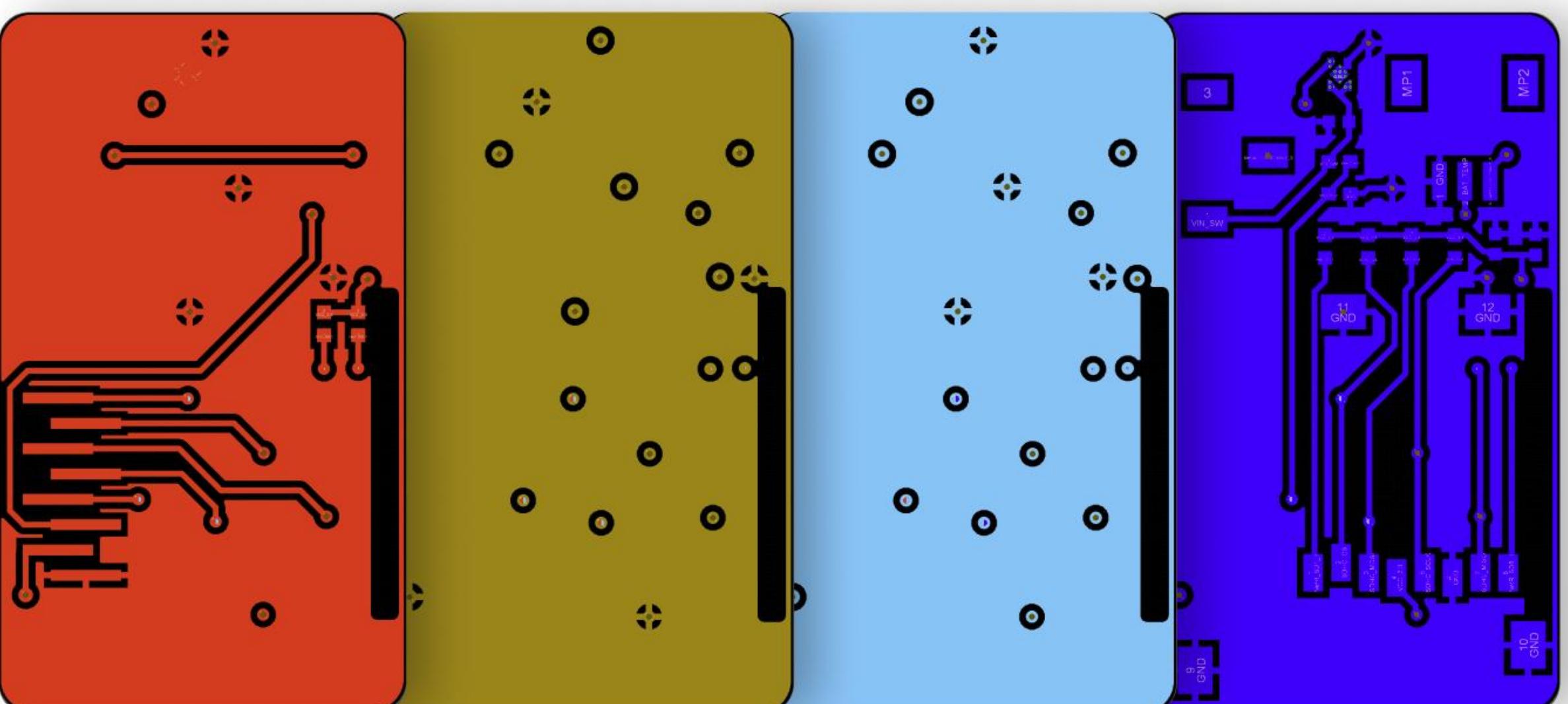


Top Board



Bottom Board

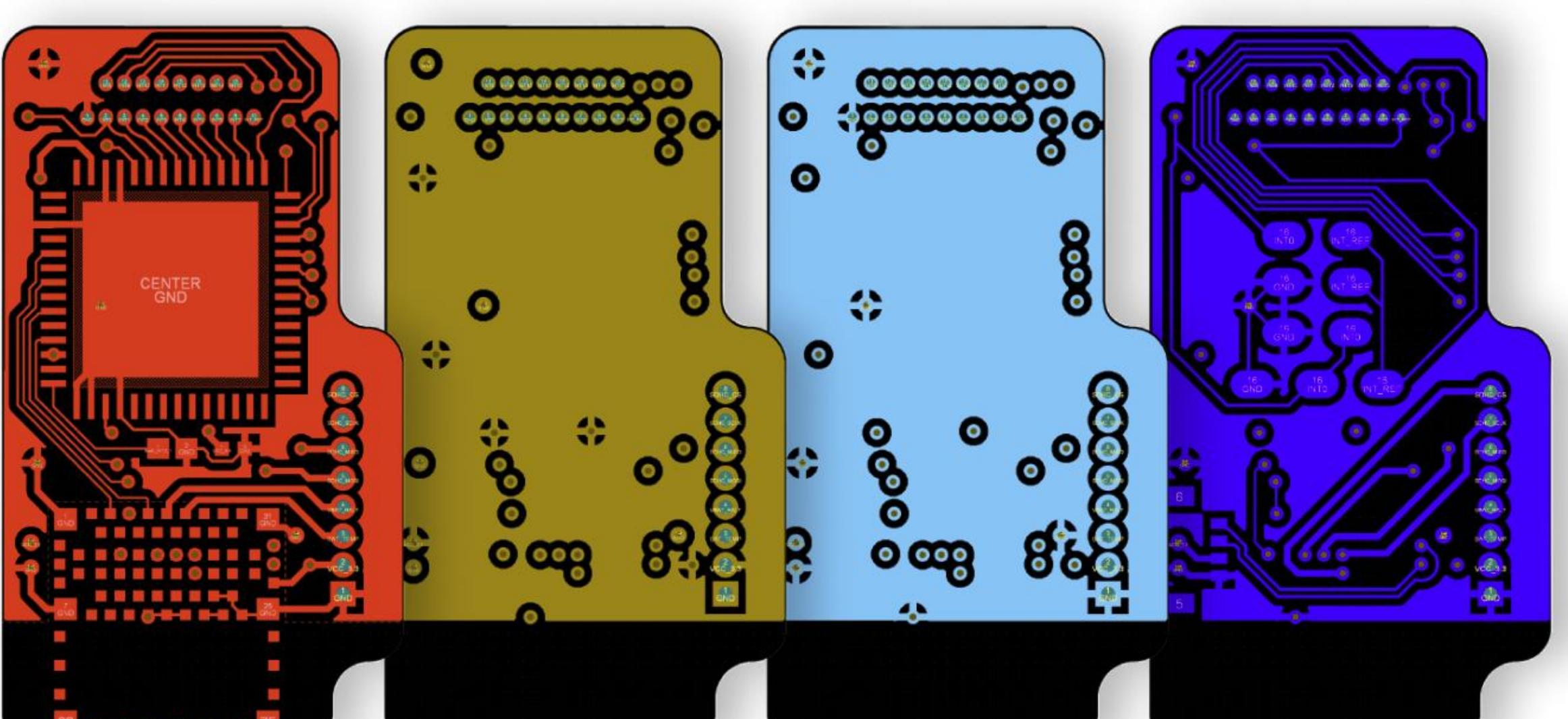
Top Layer



Signal

Bottom Layer

Top Layer



Bottom Layer

Signal

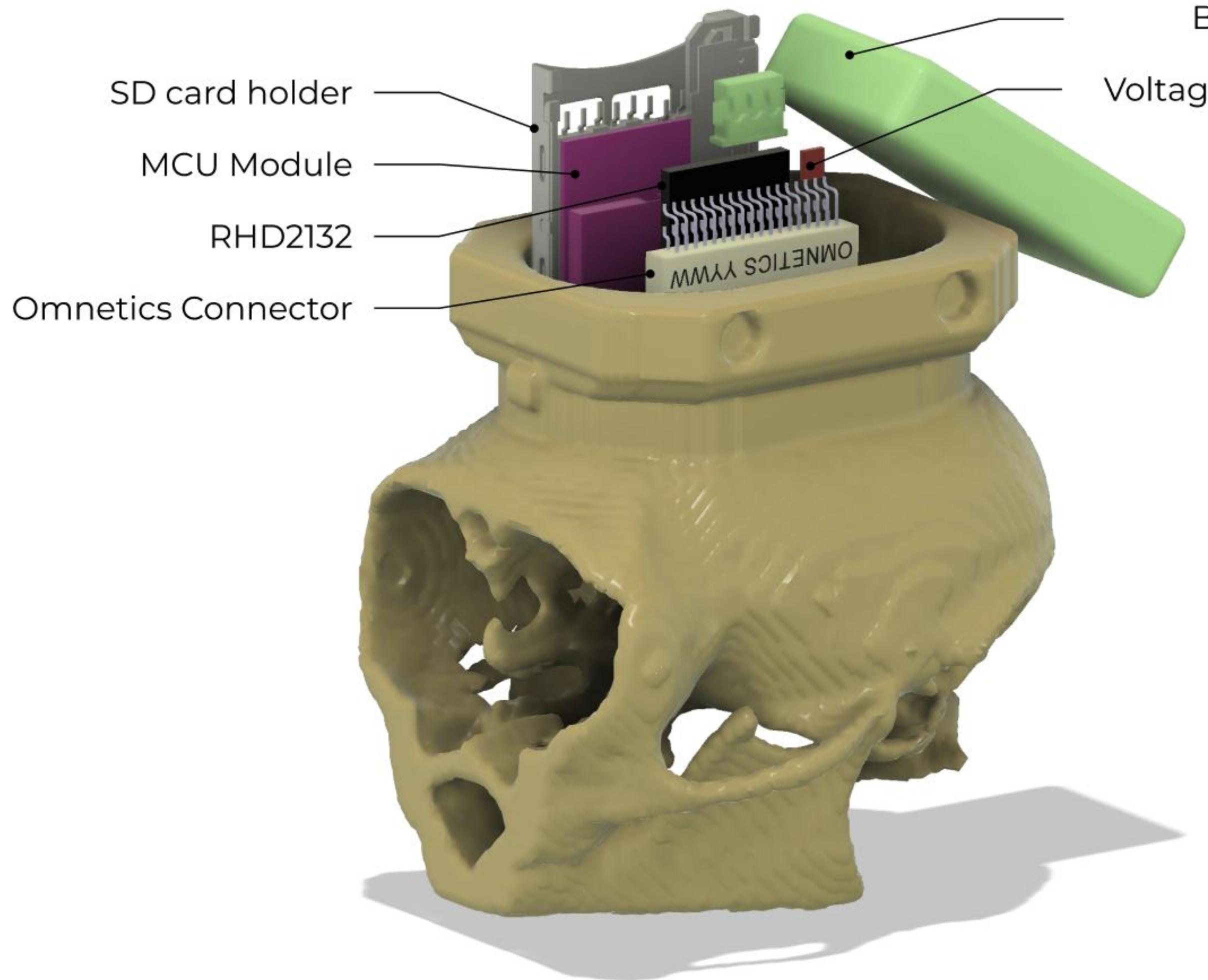
VCC

GND

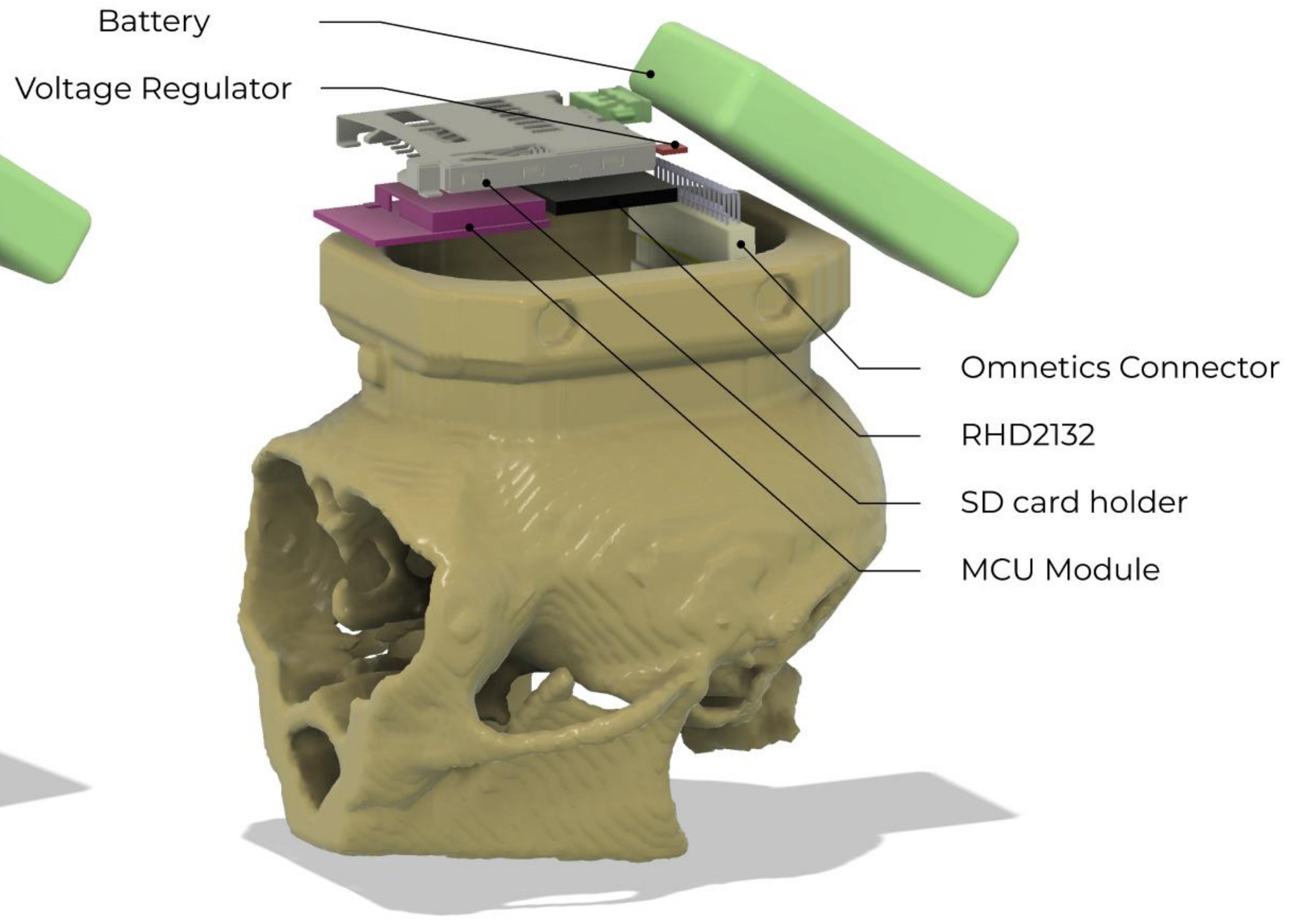
Signal

GND

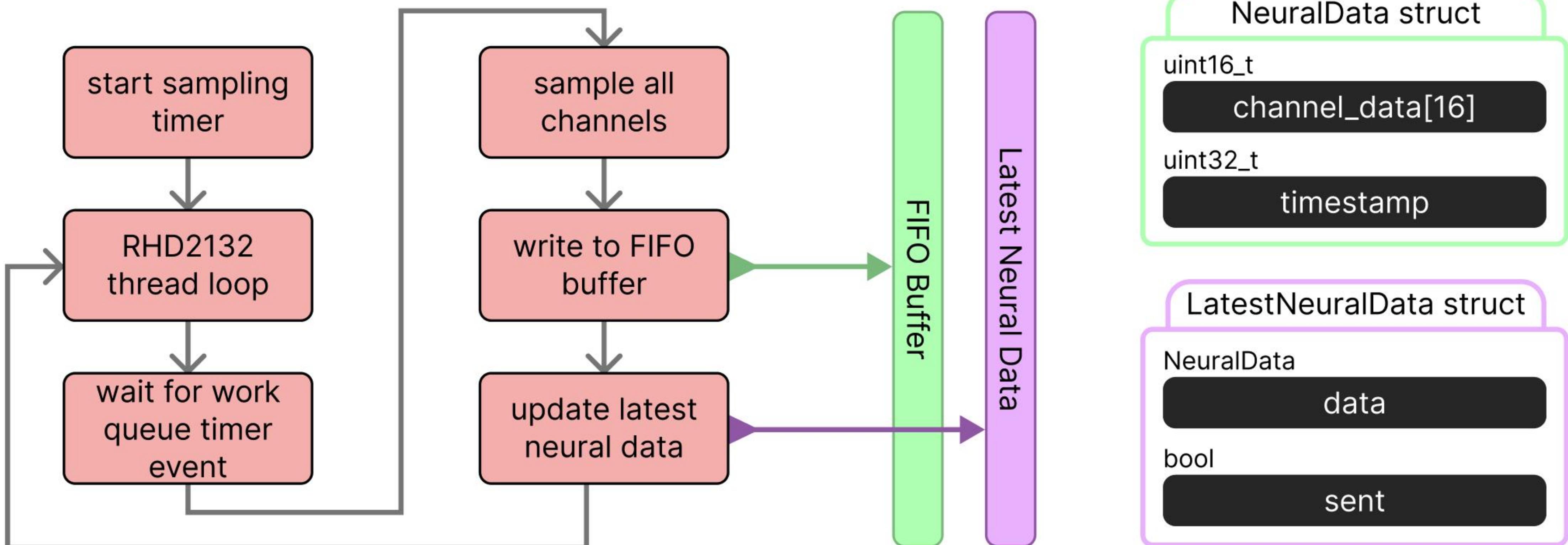
Signal

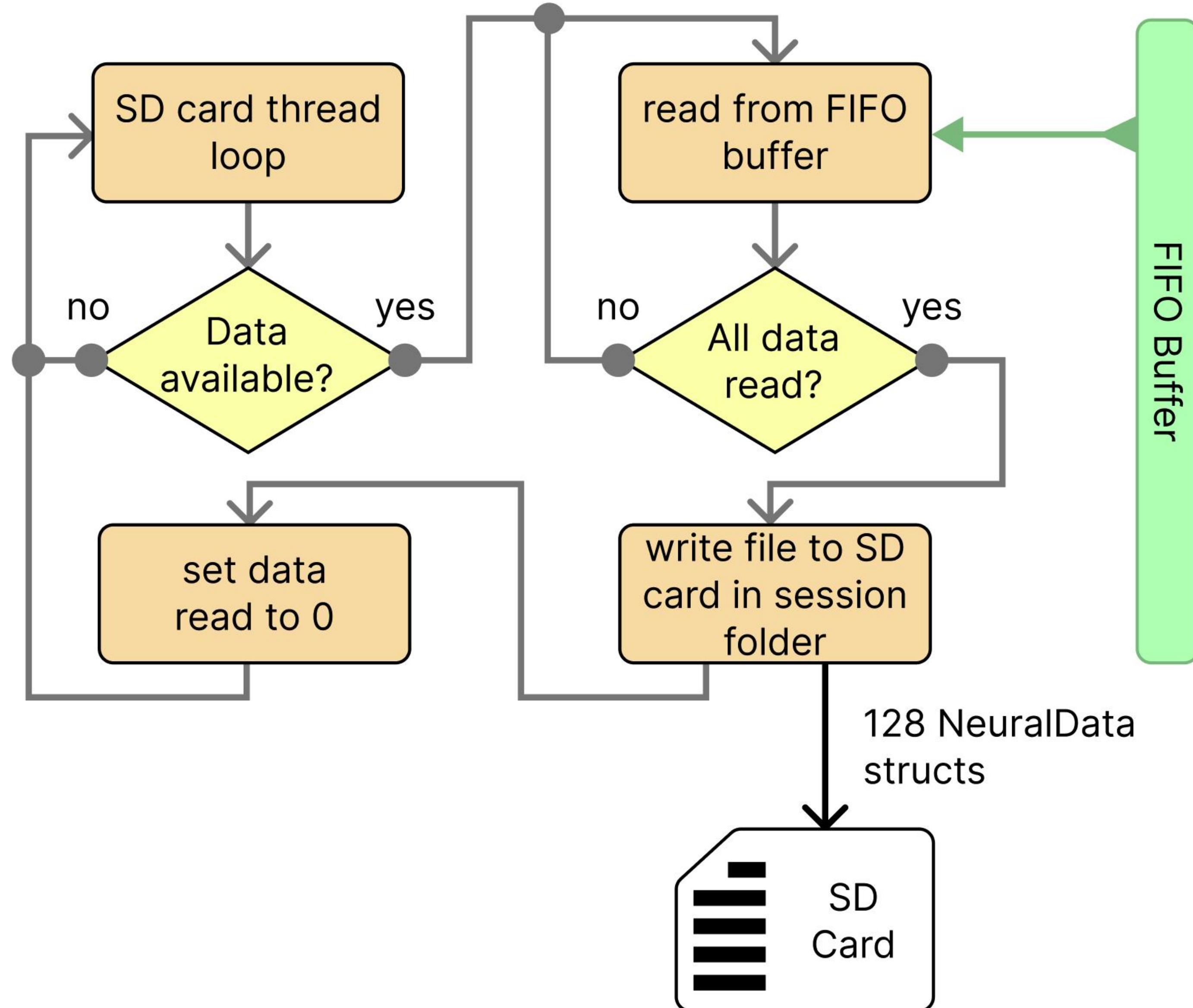


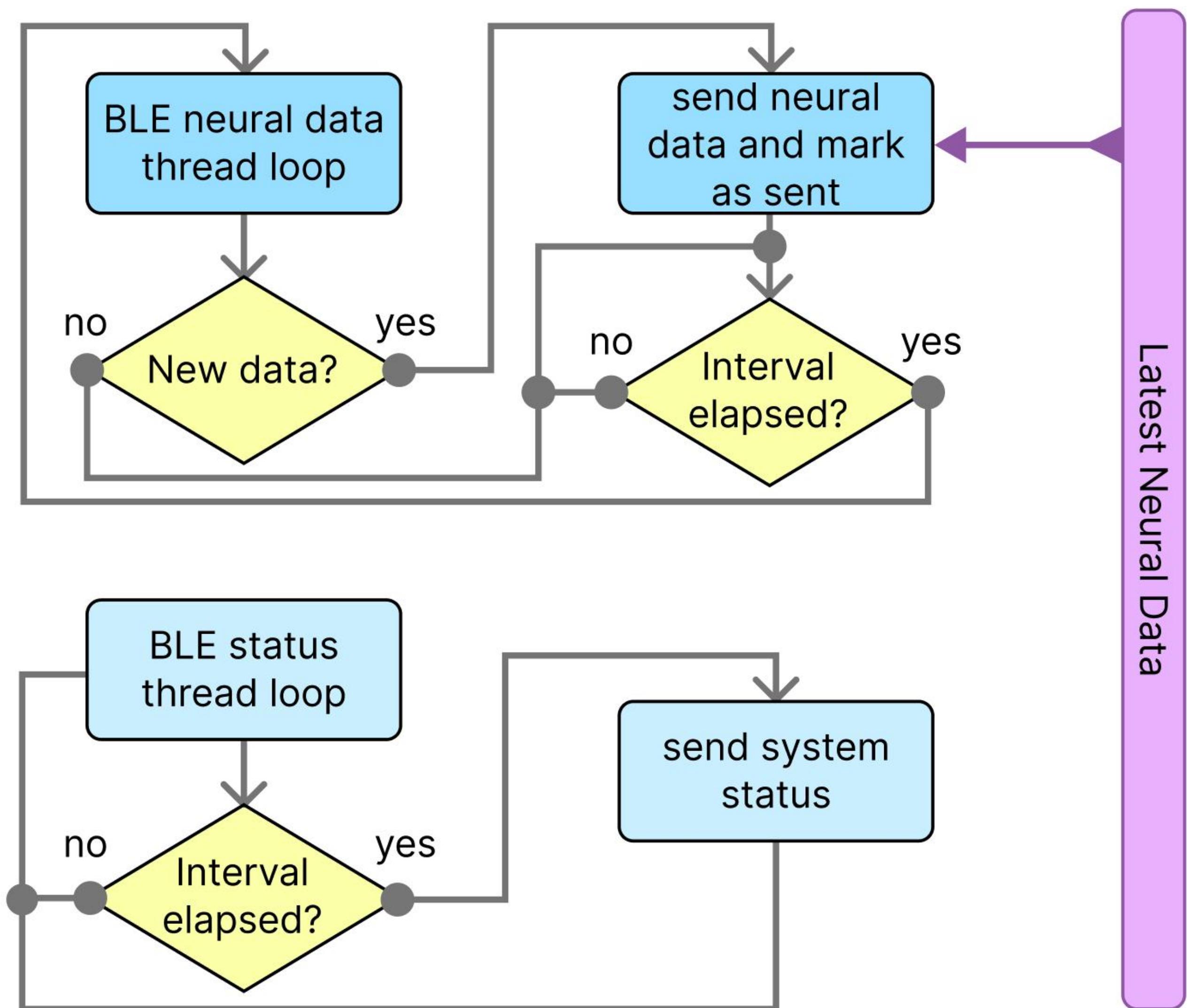
Vertical Layout



Horizontal Layout
(final)







Latest Neural Data

