Near-POC Bead Beater Technical Review

April 9th 2025

Agenda

Near-POC Bead Beater
(aka NAATOS Sample Preparation Module or SPM)
(aka CCG device, where CCG was the CDMO)

- CCG iterations (α vs γ) design differences
- GHL design improvements (Stage Gate 4 aka SG4 tests)
- Unit qualification

Design files from CCG transfer (Feb 2025)

- Near-POC Bead Beater: Feb2025 Sample Prep Module Design Files
  - Mechanical BOM: GHL-1-22000 (BOM).xlsx
  - Main PCBA BOM: GHL NAATOS Sample Prep Main Board RevC ODIC EXPORT BOM.xlsx
  - Heater PCBA BOM: GHL NAATOS Sample Prep Heater Board RevB ODIC EXPORT BOM.xlsx
  - Drawings (in progress): Feb2025 Sample Prep Module Design Files
  - Firmware code: see GHL git repo, which has shared history with ODIC (CDMO subcontractor) repo
    - Split from ODIC occurred at tag: V3.1_and_odic_splitpoint
  - Firmware annotated changelog and tabulated information: changelog.xlsx

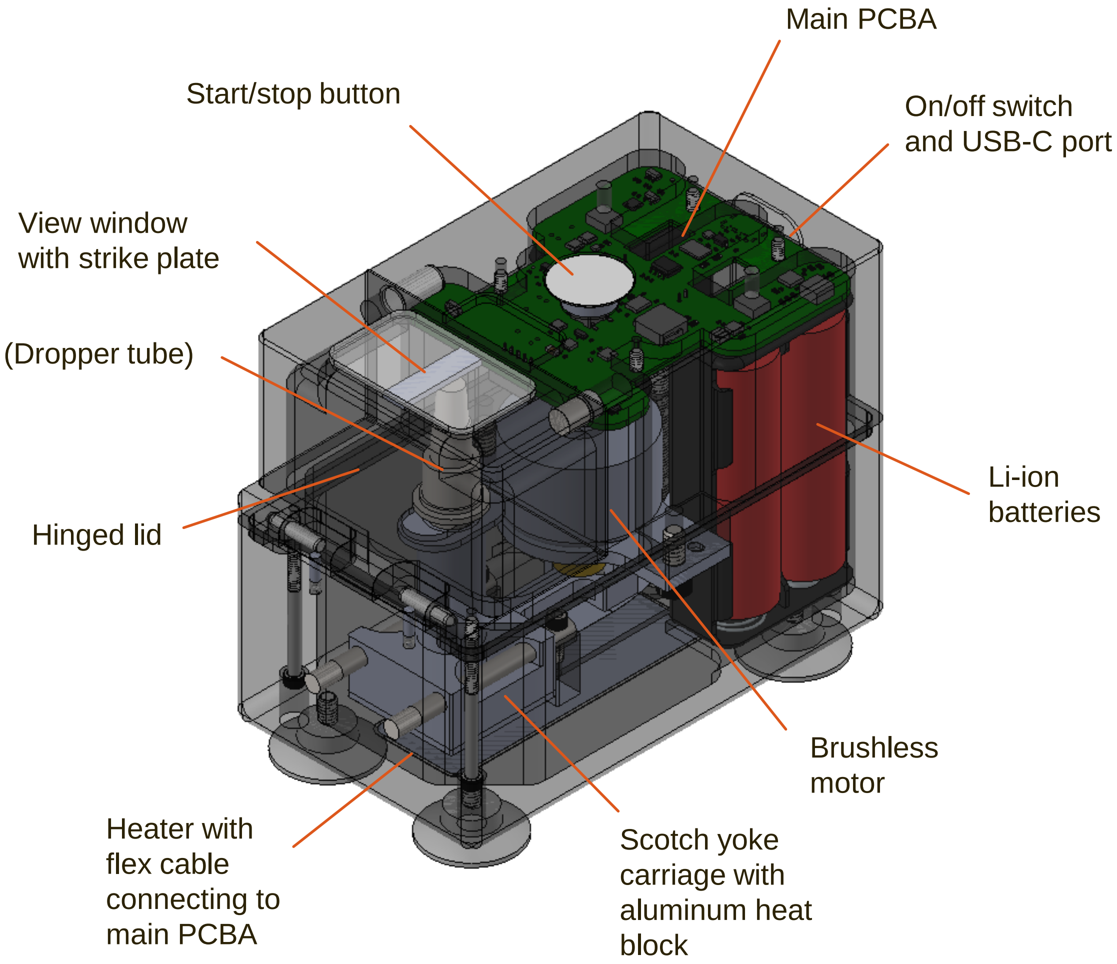
Near-POC Bead Beater Component Details ($\alpha \rightarrow \gamma$)

Near-POC Bead Beater Design Differences | Overview

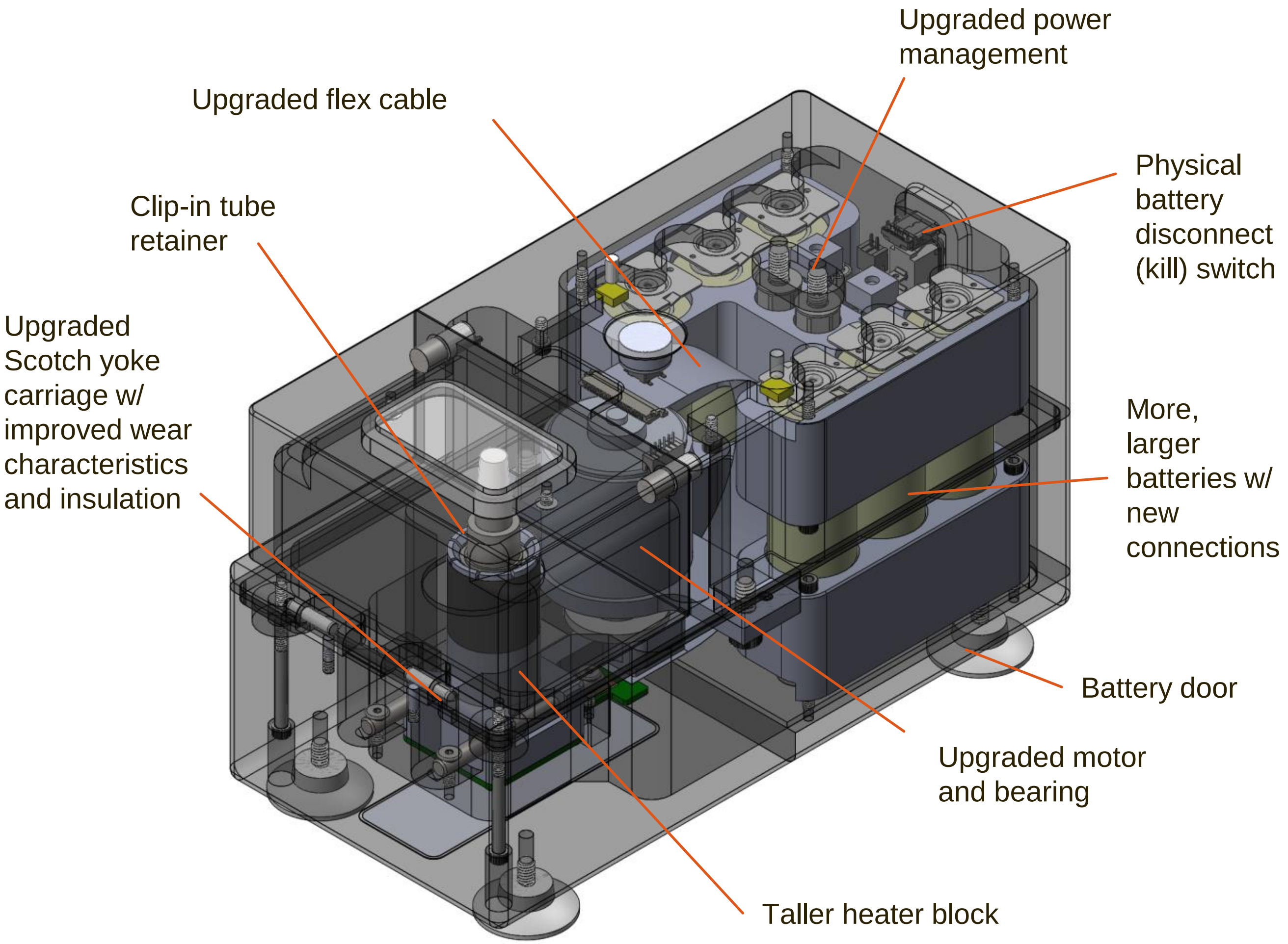
Component	CCG Device (α)	CCG Device (γ)
Overall Module Design	Overall architecture: • Single tube operation/cycle • Hinged lid with view window • Daughter heater board with aluminum heat block • Scotch-yoke carriage system with brushless motor • Battery operated (rechargeable Li-ion battery)	Notable changes from α: • Upgraded Scotch-yoke carriage with better wear characteristics and insulation • Upgraded motor and bearing • Clip-in tube retainer • Taller heat block • Upgraded flex cable • Upgraded power management on main PCBA • More and larger Li-ion batteries • Physical battery disconnect (kill) switch • Battery door
Size	5” x 2.9” x 4.2” 1.2 kg	7.6” x 3.6” x 4.4” 2.5 kg

Near-POC Bead Beater Design Differences | Overall

CCG Device (α)



CCG Device (γ)



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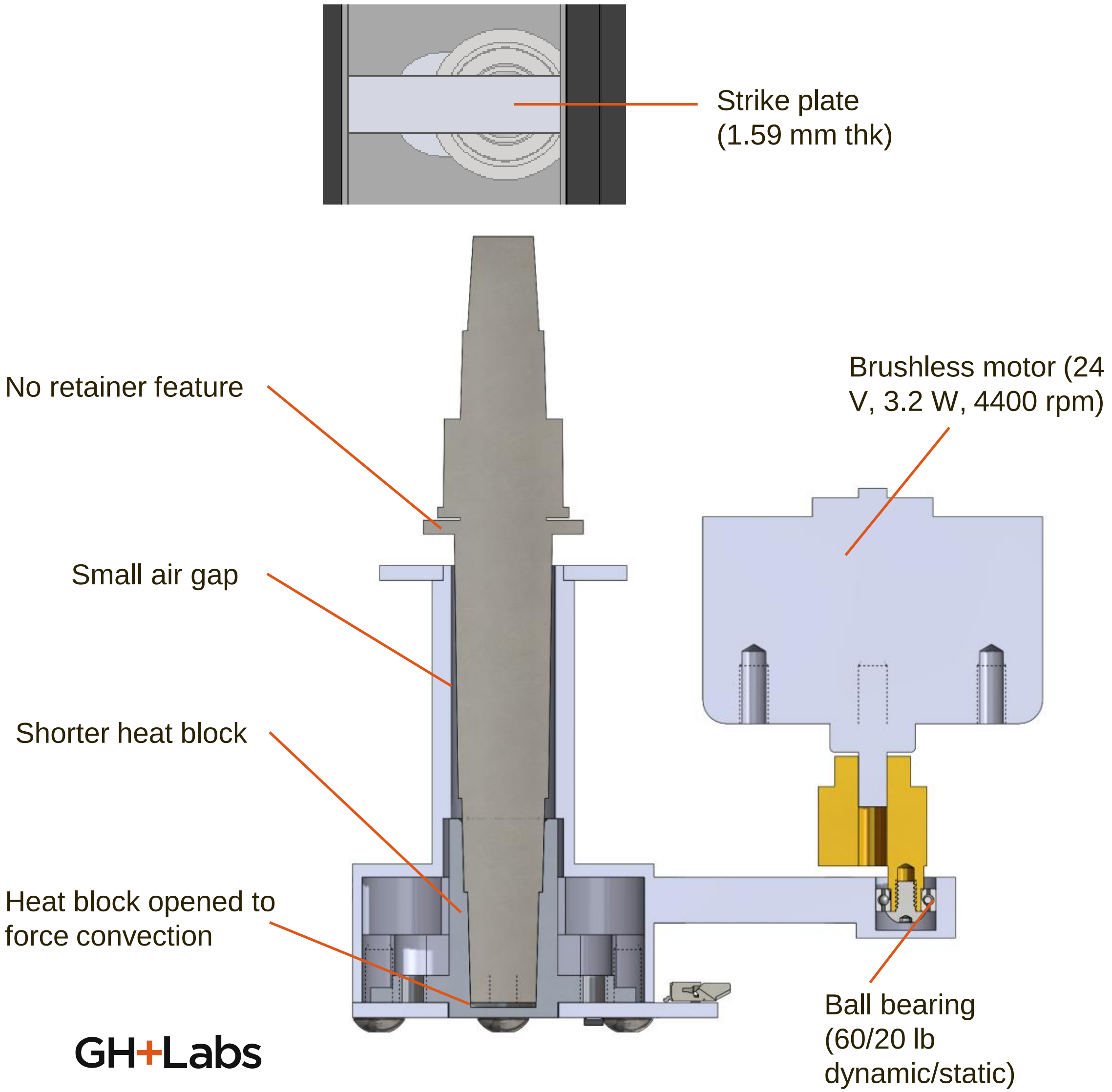
Near-POC Bead Beater Design Differences | Tube interface

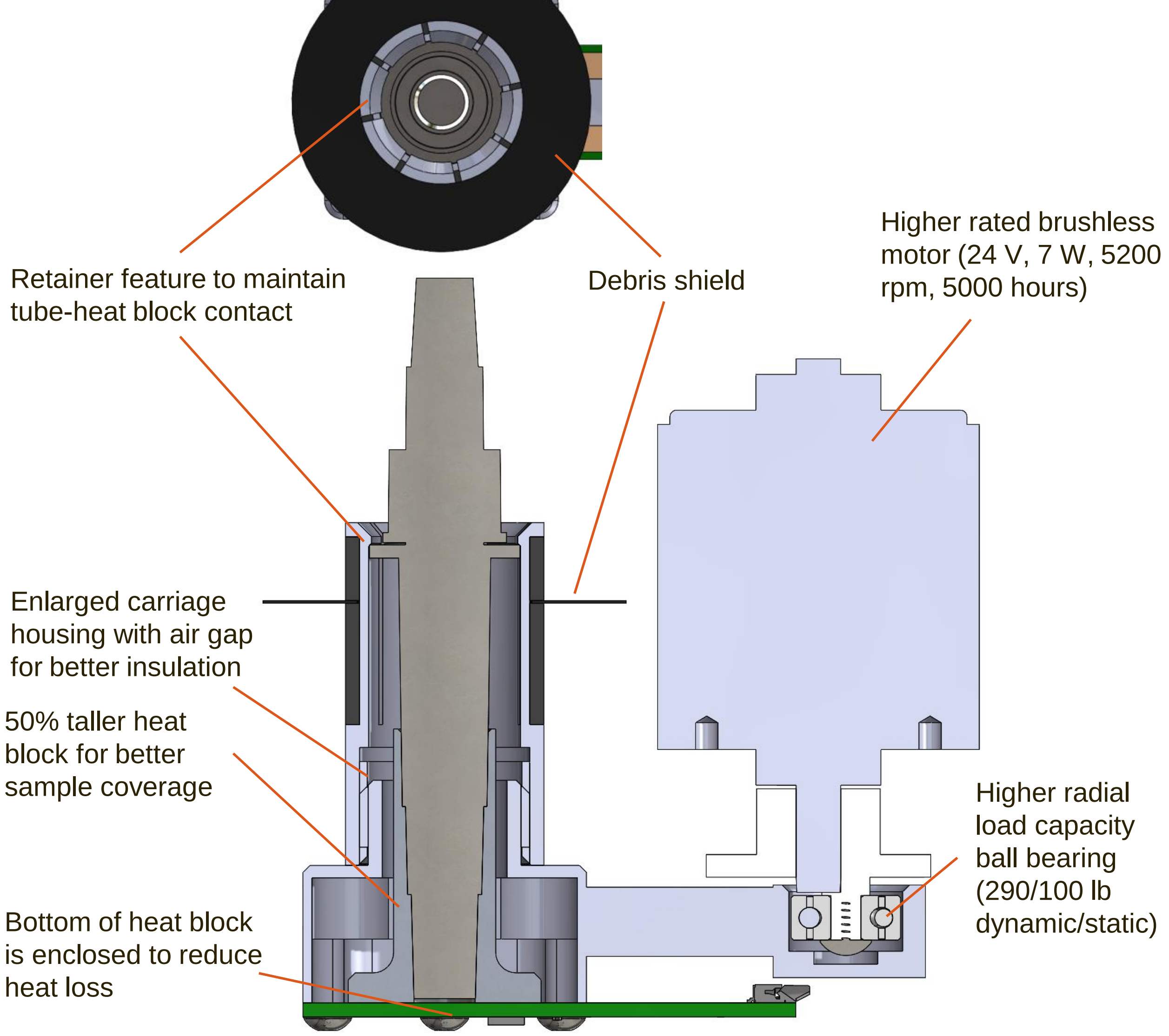
Component	CCG Device (α)	CCG Device (γ)
Throughput	1 tube/cycle	1 tube/cycle
Tube Compatibility	NAATOS PE dropper tube	NAATOS PE dropper tube
Mechanical actuator	Brushless motor and scotch yoke • Motor: 3625BL-24 (24 V, 3.2 W, 4400 rpm motor) • Bearing: 57155K346 (60/20 lb dynamic/static)	Brushless motor and scotch yoke • Motor: Higher power DIX36B (24 V, 7 W, 5200 rpm) • Bearing: Higher radial load capacity 57155k374 (290/100 lb dynamic/static)
Carriage	• Carriage housing with small air gap • No tube retainer feature (added strike plate on lid window) • Smaller debris shield	• Enlarged carriage housing with air gap for better insulation • Clip-in tube retainer feature to maintain tube-heat block contact • Debris shield
Guiderails	Nickel plated stainless steel rails	Delrin or stainless steel (17-4 Ph) rails
Amplitude/Frequency	7mm / 65 Hz	7mm / 65 Hz
Heat block	• Aluminum • Shorter heat block (19.37 mm) • Bottom is opened to force convection	• Aluminum • Taller heat block (30.67 mm) for better sample coverage • Bottom enclosed by heater to reduce heat loss

Near-POC Bead Beater Design Differences | Tube interface

CCG Device (α)



CCG Device (γ)



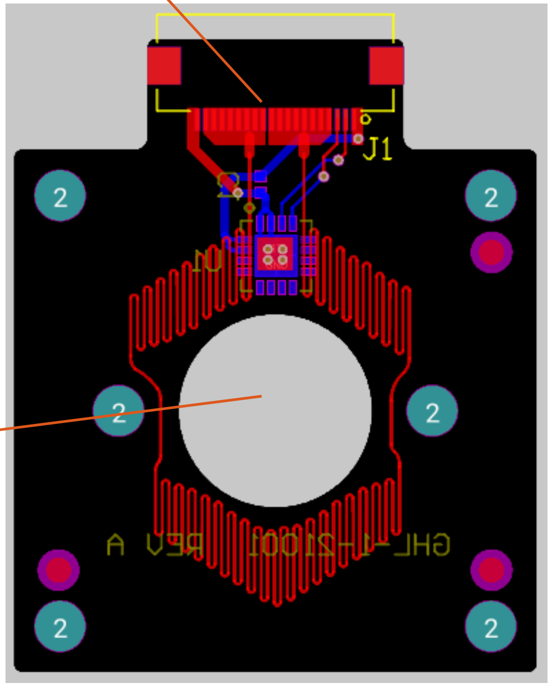
Near-POC Bead Beater Design Differences | Heater and Battery

Component	CCG Device (α)	CCG Device (γ)
Heater	• Single PCB heater with integral traces with attached aluminum heat block • Trace resistance = 2.1 Ω through electromagnetic modeling • Temperature sensor: TE Connectivity G-NICO-018 integrated on the opposite side of heater • Opened center cutout	• Single PCB heater with attached aluminum heat block • Trace resistance = 2.7 Ω measured on the board • PWM'd with a 6V supply • Temperature sensor: TE Connectivity G-NICO-018 integrated on the opposite side of heater
Heater connection	20 pin FFC connector	40 pin FFC connector which provides these advantages: decreased series power loss
Battery/Power	• 4x 18650 Li-ion batteries in parallel • Off-the-shelf battery holder with wire leads, modified for batteries to operate in parallel	• 6x 21700 Li-ion batteries in 2s3p configuration • Custom battery holder with thick gauge wires (10 ga) to reduce voltage drop

Near-POC Bead Beater Design Differences | Heater

CCG Device (α)

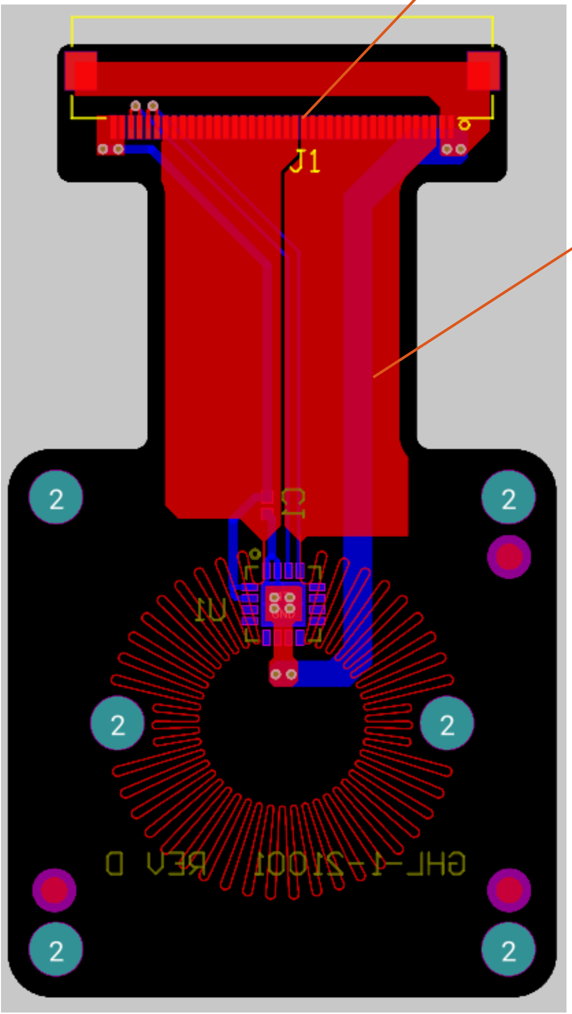
20 pin FFC connector



Cutout for heat block

CCG Device (γ)

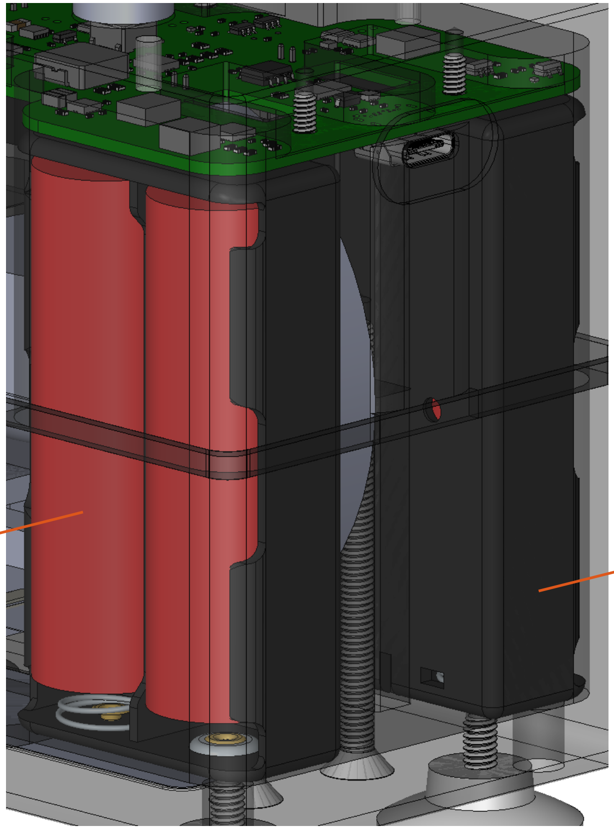
40 pin FFC connector for more robust signal



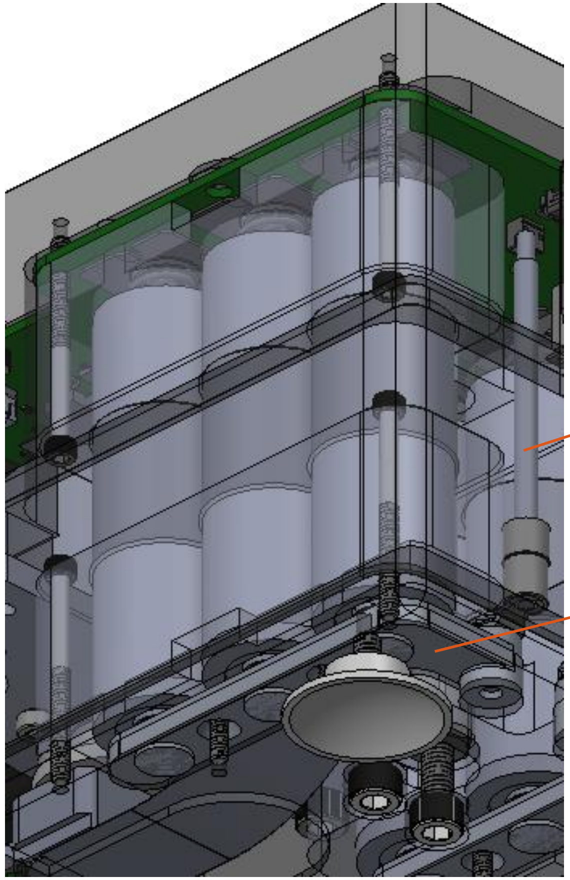
Wider trace to reduce voltage drop

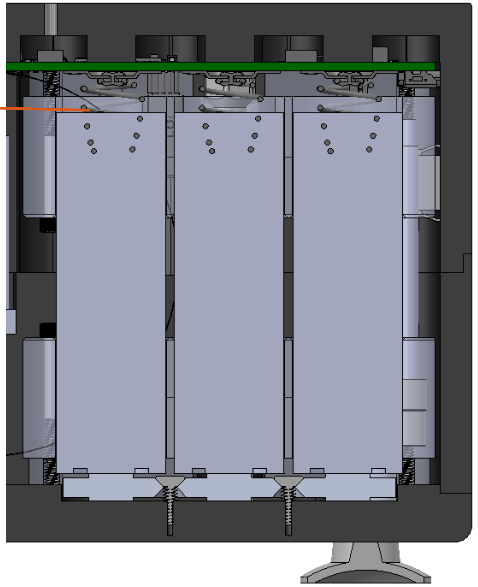
Near-POC Bead Beater Design Differences | Battery

CCG Device (α)



CCG Device (γ)





Near-POC Bead Beater Design Differences | Electronics and Firmware

Parameter	CCG Device (α)	CCG Device (γ)
Firmware	Code version: V1.6 (branch: power-module-V1.6) • Completely different branches for SPM and PM leading to asymmetric and diverging support and maintainability issues	Code version: V3.1 (tag: V3.1_and_odic_splitpoint) • Refactored (compare to alpha firmware) to be used for both PM and SPM • User customizable process cycle (temperature and motor speed control)
Power Management	Heaters ran from unregulated battery voltage with series-inductor losses, due to design problems with the 5V boost converter (which was kept switched off)	Heater boost power supply and motor power supply working well. However there is a design flaw which exposed MCU pins connected to the motor to higher than Nordic absolute maximums when the motor power supply was shutdown. A hardware and software rework was put into place as a mitigation.
Developer Features	• Data logging • Mass storage mode for file access • Status and battery indications	• Physical battery disconnect (kill) switch • File system reset on device • Serial communication, including data streaming • Automatic run modes
Other electronics related (File system, RTC, etc)	SD card	On-board solid state memory

Near-POC Bead Beater Design Differences | Power management

CCG Device (α)

- Frequent brownouts due to power architecture.
- Boost converter never worked well under load.
- Firmware ran the heaters with this converter off, pulling current through series inductor, providing major losses.
- Inconsistent heating power due to non-regulation of voltage for the heaters.
- Other major losses in battery pack holders.
- This unregulated bus voltage was then PWM’d to the heater zone.

CCG Device (γ)

- No more brownouts due to redesigned power architecture.
- The boost converter was redesigned and does work on this design → heaters are receiving regulated power.
- Kill switch mechanism added to powerpath.

Near-POC Bead Beater Component Details ($\gamma \rightarrow$ SG4)

GHL SG4 Design Update | Process cycle

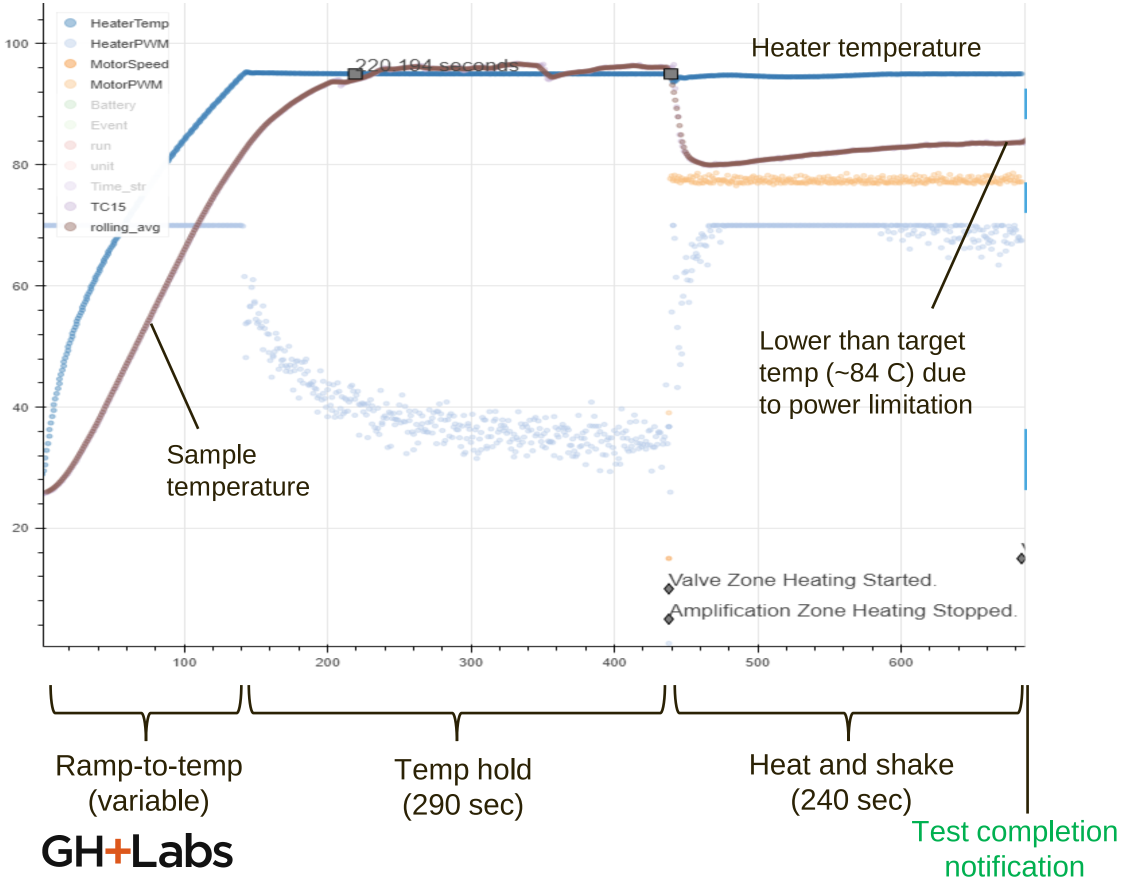
SG3 (α module)

Process cycle:

1. Ramp-to-temp [heater on, motor off]: variable
2. Temperature hold: 290 sec
3. Shaking [heater on, motor on]: 240 sec

Total time: 12-14 min (depending on ramp-to-temp time)

- Target sample temperature ~95 °C
- Target motor speed = 3900 rpm (± 50 rpm)



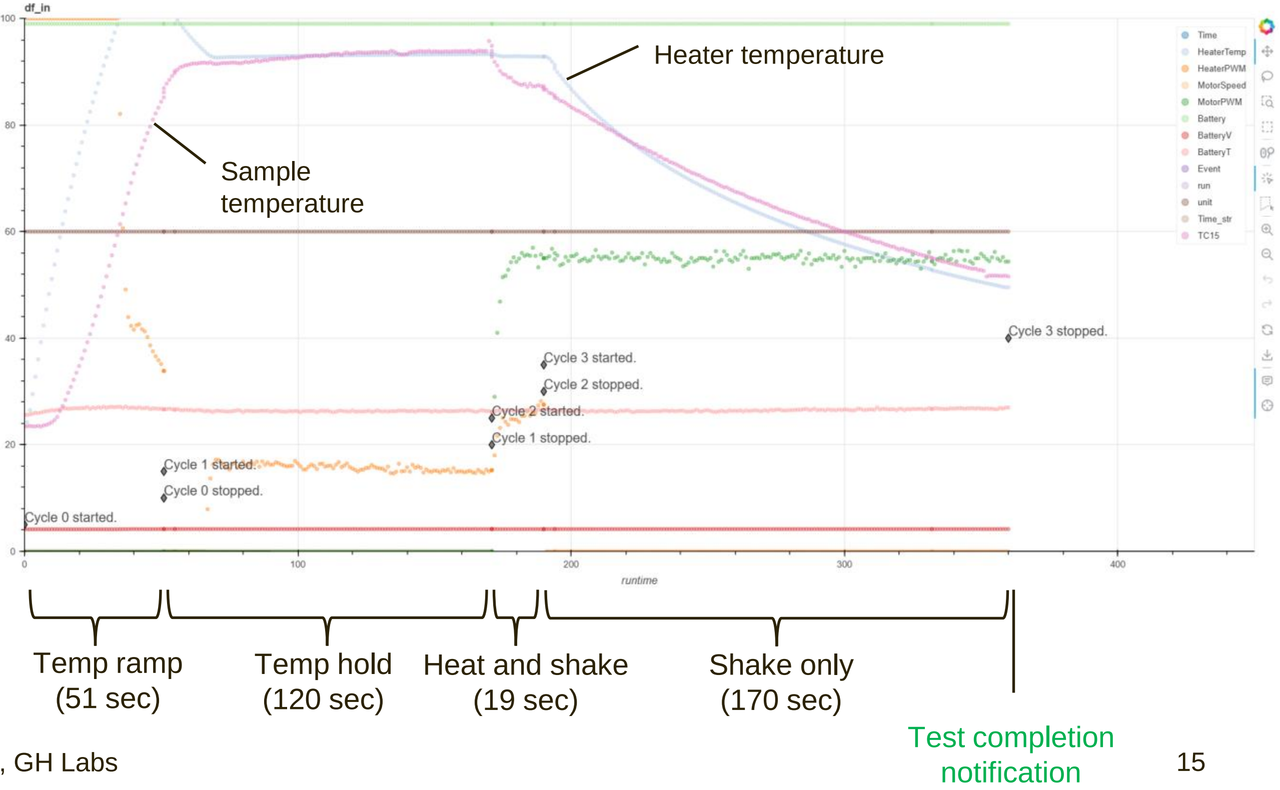
SG4 (γ module)

Process cycle:

1. Temperature ramp [heater on, motor off]: 51 sec
2. Temperature hold [heater on, motor off]: 120 sec
3. Heat and shake [heater on, motor on]: 19 sec
   - Target sample temperature >90 °C
   - Target motor speed = 3900 rpm
4. Shake only [heater off, motor on]: 170 sec
   - Target motor speed = 3900 rpm

Total time: 6 min

- During cycle 2 and 3: target sample temperature > 90 °C
- During cycle 3 and 4: target motor speed = 3900 rpm (± 50 rpm)



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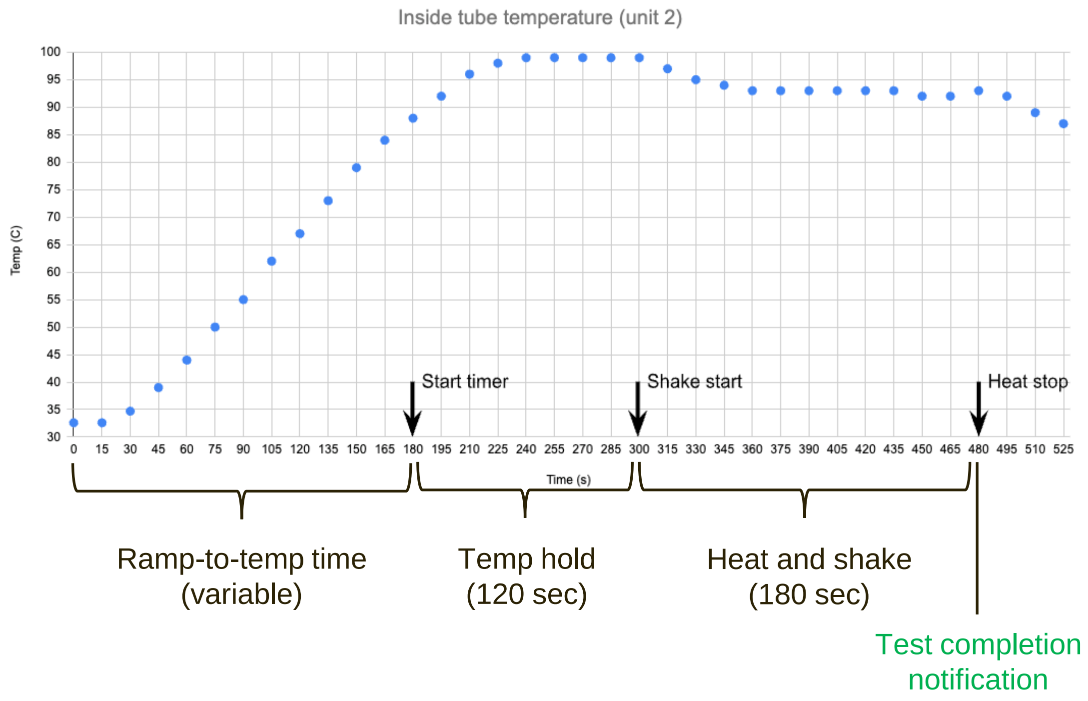
GHL SG4 Design Update | Process cycle

SG2 (Voice Coil Bead Beater)

Process cycle:
1. Ramp-to-temp [heater on, motor off]: variable
2. Temperature hold: 120 sec
3. Shaking [heater on, motor on]: 180 sec

Total time: ~8 min (depending on ramp-to-temp time)

- Target sample temperature > 90 °C
- Target motor speed = 3900 rpm (± 50 rpm)

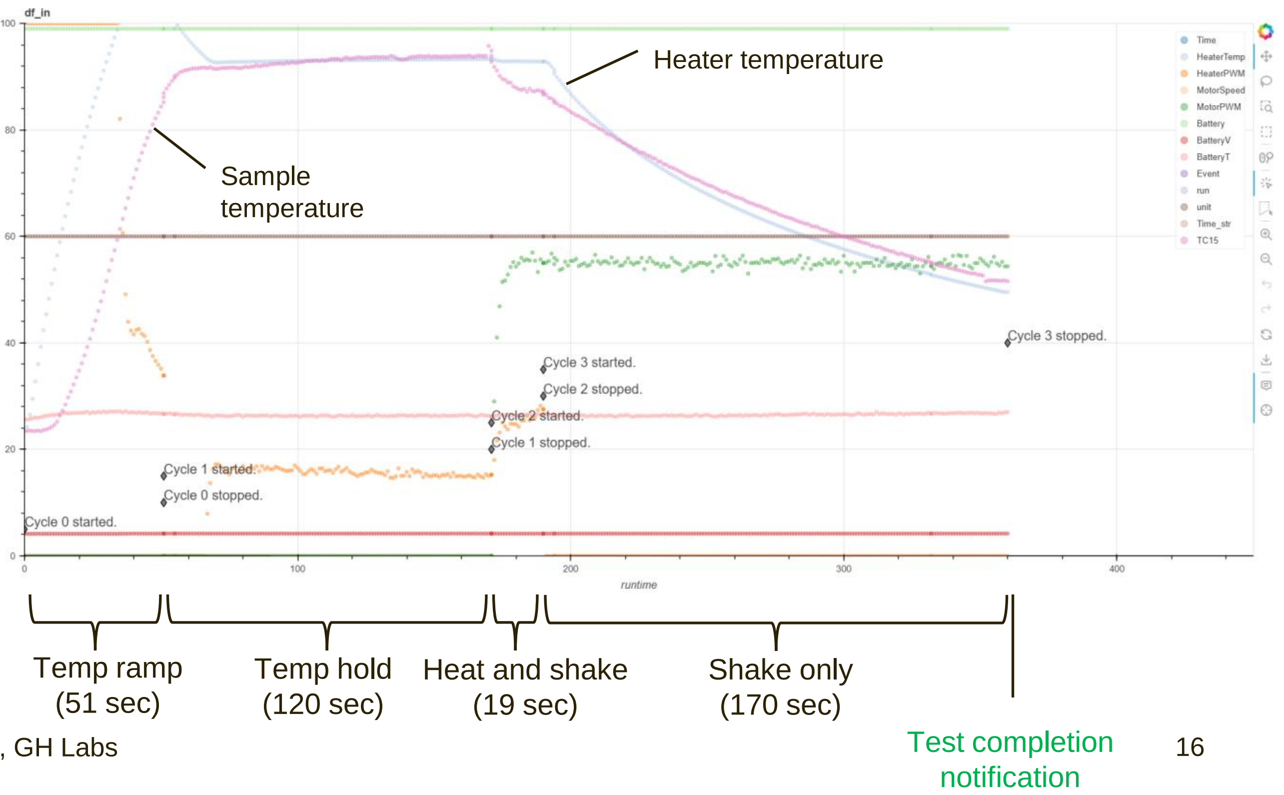


SG4 (γ module)

Process cycle:
1. Temperature ramp [heater on, motor off]: 51 sec
2. Temperature hold [heater on, motor off]: 120 sec
3. Heat and shake [heater on, motor on]: 19 sec
   - Target sample temperature >90 °C
   - Target motor speed = 3900 rpm
4. Shake only [heater off, motor on]: 170 sec
   - Target motor speed = 3900 rpm

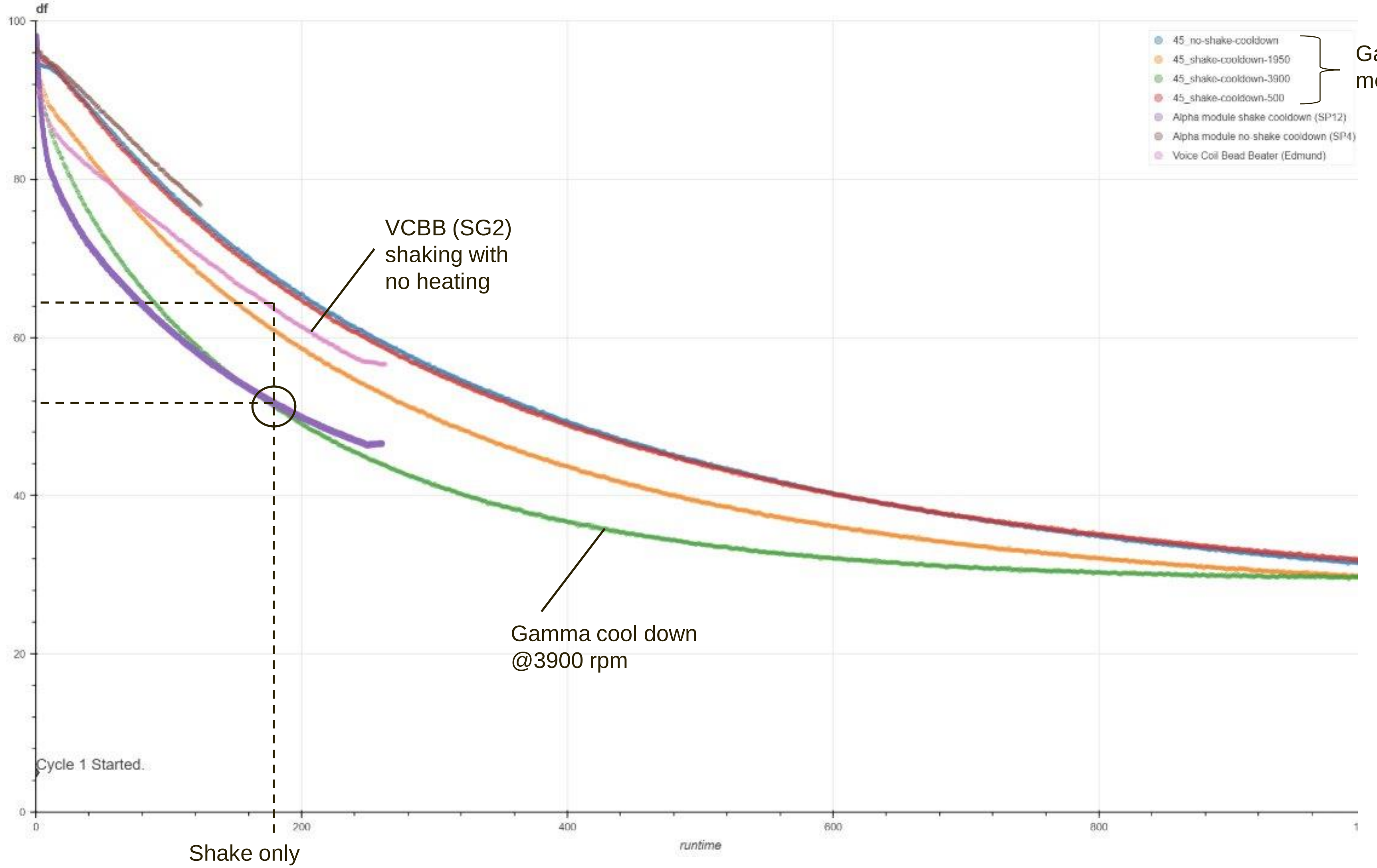
Total time: 6 min

- During cycle 2 and 3: target sample temperature > 90 °C
- During cycle 3 and 4: target motor speed = 3900 rpm (± 50 rpm)



Near-POC Bead Beater cooling curve comparison

Lower tube temperature compared to VCBB



Gamma module

Shake only duration for SG4

GHL SG4 Design Update | Guiderails

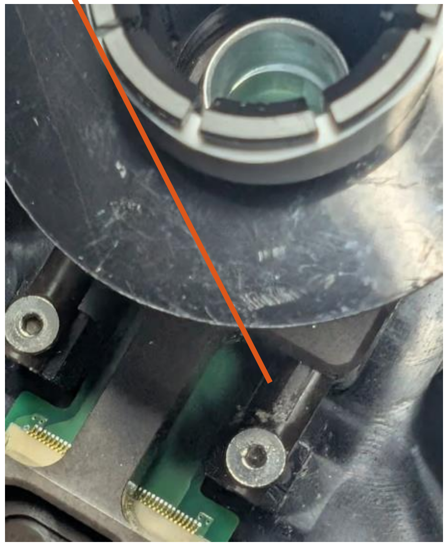
<u>Observation</u>

- Excessive wear on the carriage-guiderails interface causing the two fused together under unknown circumstances

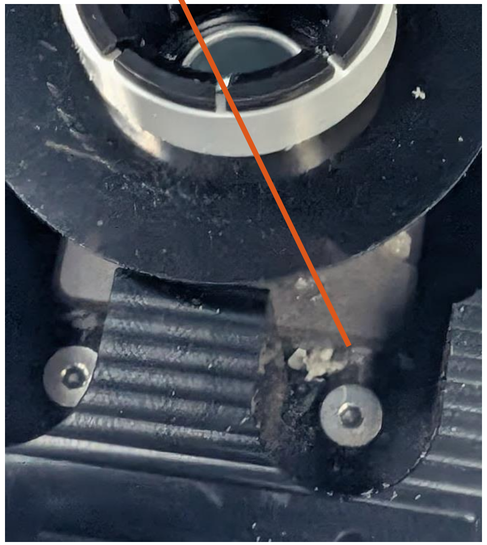
<u>Solutions</u>

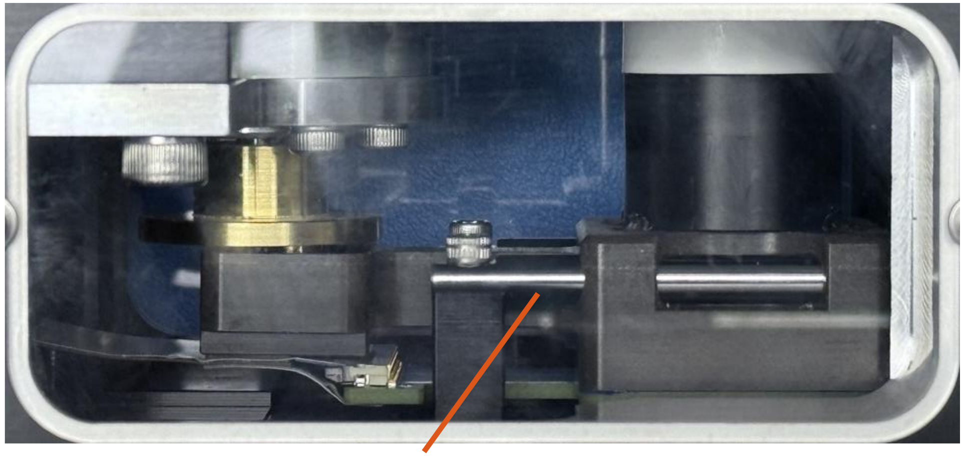
- Software: stall detection based on PWM threshold
- Hardware: new guiderails made of 17-4 Ph stainless steel
- Life test indicates no excessive wear on SS guiderails solution
  - Test 1: >300 cycles life test
  - Test 2: >30 cycles of single fault condition
  - Test 3: >300 cycles life test

Excessive wear



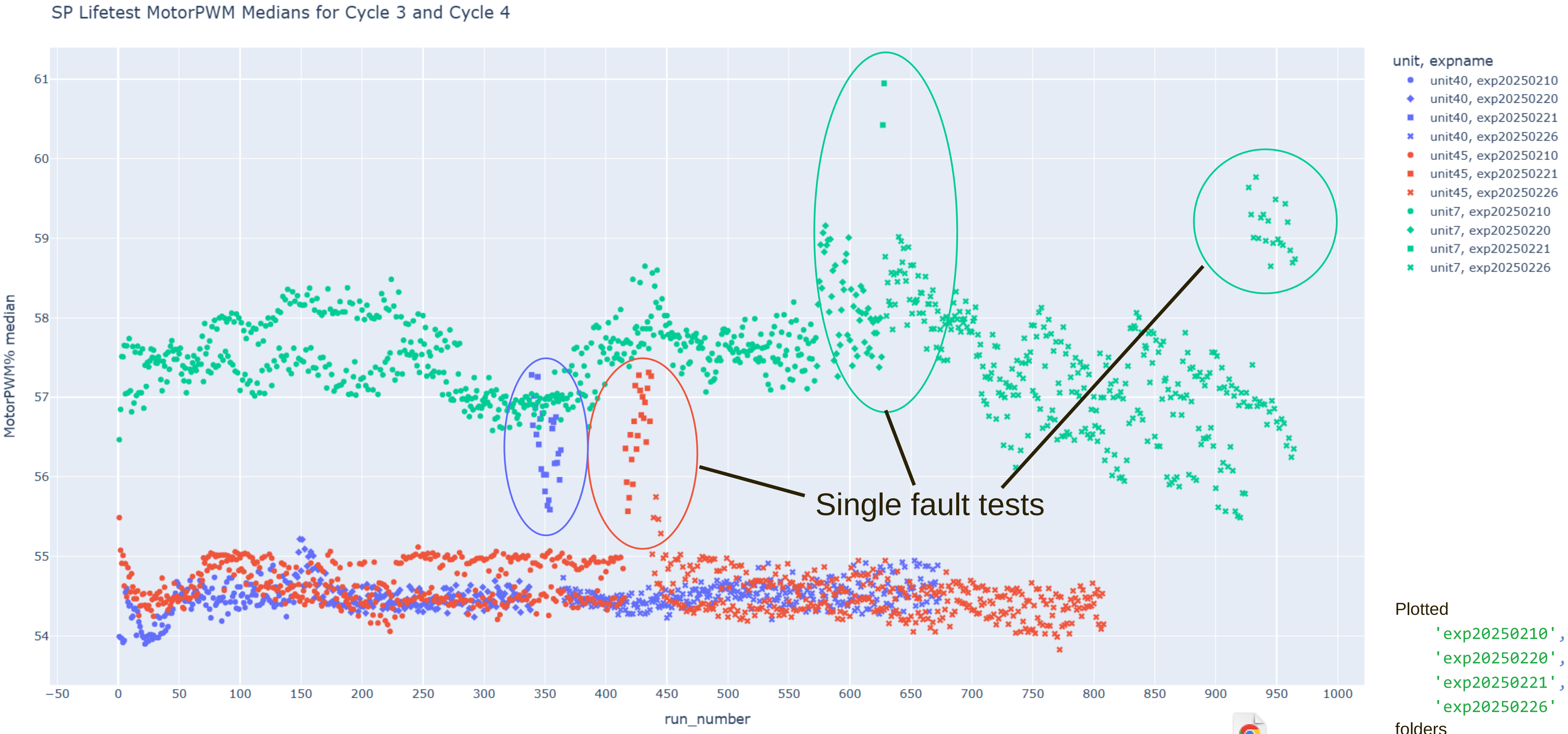
Carriage/guiderail binding





Unit 40 – Delrin carriage and guiderails
Unit 45 – Delrin carriage + bronze bearing + stainless steel guiderails
Unit 7 – Delrin carriage + stainless steel guiderails

Life Test Data



Plotted
'exp20250210',
'exp20250220',
'exp20250221',
'exp20250226'
folders

NAATOS_SAMPLEPREP_20250408T1315_PANEL_PLOTLY_summary.html

Board barcode 12

Near-POC Bead Beater Electronics Board Rev C | Issue

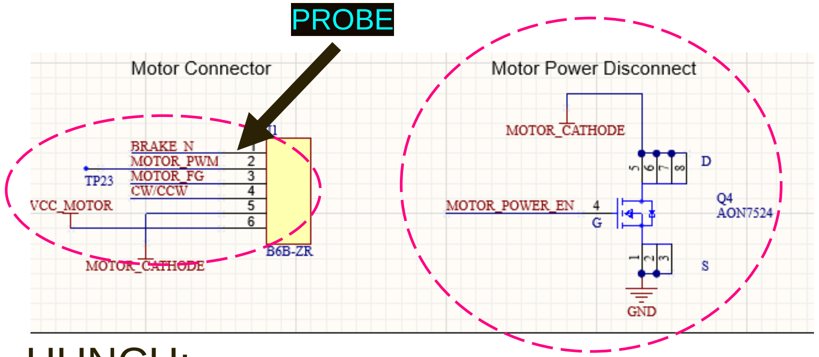
Motor over-voltage problem – Manifested as 0-RPM readback due to failed MCU IO pin

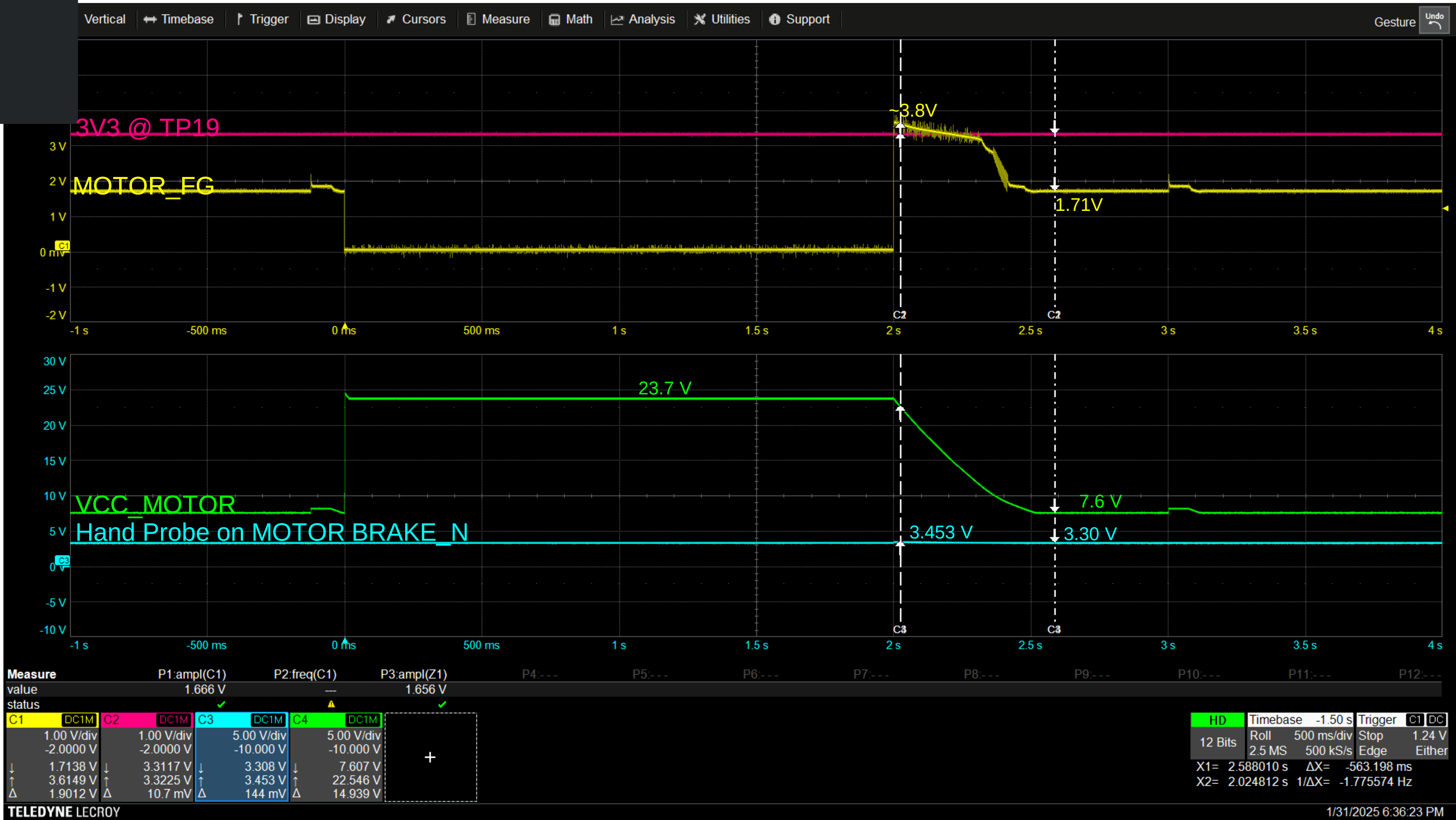
```
  // GHL TEST STUB
#if 1
  nrf_gpio_cfg_output( NRF_GPIO_PIN_MAP(1, 5) );
  nrf_gpio_pin_set( NRF_GPIO_PIN_MAP(1, 5) );   // force BRAKE_N high
  // Turn on 24V motor enable line for short time, then turn off
  nrf_gpio_pin_clear(MOTOR_PWR_EN);
  vTaskDelay(pdMS_TO_TICKS(2000));  // wait 2s
  nrf_gpio_pin_set(MOTOR_PWR_EN); // turn ON
  vTaskDelay(pdMS_TO_TICKS(2000));  // wait 2s
  nrf_gpio_pin_clear(MOTOR_PWR_EN);  //turn back off
#endif
```

External Power Supplies 12.2A 7.8V

Motor 40

8e9f03e9b76647268366b29814fae05e349c79c1 V3.1
+ software pullup on MOTOR_FG + Force BRAKE_N to output and high-level





HUNCH:
Do BRAKE_N, MOTOR_PWM, MOTOR_FG, CW_CCW lines float up when Q4 is turned off?
FAST FORWARD: Yes they do, and go above absolute maximums of MCU

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Board barcode 12

Near-POC Bead Beater Electronics Board Rev C | Issue

Manifested as 0-RPM readback due to failed MCU IO pin

External Power Supplies 12.2A 7.8V

Motor 40

8e9f03e9b76647268366b29814fae05e349c79c1
V3.1
+ software pullup on MOTOR_FG + Force BRAKE_N to output and high-level

9 Absolute maximum ratings

Maximum ratings are the extreme limits to which the chip can be exposed for a limited amount of time without permanently damaging it. Exposure to absolute maximum ratings for prolonged periods of time may affect the reliability of the device.[46]

Note	Min.	Max.	Unit
Supply voltages			
VDD	-0.3	+3.9	V
VDDH	-0.3	+5.8	V
VBUS	-0.3	+5.8	V
VSS		0	V
I/O pin voltage			
$V_{I/O}$, VDD ≤3.6 V	-0.3	VDD + 0.3	V
$V_{I/O}$, VDD >3.6 V	-0.3	3.9	V

3.6V should be maximum to not violate this;

Measured a spike to ~3.8V on MOTOR_FG when 24V is turned off. This eventually will blow out the MCU pin.

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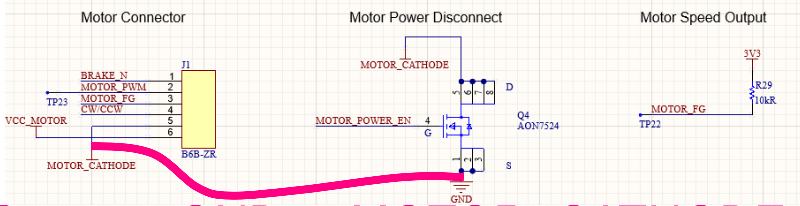
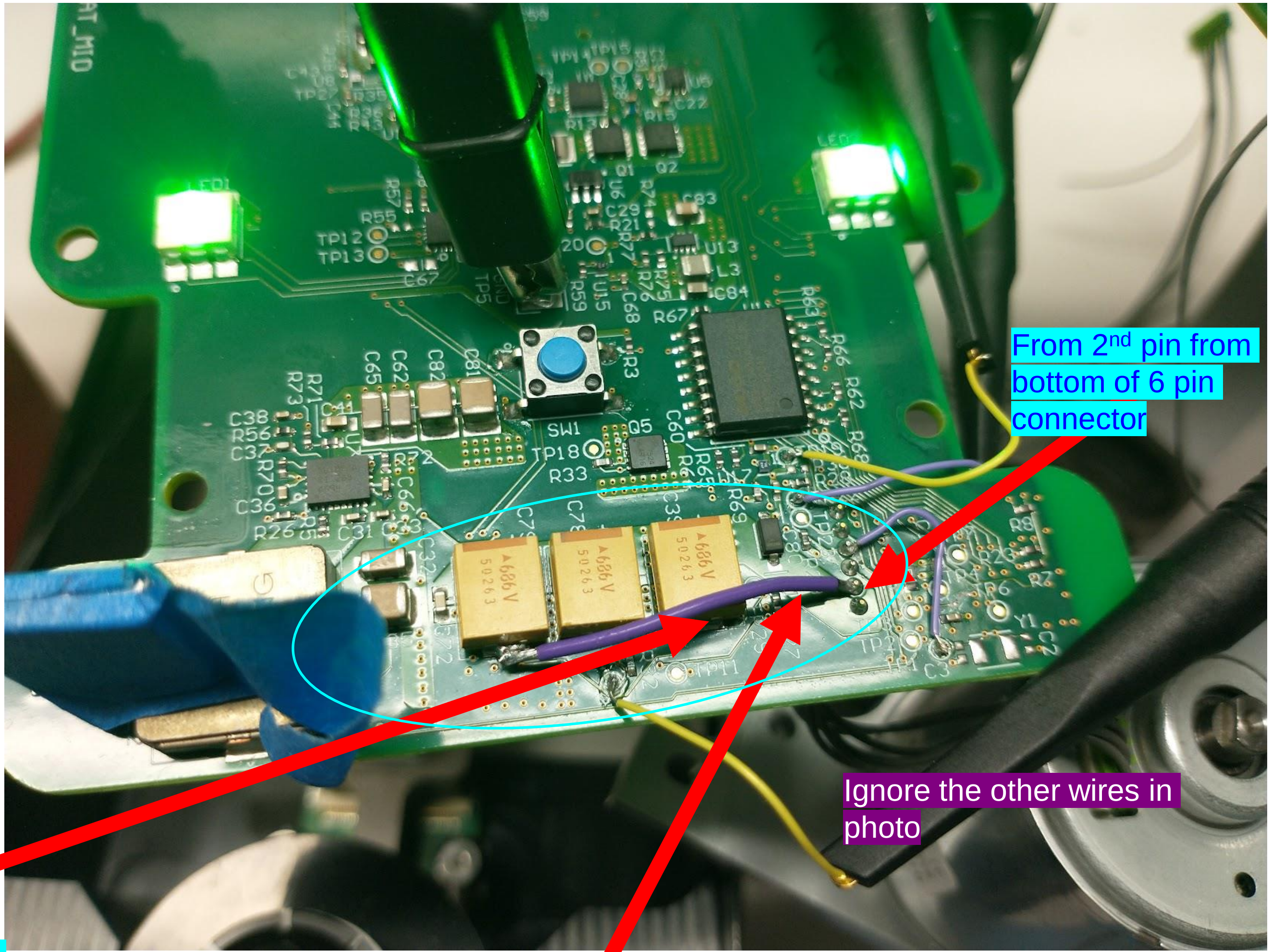
Near-POC Bead Beater Electronics Board Rev C | Rework

To be done on all NAATOS Sample Prep Rev C boards before they are assembled or retrofitted into units



Connect GND to MOTOR_CATHODE (with larger wire)



From 2nd pin from bottom of 6 pin connector

Ignore the other wires in photo

Connect to the nearest electrolytic capacitor pad (here is shown furthest) towards bottom of board

Wire at least 24 gauge thickness, or as thick as you are comfortable

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GHL SG4 Design Update (summary of post-CCG design work)

- Firmware
  - V3.1
    - Last version from ODIC
    - User customizable process cycle
  - V3.2
    - Stall detection based on PWM
    - Usability update: notification scheme change
    - Bug fix: fix temperature reading error between cycles
  - V3.3
    - Usability update: always show battery status on battery LED
    - Re-purpose cycle parameter to error out if temperature setpoint not reached in specified amount of time
  - V3.4
    - Critical fixes
      - Catch (at the cycle-level) if the cycle took too long to run
      - Prevent a run with file system error
        - Issues with default config (issues with alpha in SG3)
    - Other improvements
      - Use RTC (instead of MCU clock) as source of time for more accurate timing
      - Add serial commands
  - V3.5
    - Critical fixes
      - Check cycle runtime during run (issues with getting stuck in cycle 1)
      - Handle occasional RTC bad date through retry mechanism
      - Fix issue with battery overtemp error

Near-POC Bead Beater Unit Qualification

Near-POC Bead Beater Unit Qualification

Qualification SOP here: TMP-0001 SOP-Sample Prep Module Qualification.docx

Units Assessed

- Gamma, v3.0bghl
- Qualification performed on units received from CCG 01/23/2025

Qualification Parameters	Criteria for pass/fail
1. Physical Appearance	No major scratches or damage, specifically on read window
2. Sample prep tube fit	Tube orientation correct, securely held, can repeatedly insert and remove
3. LED functionality	LEDs turn on and can change color to match state
4. Power switch functionality	Power switch turns unit on and off
5. Cycle run	A full cycle can run
6. Clock Accurate	Check if clock is accurate, if not update it
7. Logs access	User can access logs
8. Firmware access	User can access firmware
9. Temperature profile	[Details on next slide]

Results available here: Unit Tracker (Tab: UnitBringUp20250123)

Qualification Record

Results available here: Unit Tracker (Tab: UnitBringUp20250123)

Unit	1. Physical?	2. Tube fit?	3. LED ok?	4. Switch functional?	5. Run cycle?	6. Access log/config?	7.Clock accurate?	8. Access firmware?	9. Temperature Profile ok?	Cleared to ship/use?	Notes
6	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	minor epoxy overflow on bottom of window,
8	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Data loss, unit passed QC
10	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light scratches on door window
12	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Data loss, unit passed QC
13	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light scratches on tube platform
14	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Minor x scratch on top
15	?	?	?	Yes	Yes	Yes	?	?	N/A	NO	GHL Demo Unit
17	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
18	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
19	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Data loss, unit passed QC
22	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
23	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Dip in temperature mid phase 1
27	Good	Yes	TBD	Yes							Shipped with the battery switch on. Yellow light, still wont run. Appears to be power cycling. Remove power cable still showed blue breathing LED
29	Good	Yes	Yes	Yes	NO	Yes	Yes			NO	Encoder failure
30	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light scratches on the back, light horizontal scratches on window
32	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light scratches on tube platform
38	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
39	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Needed power to initial turn on, unit previoulsy had RevB board (return from CCG)
41	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
46	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
50	Adequate	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Scratch on top surface
52	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
53	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light scratches on tube platform
54	Good	Yes	Yes	Yes	NO	Yes	Yes			NO	Some scratches on back panel. Premature halt- stopped just after cycle 2 started. Encoder issue
55	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
56	Good	Yes	Yes	Yes	NO	Yes	N/A	N/A	N/A	NO	Minor scratches on bottom plate, vibration frequency very high. Immediate liquid loss. Happened 2x. Not reading speed, Motor PWM going to 100 immediately.
57	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Data loss, unit passed QC
58	Good	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Light vertical scratches on top
59	Adequate	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Chamber door not smooth to open/close

Temperature Profile Qualification

Procedure:

1. Place a type T thermocouple into the center of a sample prep tube with 500 µL of aqueous buffer.
   a) Secure thermocouple position and cap tube with a piece of tape
2. Connect the thermocouple to a NI DAQ
3. Load the sample prep tube into the module undergoing evaluation
4. Record the temperature of the thermocouple over the course of a full run
5. Calculate the mean, min, max temperature during each phase
   a) Qualification performed during the 8minute, 2 phase SP cycle

Temperature Qualification criteria

Phase 1: Heat

During Steady State (85s to 300s)

Phase 1:

90°C ≤ Tmean ≤ 98 °C

Phase 2: Heat & shake

During Steady State (390s to 505s)

Phase 2 mean:

90°C ≤ Tmean ≤ 98 °C

Thermocouple data for each module	Unit Tracker
Python analysis script (ccg_steadstate_PWM.py)	Python Script

Unit	Phase1_Start_Row	Phase1_End_Row	Phase1_Max	Phase1_Min	Phase1_Mean	Phase1_Std	Phase2_Start_Row	Phase2_End_Row	Phase2_Max	Phase2_Min	Phase2_Mean	Phase2_Std
6_1	85	300	97.45	89.52	95.83	2.20	390	505	93.98	93.08	93.53	0.22
10_1	85	300	98.15	89.72	96.70	2.34	390	505	94.52	93.46	94.14	0.24
13_1	85	300	98.00	89.53	96.47	2.17	390	505	93.85	92.83	93.42	0.24
14_1	85	300	97.91	89.45	96.27	1.88	390	505	93.98	92.94	93.57	0.27
17_1	85	300	98.55	88.88	96.69	2.53	390	505	94.14	92.99	93.71	0.24
18_1	85	300	98.32	89.00	96.79	2.55	390	505	94.07	93.08	93.66	0.23
22_1	85	300	97.75	88.24	96.27	2.46	390	505	93.41	92.17	92.91	0.30
23_1	85	300	97.74	88.15	96.20	2.18	390	505	92.85	92.05	92.45	0.19
30_1	85	300	96.85	88.66	95.73	2.18	390	505	94.25	93.18	93.79	0.26
32_1	85	300	97.90	90.62	96.54	2.00	390	505	94.62	93.91	94.32	0.17
38_1	85	300	99.00	92.70	97.29	1.48	390	505	95.45	94.93	95.19	0.10
39_2	85	300	97.92	89.96	96.48	2.15	390	505	94.76	93.81	94.35	0.23
41_1	85	300	96.67	88.31	95.30	2.22	390	505	93.29	92.48	92.96	0.19
46_1	85	300	97.18	89.31	96.02	2.11	390	505	94.57	93.62	94.19	0.24
50_1	85	300	97.11	88.97	95.88	2.06	390	505	93.49	92.52	93.11	0.23
52_1	85	300	96.67	88.62	95.39	1.93	390	505	92.98	91.90	92.46	0.22
53_1	85	300	97.42	90.16	96.17	1.99	390	505	93.93	93.14	93.60	0.20
55_1	85	300	96.05	87.34	94.15	2.33	390	505	92.90	91.97	92.51	0.23
58_1	85	300	95.38	86.86	93.93	2.19	390	505	92.16	91.34	91.76	0.21
59_1	85	300	96.06	88.01	94.92	2.14	390	505	92.99	92.06	92.60	0.23

Units 8, 12, 19, 57 were calibrated with 6-minute cycle so data does not match phase times above or target temp ranges
Unit 15 was a demo unit, QC incomplete
Units 29, 54, 56 had encoder issues
Unit 27 had a power cycle issue, dead on arrival and had to undergo review by Simon

Appendix

Firmware: USB CDC Serial Commands as of V3.5

(as of V3.5)

Note, the comma after many of these commands is important! The string parser won't treat them as commands with that trailing comma (on commands that don't take arguments)

Command	Name	Takes Args	Examples	Explanation	Note
SETCLK	RTC Time Setting	YES	SETCLK,2024-11-14 14:27:34 or SETCLK,2024-11-14T14:27:34	Set the RTC time to the specified timestamp. Before setting, a software reset will be issued to the RTC chip (same as RSTCLK)	convenient to use with YAT (yet another terminal) timestamp insertion: SETCLK,\!(TimeStamp())
TSTCLK	RTC Test		TSTCLK,		
RSTCLK	RTC Software Reset		RSTCLK,	Send a software reset the RTC chip.	
LSDIR	Output listing of filesystem directories		LSDIR,	Output to serial port a summary listing of the filesystem root directory. Each folder will be entered and the file entries in that folder counted, and returned in this message.	
REBOOT	Reboot MCU		REBOOT,	Reboot MCU (must be in MAIN_STANDBY state)	
STATUS	Output summary information		STATUS,	Output to serial port some Status and ID information. Example: 14:07:51 - V="3.5" T="PM" ECL=0x00 TS="2025-03-14 14:07:54" MAIN_STATE="MAIN_STANDBY" SN="DBF4CF86E4F8" 14:07:51 - Vbatt=3.924000 SOC=70 Tbatt=27.917969 Tamp=69.151276 Tvalve=70.782478	V = firmware version, T = device type (PM-powerodule, SP=sampleprep), ECL=cumulative error flags in logger module, TS=current rtc time, MAIN_STATE=what state are we in, SN=nordic-provided hardware mac address which can serve as a unique identifier for each board, Vbatt = fuel gauge provided battery voltage, SOC=fuel gauge provided state of charge Remaining fields are the last reading of various sensors
CFGGET	Config get		CFGGET,	Output to serial port a summary of the active run and cycle configurations.	Behavior never tested with more than 4 cycles, there is some string limit that may be exceeded with >8 cycles
CFGSET	Config set	YES	CFGSET,		
TODFU	Enter DFU mode		TODFU,	Enter DFU for firmware upgrade, by simulating 3 rapid button presses (must be in MAIN_STANDBY state)	
TOMSC	Enter MSC mode		TOMSC,	Enter mass storage mode for USB file operations, by simulating long button press (must be in MAIN_STANDBY state)	
EXITMSC	Exit MSC mode		EXITMSC,	Exit mass storage mode, by simulating a button press (must be in MAIN_FILE state); the firmware effectively performs a reboot as part of this transition	
REFORMAT	Reformat filesystem and reboot		REFORMAT,	Perform a filesystem reset, much like holding down button while powering-up. Then system is rebooted.	On some devices , at some times, this needs to be issued more than once, followed by some reboots, perhaps. You may see the fast flashing magneta/yellow when this is happening and you need to try this again. Cause unknown / not investigated.

Firmware: conditions to Start Run

(as of V3.5)

Condition To Start Run (avoid Solid Yellow in Standby) [conditions_for_run bitfield struct union]

Bitfield	Explanation
temperature_zones_in_range	In standby mode temperatures are refreshed once a second. * If config.min_run_zone_temp_en is TRUE, the latest temperature of any zone must be < config.min_run_zone_temp * The latest temperature of any zone must be > 0.1 degC (this checks for something really wrong with sensor communication) Essentially requires the temperatures in the device to have cooled down sufficiently, and show above zero.
battery_charge_level_acceptable	Battery charge level must not be "red"
machine_can_run	All machine conditions must be true (see Conditions To Have Good Machine)

Firmware: conditions to have Machine Okay

Conditions To Determine if Device Okay or Is Machine Good (avoid Fast Flashing Yellow/Magenta in Standby) [conditions_for_machine bitfield struct union]

Bitfield	Explanation
configs_loaded_and_validated	Checked once at bootup. Configs could be loaded from filesystem without error. Inside read_filesystem_and_configurations… If get_naatos_configuration_parameters() and get_cycle_configurations_parameters() do not return okay, this will be false
filesystem_deemed_okay	Checked once at bootup. After all startup filesystem operations, check is_naatos_storage_okay() which will return a naatos_storage_initalized local variable from the naatos_storage.c compilation unit.
battery_has_stayed_cool	Checked every standby cycle (at samplerate) Battery temperature thermistor (as measured by fuel gauge chip) must be <59.0 degrees C
canary_value_noninitializer	the active master config value config.canary was not 999; when default configs are written out, it would be 12345; so this is a type of canary in the coalmine situation to indicate a filesystem problem, and also test the notification scheme easily
canary_value_nondefault	the active master config value config.canary was not 747; when default configs are written out, it would be 12345; so this is a type of canary in the coalmine situation to indicate a filesystem problem, and also test the notification scheme easily
norflash_could_mount_filesystem	Checked once at bootup. nor_flash_could_mount_filesystem in naatos_storage.c compilation unit was true

Firmware: reasons why a run would stop before it completed (V3.5)

Reasons why a run would stop before successful completion (as of V3.5)

Cycle error enums	Explanation	When Does NOT Apply	Example Logfile Event Text	Simon Notes
CYCLE_ERROR_ACTUAL_RUNTIME_HAD_A_MISMATCH	when cycle is completed, the rtctime or cputicktime difference to cycle_config.cycle_run_time is within cycle_config.accept_cycle_time_error	* if any cycles in the run have a cycle_config.ramp_to_temp_before_start_cycle set to true (would imply variable time behavior) * cycle_config.accept_cycle_time_error is 0	Cycle run time error was beyond the configured threshold of 7.5 seconds	catches a severe time mismatch at the cycle level
CYCLE_ERROR_FINISHED_BUT_ACTUAL_RUNTIME_HAD_A_MISMATCH	when the whole run is completed otherwise successfully (right when the last cycle ends), but the whole run rtctime or cputicktime difference to the sum of all cycle_config.cycle_run_time s is greater than config.accept_run_time_error_s	* if any cycles in the run have a cycle_config.ramp_to_temp_before_start_cycle set to true (would imply variable time behavior) * config.accept_run_time_error_s is 0	Total run time taken error was beyond the configured threshold of 30 seconds	catches a severe time mismatch at the run level
CYCLE_ERROR_TIME_ERROR_BETWEEN_RTC_AND_CPUTICKS_DURING_RUN	when a cycle is running and the rtcelapsed has diverged from tickelapsed by greater than config.accept_run_time_error_s		Caught time-error beyond 30 sec between RTCelapsed_s:50 & TICKelapsed_s:4 while cycle_run_time_s was 30 sec	catches the cycle never stopping problem we saw
CYCLE_ERROR_BUTTON_EXIT	when the pushbutton is actuated during run		Cycle cancled via button	
CYCLE_ERROR_SENSOR_BREAK	when the hall effect and/or optical sensor is switched during the run		Optical sensor interrupted.	
CYCLE_ERROR_TIMEOUT_DURING_RAMP	when ((time in the cycle elapsed) > cycle_config.ramp_to_temp_timeout) and any of the temperatures have not yet met or exceeded their respective setpoints in this cycle	* cycle_configs.ramp_to_temp_timeout is 0	Ramp to temp timed out. Stopping cycle.	
CYCLE_ERROR_OVER_TEMP_BATTERY	battery temperature thermistor reading >= 59.0 degC		Battery over temperature error:	
ERR_TEMP_SENSOR_READ / CYCLE_ERROR_I2C_FAIL	when temperature sensor could not be read correctly (in respective sensor.c file)		I2C sensor read error	
ERR_OVERTEMP_EVENT / CYCLE_ERROR_OVER_TEMP	when a temperature reading in a respective sensor zone is greater than it's configured setup (PM: config.amp_max_temp and config.valve_max_temp; SP: config.heater_max_temp)		Sample over temperature error	
CYCLE_ERROR_MOTOR_STALLED_PERCENT	when motor RPM drops this PERCENT below the motor setpoint	* motor is not configured to run in the cycle * measured motor RPM has not yet met or exceeded the motor RPM setpoint in the current cycle * config.motor_stall_en is false	Motor stalled detected due to drop in motor speed.	
CYCLE_ERROR_MOTOR_STALLED_PWM	when motor PWM control value exceeds config.motor_stall_pwm		Motor stalled detected due to an increase in PWM	
Not a defined error / a watchdog reboot	other uncaught error conditions or programming bugs. this will not show any explanation in logfile (because it's uncaught) but result in a reboot triggered by the hardware watchdog timer			

Firmware: simplified/annotated git log

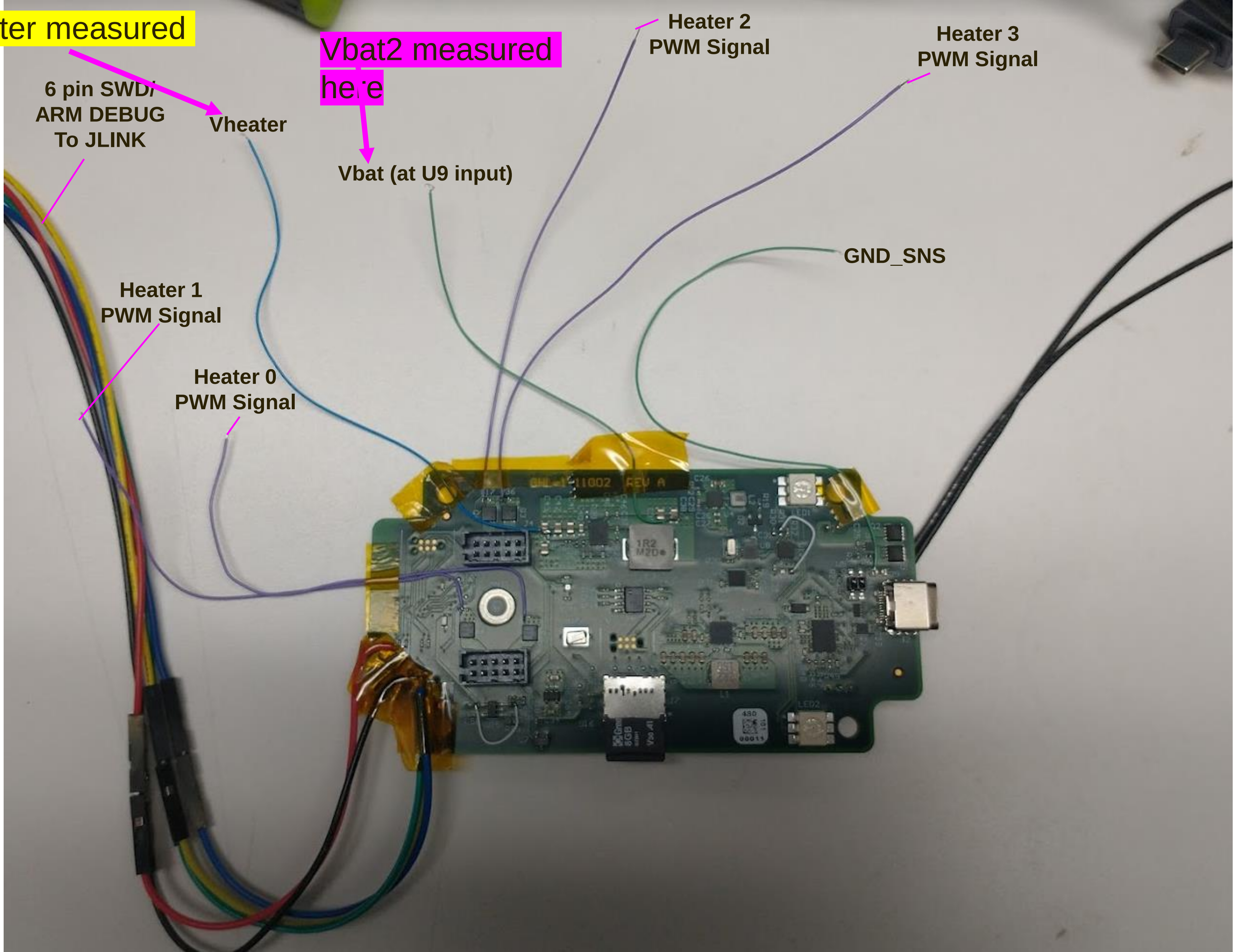
VersionTag	Change Summary
V3.1	LAST ODIC TOUCHPOINT
V3.2rc1	add USB cdc commands
V3.2rc1	improve robustness, reduce bugs, add debug outputs
V3.2rc1	add additional logging for low-battery transitions
V3.2rc1	add additional logging on bootup
V3.2rc1	rework USB to allow simultaneous CDC and MSC modes
V3.2rc1	change powermodule run-start conditions to require state change
V3.2rc1	fix problem where powermodule was rebooting after successful run completion
V3.2rc1	set default config
v3.2rc2	add powermodule buzzer support
v3.2rc2	add USB cdc commands
v3.2rc2	fix RTC reset issue seen when batteries first plug in
v3.2rc2	rework configuration file framework to use key-value tables
v3.2rc2	set default config
v3.2rc2	fix sampleprep issue which manifested with subsequent runs after stall could terminate early with erroneous stall message; add I2C retry counter logging
v3.2rc3	fix typo with powermodule configuration table
v3.2rc4	make powermodule also support do_automatic_runs
v3.2rc4	add USB cdc commands
v3.2rc4	fix powermodule usage of front led set
v3.2rc4	led notifications: speed up all breathing patterns
v3.2rc4	led notifications: rework framework, add double-yellow graceperiod, solid-red sample invalidation
v3.2rc4	add powermodule buzzer support
v3.2rc4	led notifications: add solid-yellow run startability capability; and red-magenta flashing for device cannot run
v3.2rc4	improve robustness, reduce bugs, add debug outputs
v3.2rc4	fix bug transitioning from power-module cycle 3 to power-module cycle 4 related to temperature sensor reading
v3.2rc4	set default config

VersionTag	Change Summary
v3.2rc4	make powermodule also support do_automatic_runs
v3.2rc4	add USB cdc commands
v3.2rc4	fix powermodule usage of front led set
v3.2rc4	led notifications: speed up all breathing patterns
v3.2rc4	led notifications: rework framework, add double-yellow graceperiod, solid-red sample invalidation
v3.2rc4	add powermodule buzzer support
v3.2rc4	led notifications: add solid-yellow run startability capability; and red-magenta flashing for device cannot run
v3.2rc4	improve robustness, reduce bugs, add debug outputs
v3.2rc4	fix bug transitioning from power-module cycle 3 to power-module cycle 4 related to temperature sensor reading
v3.2rc4	set default config

VersionTag	Change Summary
v3.3	led notifications: led driver re-write, always show battery on the BATTERY led
v3.3	set default config
v3.4	add USB cdc commands
v3.4	add check for total run time taken within tolerance
v3.4	use RTC time for run state machine
v3.4	fix powermodule issue with valve power supply, we are now reinitializing the chip completely every sensor sample cycle
v3.4	catch at the cycle-level if the cycle took too long to complete
v3.4	set default config
v3.5	set default config
v3.5	handle occasional RTC bad date through retry mechanism
v3.5	catch in the middle of a cycle if our runtime according to cputicks has a severe disagreement from the rtc time we are using to measure the cycle runtime
v3.5	improve reliability of DFU entry
v3.5	add a retry mechanism in powermodule sensors data collection to deal with valve power supply workaround
v3.5	fixed issue with battery overtemperature error, where it would not have been handled appropriately

Near-POC Bead Beater CCG Device (a)

202409 Power System Troubleshooting

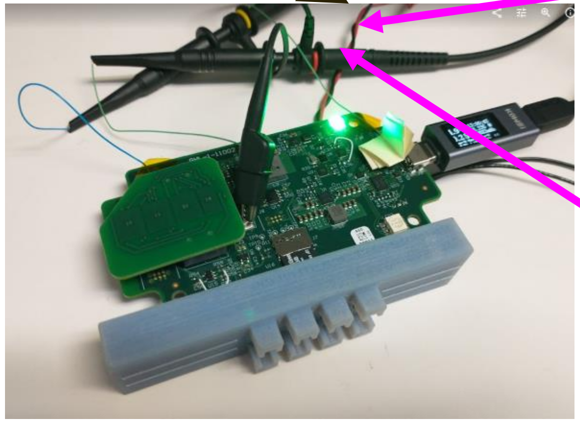

Vheater measured here
Vbat2 measured here
6 pin SWD/
ARM DEBUG
To JLINK
Vheater
Vbat (at U9 input)
Heater 2
PWM Signal
Heater 3
PWM Signal
GND_SNS
Heater 1
PWM Signal
Heater 0
PWM Signal

4.2V from Keithly 2461 as Vbattery

Wired Keithley for 4-wire Source Mode

To Reduce Power-Supply Sag

Vbatt provided by SMU

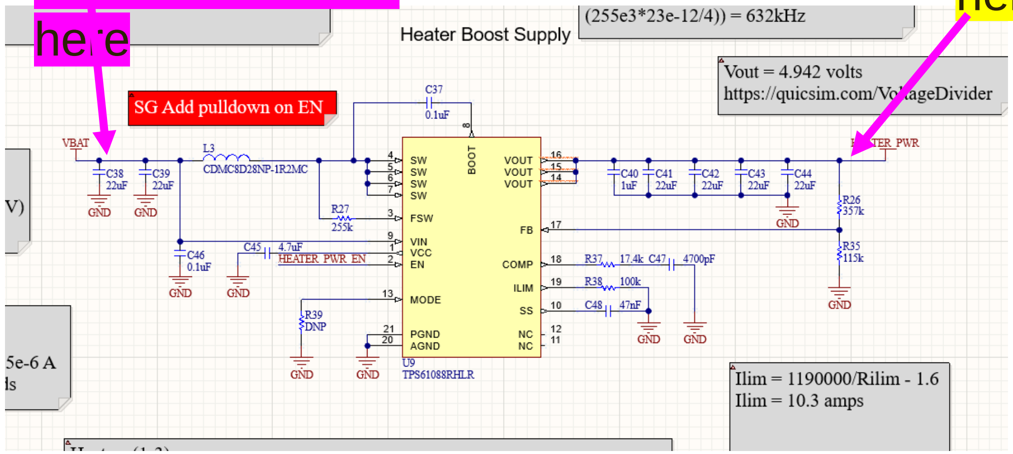


Vbat1 measured here

Current measured on one of the battery wires

Vheater measured here

Vbat2 measured here



Custom Test Stub in FW (started on V1.6 as base)

- Upon first main() call, start the PWM heaters one at a time followed by short delay

```
pwm_manual_set_channel(0,0);  // H1 valve
vTaskDelay(pdMS_TO_TICKS(25));
pwm_manual_set_channel(0,50);  //
vTaskDelay(pdMS_TO_TICKS(25));
pwm_manual_set_channel(1,50);  //
vTaskDelay(pdMS_TO_TICKS(25));
pwm_manual_set_channel(2,50);  //
vTaskDelay(pdMS_TO_TICKS(25));
pwm_manual_set_channel(3,50);  //
```

← All 50% pwm duty cycle

- Wait 2.5 seconds

```
// wait 2.5 seconds
vTaskDelay(pdMS_TO_TICKS(100));
```

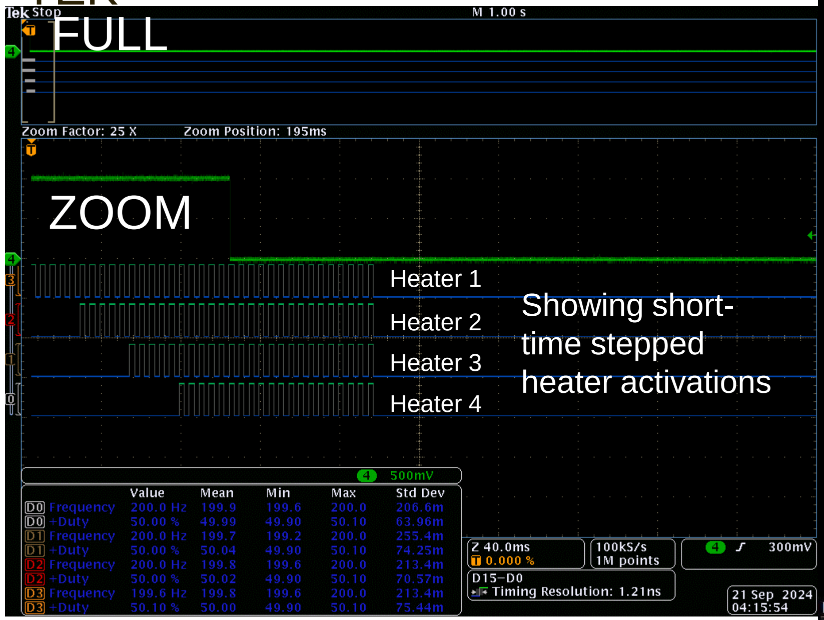
- Then turn off

```
// force all pwm's off
pwm_manual_set_channel(0,0);  // H1 valve
pwm_manual_set_channel(1,0);  // H2 amp0
pwm_manual_set_channel(2,0);  // H3 amp1
pwm_manual_set_channel(3,0);  // H4 amp2
```

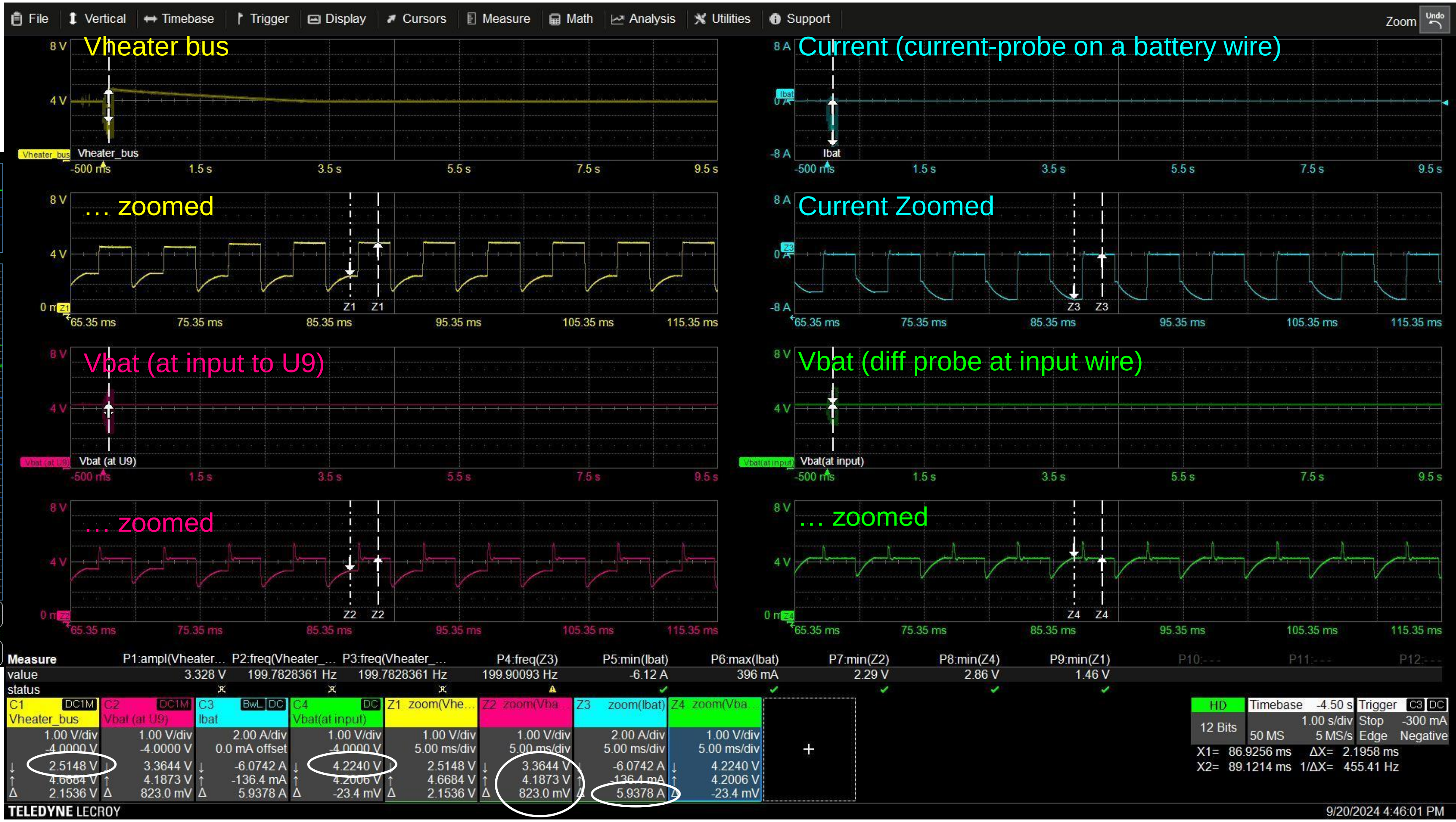
No temperature feedback/PID for this test

- Lecroy probing batt current, differential battery voltage input, Vheater bus, Vbat measured right at U9 input
- TEK MDO4054B-6 probing (w/logic probe) gate control signals, triggered from Lecroy trigger
- Keithly 2461 SMU Set to 7.35 A current limit, 4-wire voltage source to Vbat input wires

TEK



LECROY



VBAT = 4.2

20240920_154336_lcy.jpg

20240920_154336_tek.png

AUTOMATION HELPED TO CAPTURE THIS STUFF

Measurements compared between Pulse Off and Pulse On (all 4 heaters) , at the white cursors

GH+Labs

- Lecroy probing batt current, differential battery voltage input, Vheater bus, Vbat measured right at U9 input
- TEK MDO4054B-6 probing (w/logic probe) gate control signals, triggered from Lecroy trigger
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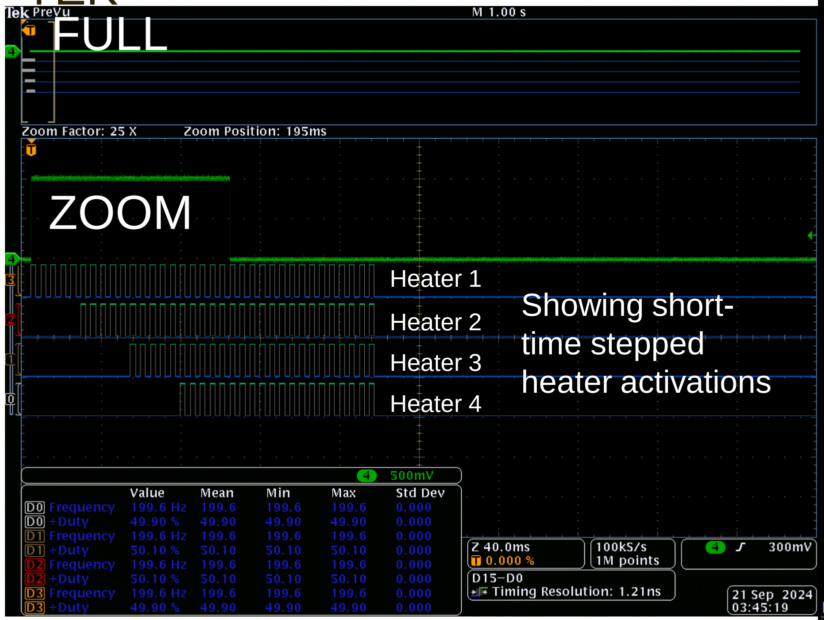
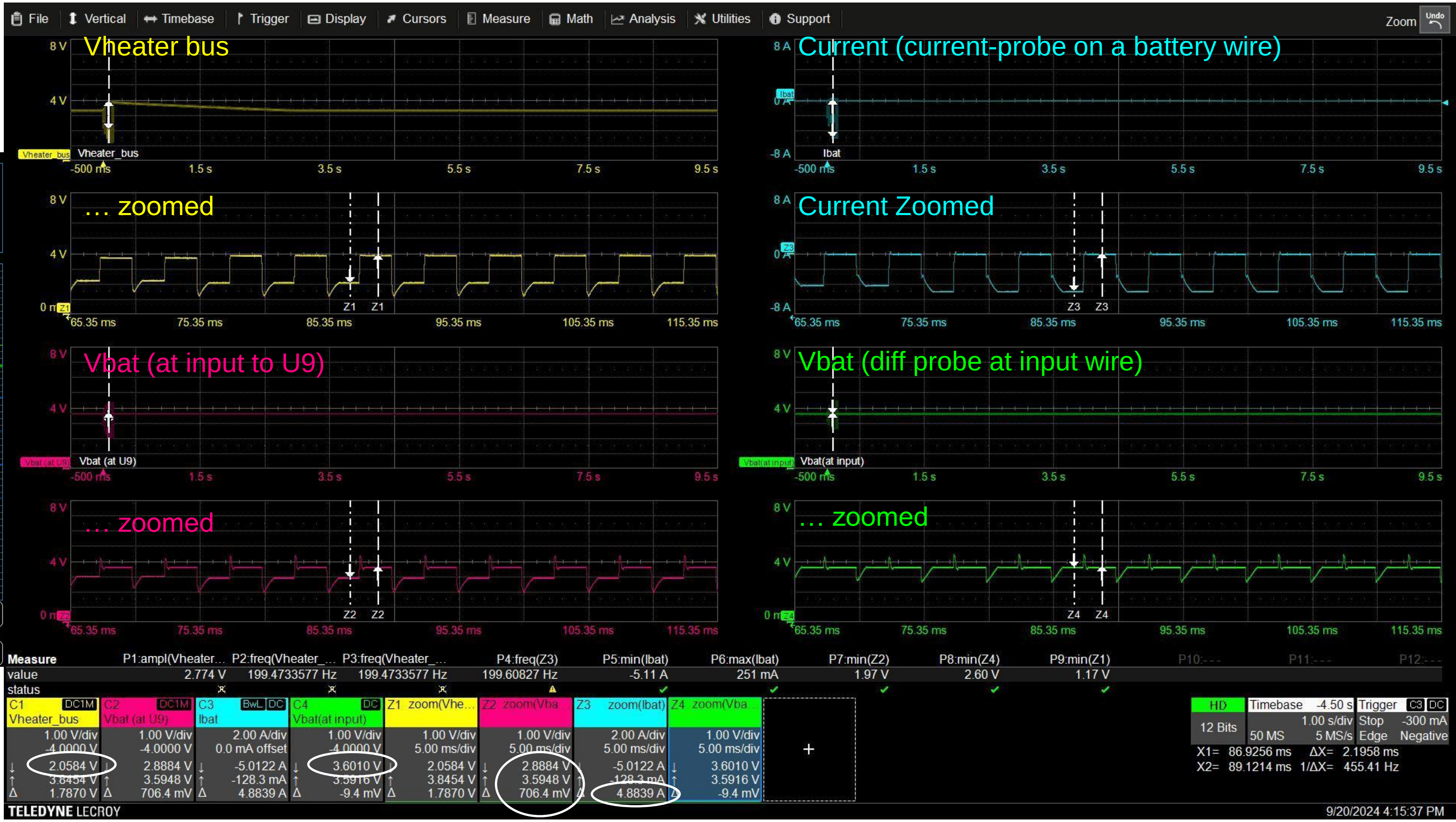
TEK



LECROY



VBAT = 3.6
20240920_151649_lcy.jpg
20240920_151649_tek.png

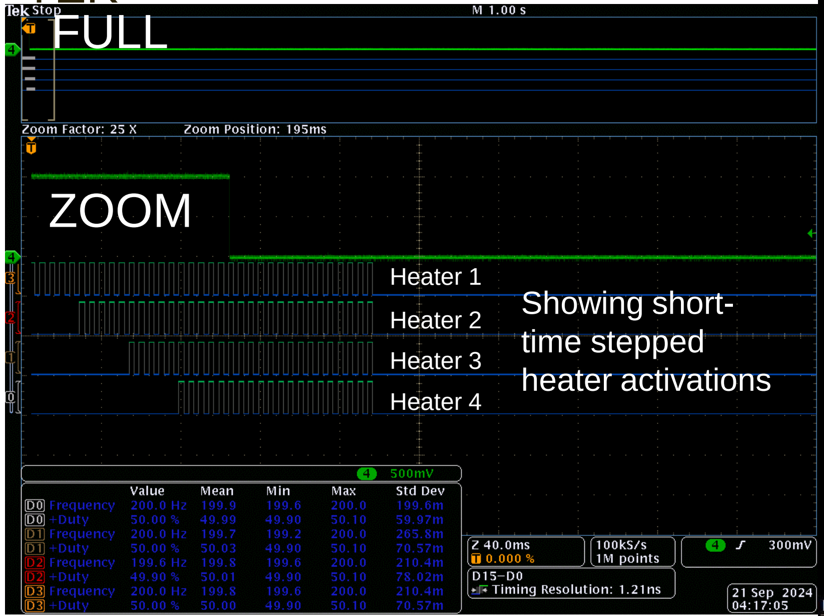
Measurements compared between Pulse Off and Pulse On (all 4 heaters) , at the white cursors

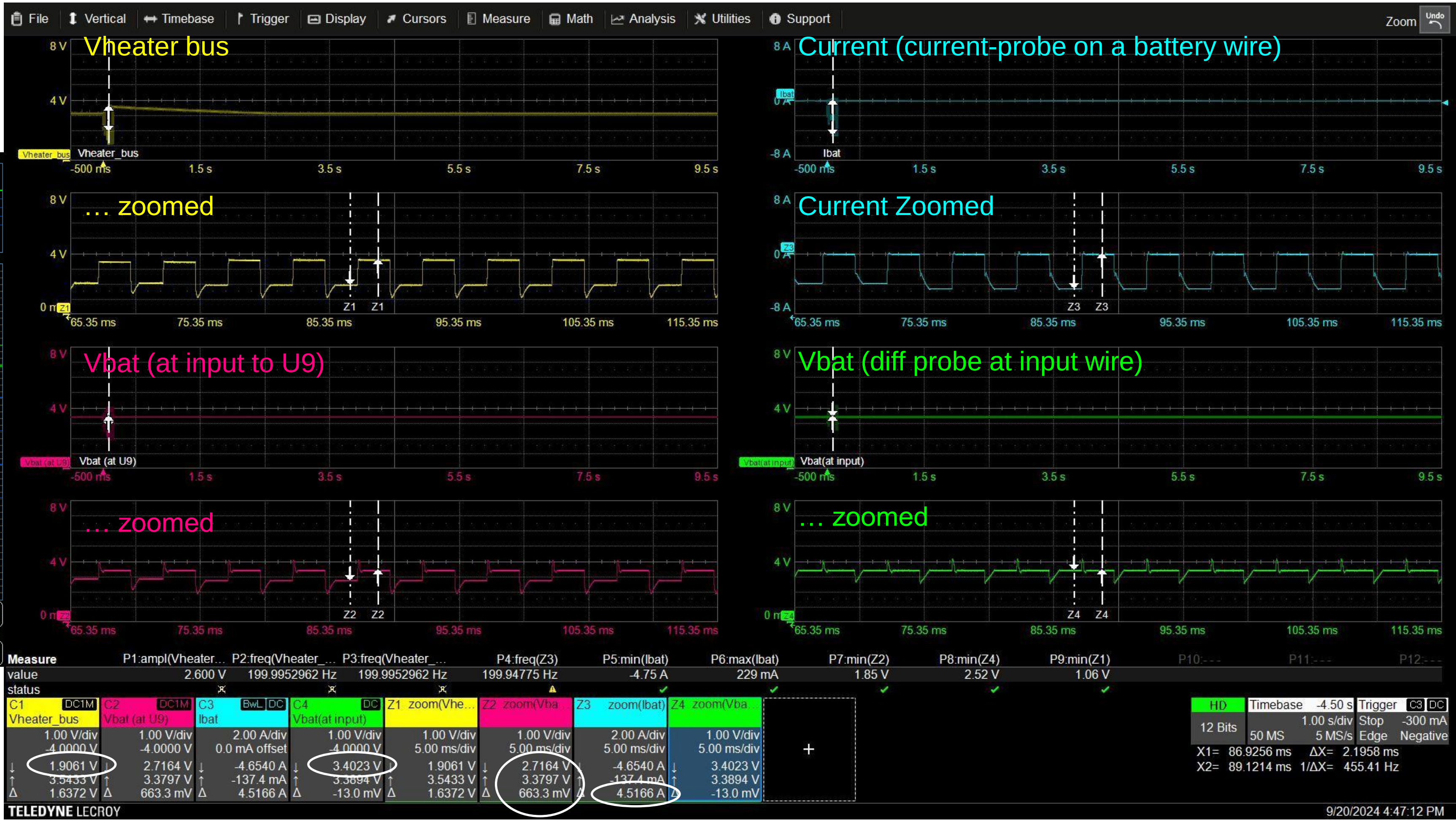
AUTOMATION HELPED TO CAPTURE THIS STUFF

- Lecroy probing batt current, differential battery voltage input, Vheater bus, Vbat measured right at U9 input
- TEK MDO4054B-6 probing (w/logic probe) gate control signals, triggered from Lecroy trigger
- Keithly 2461 SMU Set to 7.35 A current limit, 4-wire voltage source to Vbat input wires

LECROY

TEK





VBAT = 3.4

20240920_154447_lcy.jpg

20240920_154447_tek.png

AUTOMATION HELPED TO CAPTURE THIS STUFF

Measurements compared between Pulse Off and Pulse On (all 4 heaters) , at the white cursors

GH+Labs

- Lecroy probing batt current, differential battery voltage input, Vheater bus, Vbat measured right at U9 input
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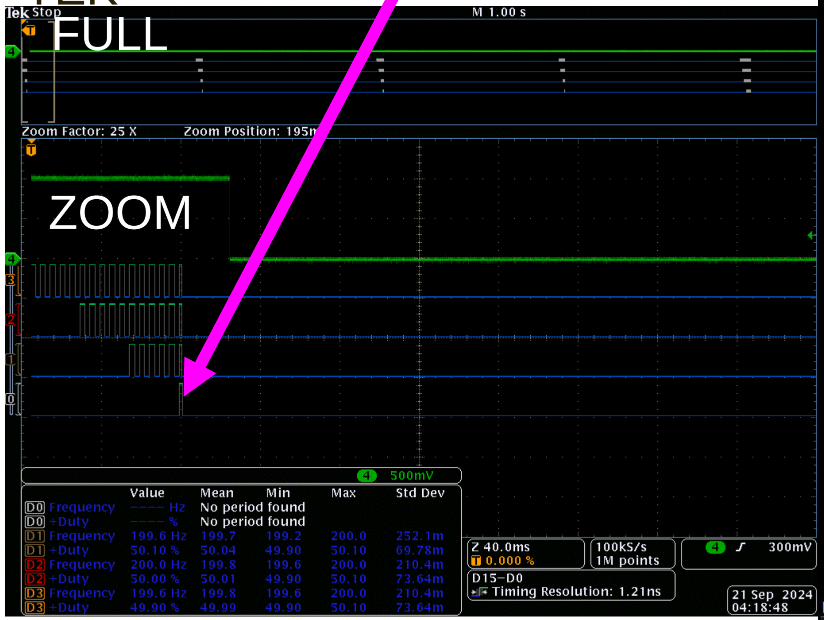
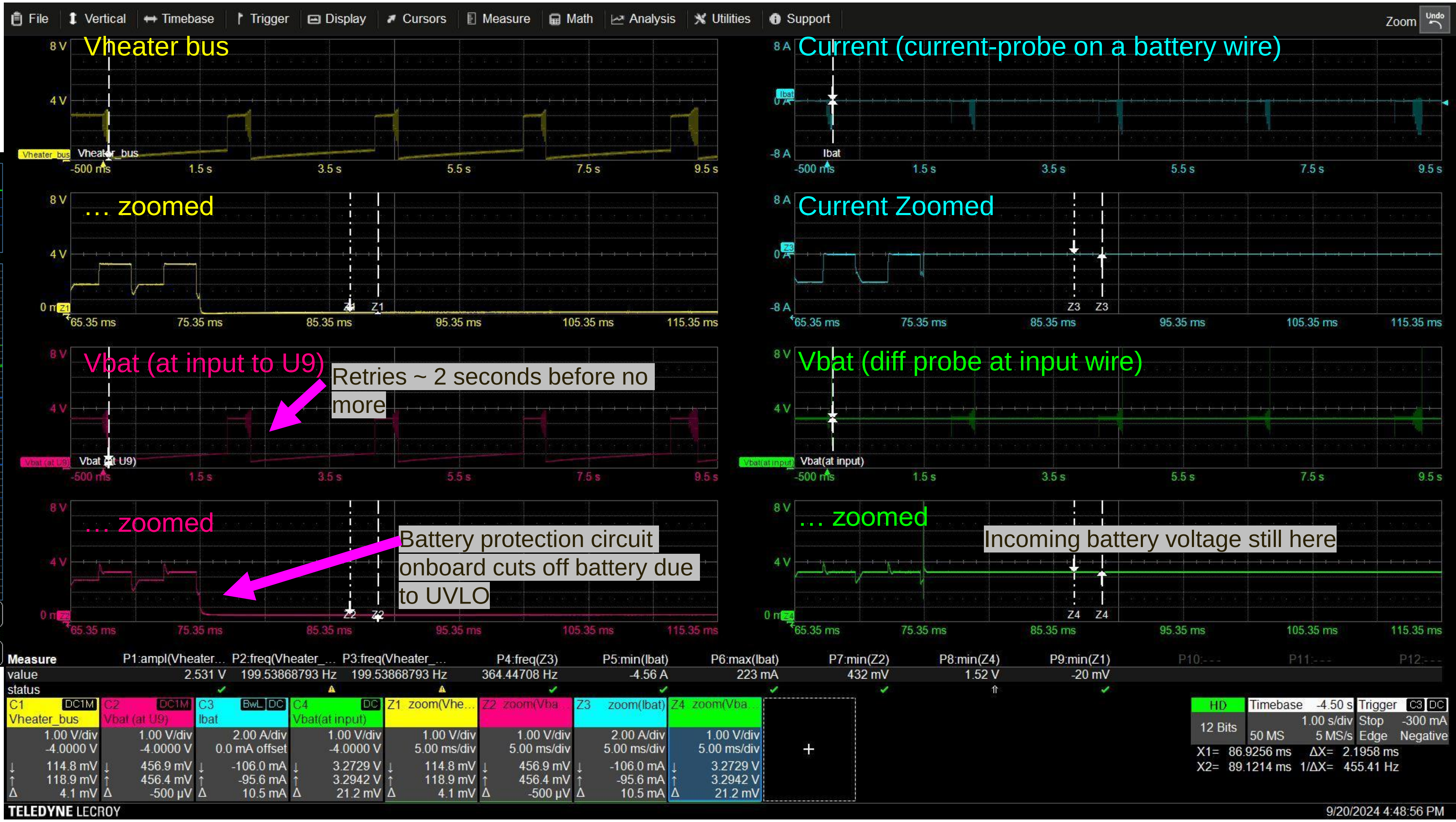
BROWNOUT OCCURS

TEK



LECROY



VBAT = 3.3

20240920_154361_lcy.jpg

20240920_154361_tek.png

AUTOMATION HELPED TO CAPTURE THIS STUFF

Measurements compared between Pulse Off and Pulse On (all 4 heaters) , at the white cursors

Data Table Extracted From Series Of Measurements At Various Battery Voltages Applied

Custom test fw
No usb connected

Capture File	Vbat (V)	Ibat Pk (A)	VbatAtU9 NoPulse (V)	VbatAtU9 4HeatPulse (V)	VbatAtU9 Vdrop (V)	VbatAtU9 PwrWaste (W)	Vheater NoPulse (V)	Vheater 4HeatPulse (V)	Vheater Vdrop (V)	EstVHeater PulsePwr Delivered (W)	EstVbat PulsePwr DrawnFromBattery (W)	Est Pwr Wasted (W)	Est Efficiency Of Heating	Brownout
20240920_154336_lcy.jpg	4.2	5.9378	4.1873	3.3644	0.8229	4.886	4.66	2.5148	2.1452	14.93	24.94	10.006	59.9%	
20240920_154239_lcy.jpg	4.1	5.8705	4.0867	3.2731	0.8136	4.776	4.5395	2.4398	2.0997	14.32	24.07	9.746	59.5%	
20240920_154122_lcy.jpg	4	5.573	3.9896	3.2029	0.7867	4.384	4.4117	2.3635	2.0482	13.17	22.29	9.120	59.1%	
20240920_154011_lcy.jpg	3.9	5.532	3.8833	3.1209	0.7624	4.218	4.2614	2.2852	1.9762	12.64	21.57	8.933	58.6%	
20240920_153830_lcy.jpg	3.8	5.362	3.785	3.0465	0.7385	3.960	4.127	2.1903	1.9367	11.74	20.38	8.631	57.6%	
20240920_153726_lcy.jpg	3.7	5.1789	3.6811	2.9655	0.7156	3.706	3.9874	2.1544	1.833	11.16	19.16	8.005	58.2%	
20240920_151649_lcy.jpg	3.6	5.0122	3.5948	2.8884	0.7064	3.541	3.8454	2.0584	1.787	10.32	18.04	7.727	57.2%	
20240920_153423_lcy.jpg	3.5	4.8431	3.4856	2.8048	0.6808	3.297	3.6987	1.9902	1.7085	9.64	16.95	7.312	56.9%	
20240920_154447_lcy.jpg	3.4	4.516	3.38	2.72	0.66	2.981	3.54	1.9061	1.6339	8.61	15.35	6.746	56.1%	
20240920_153547_lcy.jpg	3.4	4.6568	3.3896	2.7256	0.664	3.092	3.5574	1.9165	1.6409	8.92	15.83	6.908	56.4%	
20240920_154631_lcy.jpg	3.3	Brownout at 3.3V												TRUE

Significant voltage drops on Vbat (not due to the actual battery drops) which are measured during steady states of the pulses

Estimated power being delivered to the heaters during steady-on (but not accounting for losses from this point to the actual heater trace)

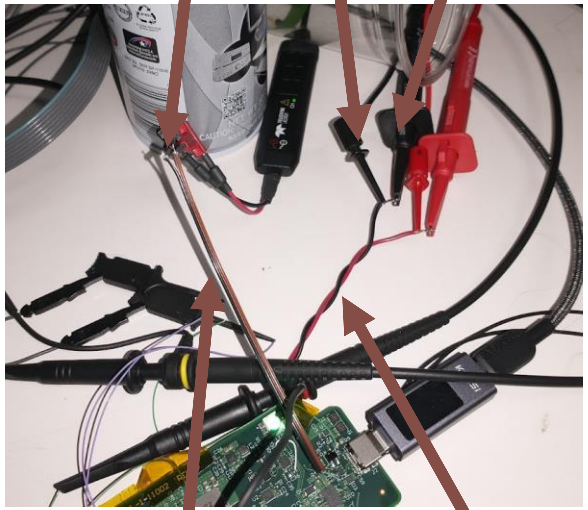
Wasted power during steady-on times

20240924_112233_lcy.png
Vbat = 3.6V

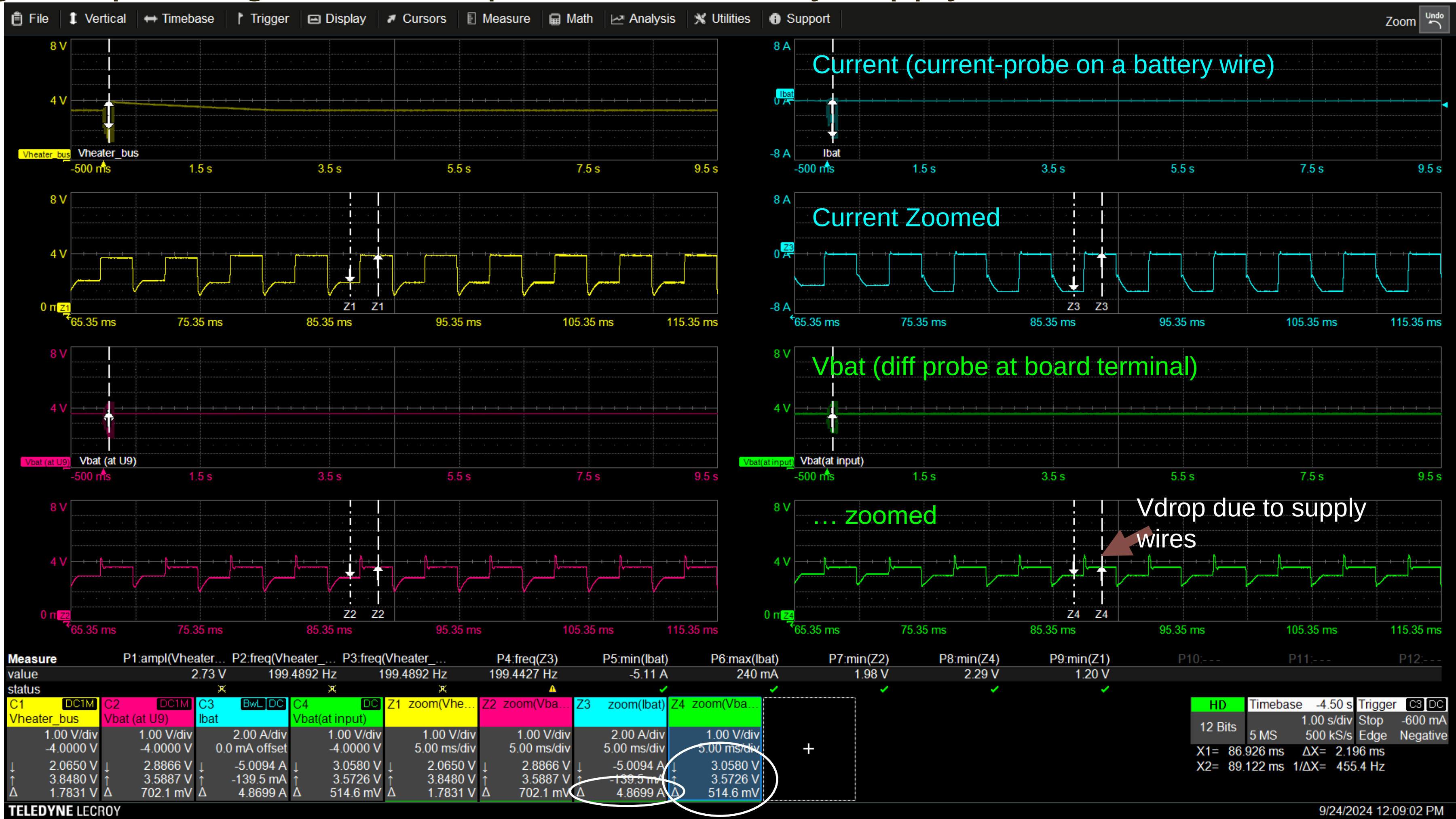
Effect of Wires

- Soldered non-current-carrying wires off of the Vbat input leads
- Probing Vbat shows voltage drop during current-on periods on battery supply wires

SMU Sense
SMU Force
LCY Diff Probe



Newly added
Supply wires



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20240924_113537_lcy.png
Vbat = 3.6V

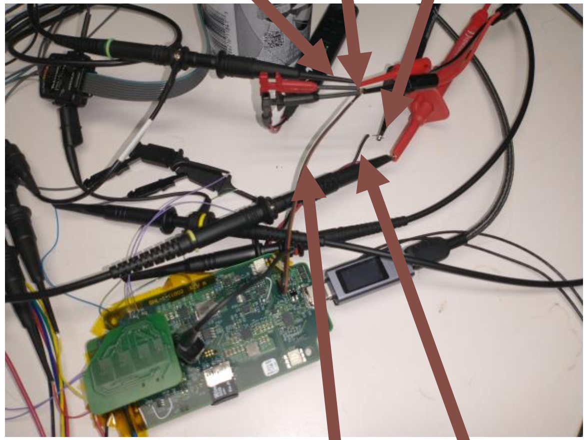
Effect of Wires

- Moving SMU sense wires to the non-current-carrying terminals…
- Eliminate the wire voltage drop going into the board (but spike increases)

SMU Sense

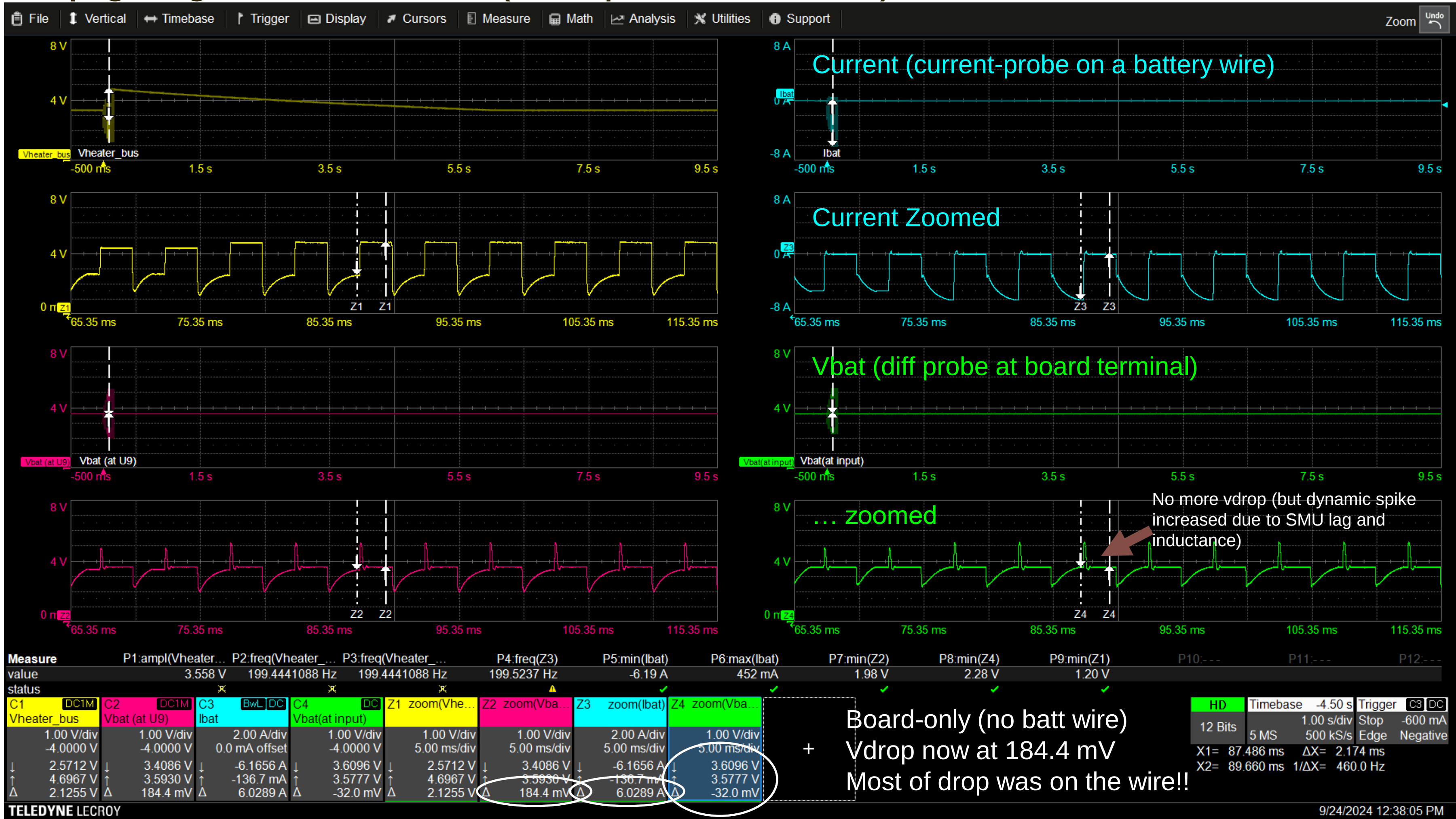
LCY Diff Probe

SMU Force



Newly added

Supply wires



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Data Table Extracted From Series Of Measurements At Various Battery Voltages Applied

Custom test fw
No usb connected

Capture File	Vbat (V)	Ibat Pk (A)	VbatAtU9 NoPulse (V)	VbatAtU9 4HeatPulse (V)	VbatAtU9 Vdrop (V)	VbatAtU9 PwrWaste (W)	Vheater NoPulse (V)	Vheater 4HeatPulse (V)	Vheater Vdrop (V)	EstVHeater PulsePwr Delivered (W)	EstVbat PulsePwr DrawnFromBattery (W)	Est Pwr Wasted (W)	Est Efficiency Of Heating	Brownout
20240924_114438	4	6.071423	3.957717	3.40873	0.548987	3.333	3.957717	3.40873	0.548987	20.70	24.29	3.590	85.2%	
20240924_114647	3.8	6.071423	3.788798	3.40873	0.380068	2.308	3.788798	3.40873	0.380068	20.70	23.07	2.376	89.7%	
20240924_113537	3.6	5.982138	3.577649	3.366501	0.211148	1.263	3.577649	3.366501	0.211148	20.14	21.54	1.397	93.5%	
20240924_114851	3.5	5.803566	3.45096	3.282041	0.168919	0.980	3.45096	3.282041	0.168919	19.05	20.31	1.265	93.8%	
20240924_115058	3.4	5.535709	3.366501	3.197582	0.168919	0.935	3.366501	3.197582	0.168919	17.70	18.82	1.121	94.0%	
20240924_130241	3.3	Brownout at 3.3V												TRUE

Voltage drops on Vbat AFTER the battery-entry wires

Dissipated on the board on it’s way to the boost converter

Estimated power being delivered to the heaters during steady-on (but not accounting for losses from this point to the actual heater trace)

Total wasted (board up to U9 + across U9)

BOOST ENABLE?

```
bool GHL_sg_test_boost = true;
bool GHL_sg_test_pwmA = true;


// initial wait
vTaskDelay(pdMS_TO_TICKS(100));
if(GHL_sg_test_boost) {
  nrf_gpio_pin_set(BOOST_CONTROL_ENABLE_PIN); // turn on boost for heaters
  vTaskDelay(pdMS_TO_TICKS(100));
}
if(GHL_sg_test_pwmA)  {
  //pwm_manual_set_channel(0,50);  // H1 valve
  //pwm_manual_set_channel(2,90);  // H4 amp2


  pwm_manual_set_channel(0,0);  // H1 valve
  vTaskDelay(pdMS_TO_TICKS(25));

  pwm_manual_set_channel(0,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(1,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(2,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(3,50);  //

  //pwm_manual_set_channel(2,50);  //
}


// wait 2.5 seconds
vTaskDelay(pdMS_TO_TICKS(100));


// cleanup
if(GHL_sg_test_boost) {
  nrf_gpio_pin_clear(BOOST_CONTROL_ENABLE_PIN); // turn off boost for heaters
}
if(GHL_sg_test_pwmA)  {
  // force all pwm's off
  pwm_manual_set_channel(0,0);  // H1 valve
  pwm_manual_set_channel(1,0);  // H2 amp0
  pwm_manual_set_channel(2,0);  // H3 amp1
  pwm_manual_set_channel(3,0);  // H4 amp2
}
```

Turn on Boost
Wait 100 ms

One At A Time Turn On Heater PWM (50%)
100 ms separation

Wait 100 ms (all 4 running)

Turn Off Boost

Turn Off Heater PWM’s

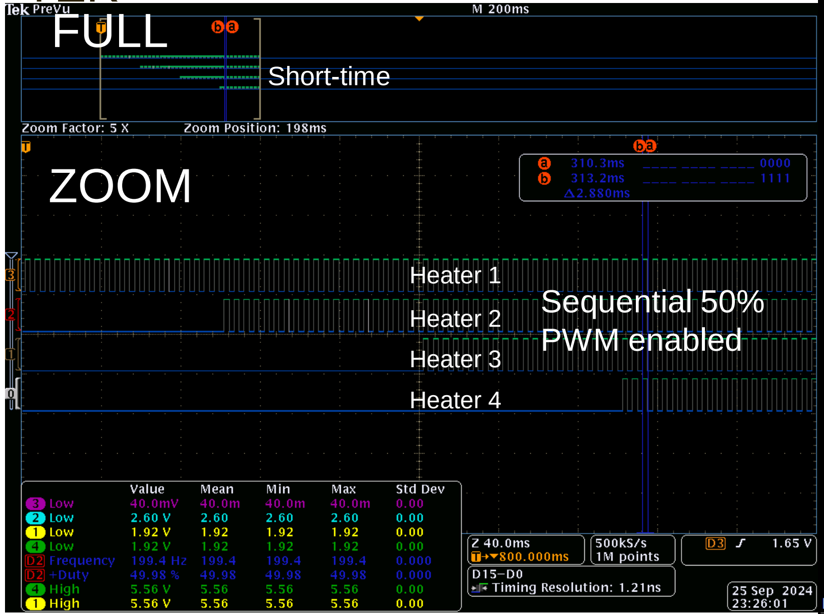
GH+Labs

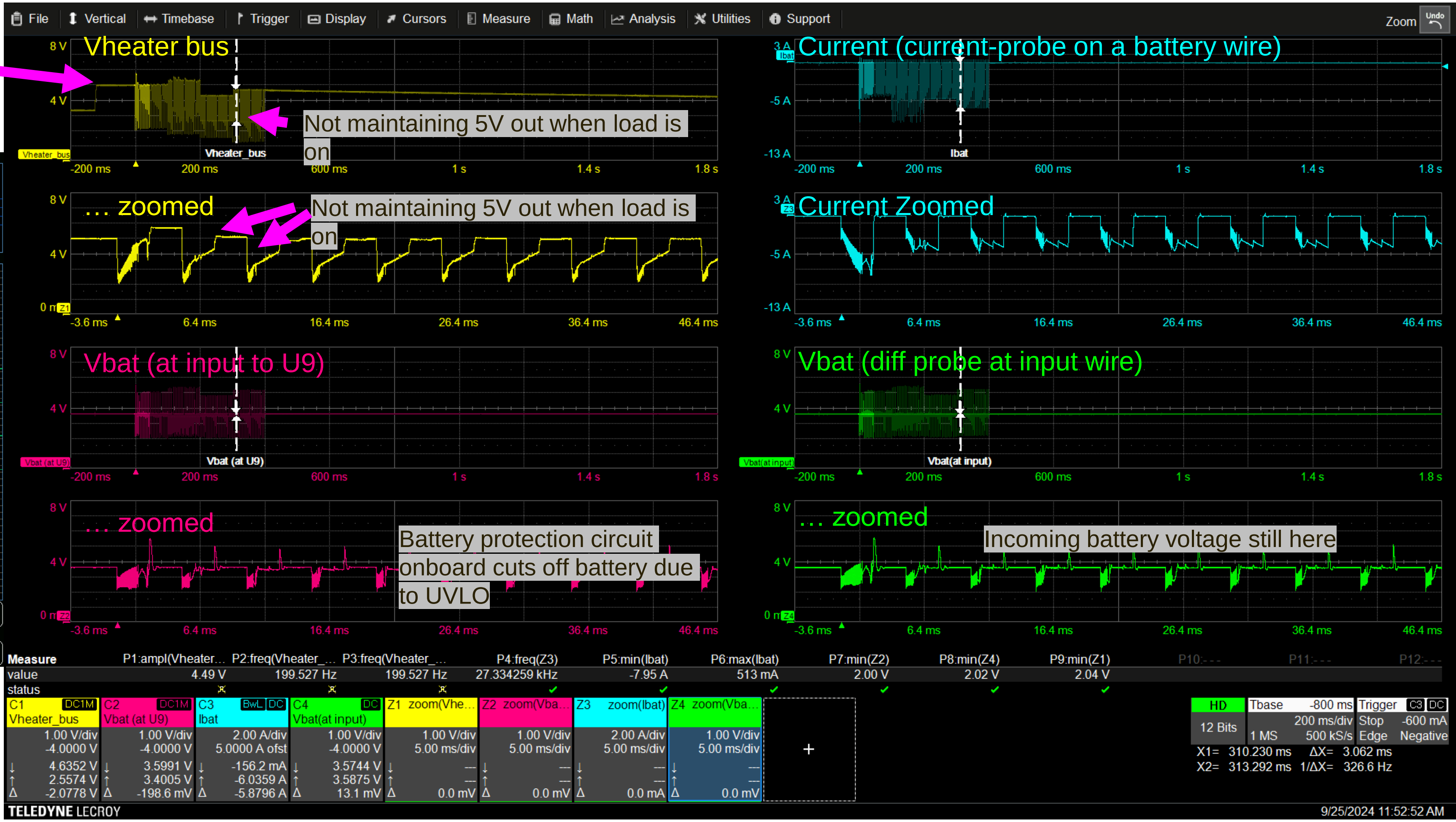
- Lecroy probing batt current, differential battery voltage input at connector, Vheater bus, Vbat measured right at U9 inp
- TEK MDO4054B-6 probing (w/logic probe) gate control signals, H2 legs, and Vheater bus and Vbat
- Keithly 2461 SMU Set to 7.35 A current limit, 4-wire voltage source to Vbat input wires

LECROY

Boost Converter Enabled
(goes to 5V)

TEK





VBAT = 3.6
20240925_105024_lcy.png
20240925_105024_tek2.png

Measurements compared between Pulse Off and Pulse On (all 4 heaters) , at the white cursors

AUTOMATION CAPTURED SCREENS + TRACE DATA

GH+Labs

BOOST ENABLE? – Single Heater Pattern

```
bool GHL_sg_test_boost = true;
bool GHL_sg_test_pwmA = true;


// initial wait
vTaskDelay(pdMS_TO_TICKS(100));
if(GHL_sg_test_boost) {
  nrf_gpio_pin_set(BOOST_CONTROL_ENABLE_PIN); // turn on boost for heaters
  vTaskDelay(pdMS_TO_TICKS(100));
}
if(GHL_sg_test_pwmA)  {
  //pwm_manual_set_channel(0,50);  // H1 valve
  //pwm_manual_set_channel(2,90);  // H4 amp2


  pwm_manual_set_channel(0,0);  // H1 valve
  vTaskDelay(pdMS_TO_TICKS(25));

  pwm_manual_set_channel(0,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(1,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(2,50);  //
  vTaskDelay(pdMS_TO_TICKS(100));
  pwm_manual_set_channel(3,50);  //

  //pwm_manual_set_channel(2,50);  //
}


// wait 2.5 seconds
vTaskDelay(pdMS_TO_TICKS(100));


// cleanup
if(GHL_sg_test_boost) {
  nrf_gpio_pin_clear(BOOST_CONTROL_ENABLE_PIN); // turn off boost for heaters
}
if(GHL_sg_test_pwmA)  {
  // force all pwm's off
  pwm_manual_set_channel(0,0);  // H1 valve
  pwm_manual_set_channel(1,0);  // H2 amp0
  pwm_manual_set_channel(2,0);  // H3 amp1
  pwm_manual_set_channel(3,0);  // H4 amp2
}
```

Turn on Boost
Wait 100 ms

One At A Time Turn On Heater PWM (50%)
100 ms separation

Wait 100 ms (all 4 running)

Turn Off Boost

Turn Off Heater PWM’s