

Electric Adjustable Smart Cup Base

ECE 445 Design Document – Fall 2026

Project # 41

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1 Introduction

1.1 Problem and solution

People can overlook drinking water while working or studying. Water supports normal body function [1], but a reminder timer does not establish whether water has left a bottle. Our reusable desk base accepts bottles of different diameters and estimates removed water from settled mass changes. A local display shows the removed-volume estimate, goal and reminder interval without a phone or cloud service.

We will build a desk base that estimates water removed from an existing bottle using four SC928NB half-bridge load cells, a custom HX711 interface, an ESP32-S3 controller, a local OLED and three buttons, and rechargeable power. The bottle lifts out of the base. Core acceptance depends on mass measurements and settling logic. A separate ADXL343 tilt feature is optional.

The controller, POWER and HX711 layouts have been submitted for the first PCB round. The HX711 requires the assembly changes in Section 2.4. Requirements describe the completed prototype; measured verification results will follow assembly.

The design combines a floating weighing platform, a friction-adjusted guide ring, four small half bridges, team-assembled analog and controller boards, and a rechargeable power PCB. The ring constrains lateral motion while the load cells carry the vertical load. Stable decreases accumulate; increases are classified as refills. A pour or spill also reduces mass, so the display says “REMOVED EST” rather than claiming confirmed consumption. The device is a convenience aid, not a medical instrument [2] – [4].

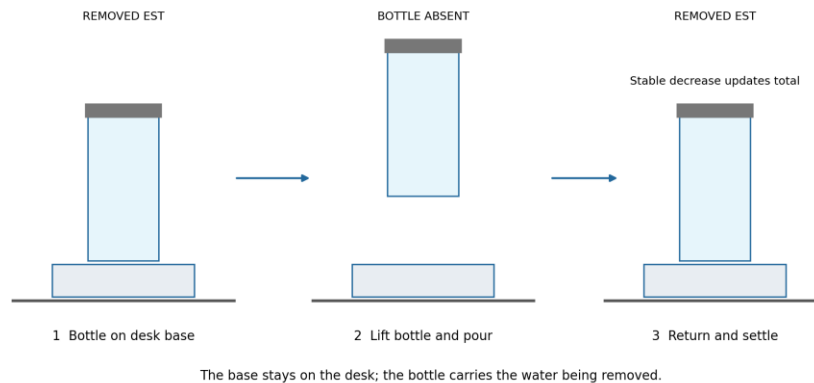


Figure 1. Intended desk use. Lift the bottle out, remove water, return it, and wait for a settled mass. The base remains on the desk.

1.2 High level requirements

- HL1. For bottle-plus-contents masses within the intended operating range of approximately 1–3 kg, the system shall estimate representative water-removal events between 50 and 300 mL with an absolute error no greater than ± 50 mL in at least 75% of verification trials.
- HL2. The system shall distinguish normal bottle handling from water-removal events, producing no false removal event in at least 80% of at least 20 representative unchanged-mass motion trials. For settled increases in bottle mass, at least 4 of 5 representative refill trials shall be classified as refills without increasing the accumulated removed-volume estimate.
- HL3. The battery-powered system shall operate continuously for at least 120 minutes without an unintended reset or loss of the accumulated removed volume total. After a valid stable event is accepted, the displayed result shall update within 3 s in at least 5 of 6 timing trials. Goal and reminder settings shall be adjustable through the three-button interface as verified in U1.

2 Design

2.1 Architecture and interfaces

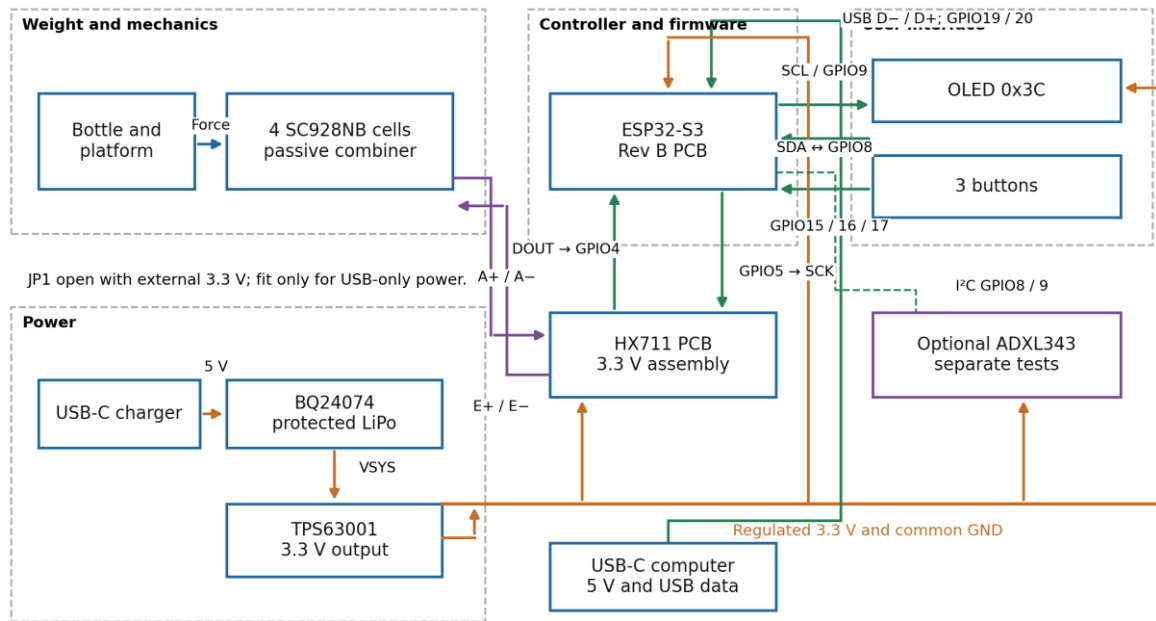


Figure 2. Modular architecture. Dashed boundaries group subsystems; orange paths distribute 3.3 V and common ground to every powered block. Blue is force, purple is bridge wiring, and green is digital control or data. The optional ADXL343 uses the same I²C bus and is excluded from HL1–HL3.

The four half bridges form one differential bridge through a passive combiner. The HX711 reads channel A at gain 128 and nominal 10 samples/s. The ESP32 stores successive settled masses, classifies their differences, updates the OLED and handles buttons. The BQ24074 charges a protected cell and supplies the TPS63001, which powers the electronics at 3.3 V [3]–[8].

Table 1. Defined board interfaces. ESP, POWER and HX prefixes distinguish references on separate boards.

Interface	Signal	Connection
POWER → ESP	3.3 V/GND	ESP J2 pin 2 = +3V3; pin 1 = GND. Strain-relieved output cable; JP1 open.
Bridge ↔ HX	E+/E− and A+/A−	E+ = analog 3.3 V; E− = GND; differential return to HX INA+/INA−.
HX ↔ ESP	3.3 V logic	HX K3: 1 SCK, 2 DOUT, 3 VCC, 4 GND. ESP GPIO5 drives SCK; GPIO4 reads DOUT.
OLED ↔ ESP	100 kHz I ² C	GPIO8 SDA; GPIO9 SCL; address 0x3C; 3.3 V supply. One effective pull-up pair to 3.3 V.
Buttons → ESP	Active-low GPIO	GPIO15/16/17; internal pull-ups; 30 ms debounce.
Computer ↔ ESP	USB 5 V and data	Native D−/D+ on GPIO19/20. Fit JP1 only for USB-only power with external 3.3 V disconnected.
ADXL ↔ ESP	Optional 100 kHz I ² C	GPIO8/9, address 0x53, 3.3 V/GND; separate carrier and tests.

2.2 Test conditions and measurement definitions

Core weighing tests use a bench within $\pm 2^\circ$ of level, 20–25 °C room temperature, and a bottle center within 25 mm of platform center. Tare the empty platform, calibrate with known masses, then store the bottle baseline separately. A reference balance

with ≤ 1 g resolution checks test masses; record its stated uncertainty. Nominal 100 g test masses must weigh 100 ± 2 g. No results have yet been collected.

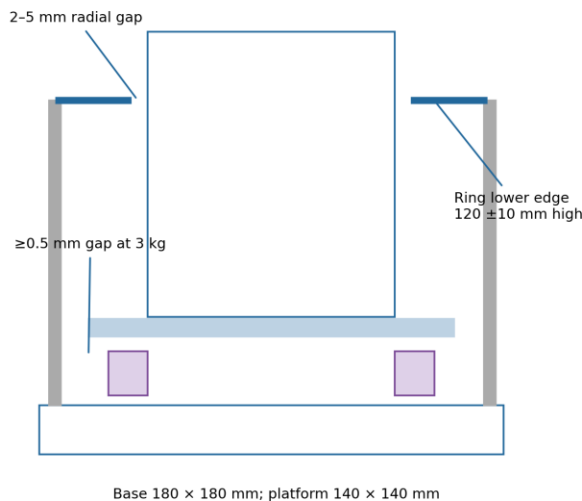
At 10 samples/s, apply a five-sample median filter. STABLE requires at least 40 valid filtered samples in a continuous 5 s window with maximum minus minimum ≤ 20 g; use the median of that window as its plateau mass. Invalid or saturated conversions restart the window. Differences below 30 g are ignored. A decrease of 30–350 g is removal; an increase of 30–350 g is refill. A magnitude above 350 g is flagged OUT OF RANGE and updates the baseline without accumulating removal. Each accepted plateau commits at most once. For water, firmware uses $1 \text{ g} \approx 1 \text{ mL}$; reference testing accounts for density [30].

2.3 Mechanical subsystem and bridge combiner

Inputs are bottle load and bridge excitation; outputs are force at the four cells and $A+/A-$ to the HX711. This subsystem supports HL1 and HL2 by preventing a parallel load path through the fixed frame. A 140×140 mm floating platform rests on four retained SC928NB seats at the corners of a 100×100 mm square inside a 180×180 mm base. Platform/base widths and seat spacing have ± 1 mm fabrication tolerance. The guide lower edge is 120 ± 10 mm above the platform.

Two C-shaped guides slide along the inner ring on close-fit tabs and retain their setting by friction. They accommodate 60–100 mm bottle diameters with 2–5 mm radial clearance; they do not clamp the bottle. The bottle lifts out vertically. If printed tabs cannot retain adjustment, friction-fit rods through the upper ring replace the adjustment mechanism. Final slide clearance is selected using a print-fit coupon and must pass M1. Sensor cradles retain the cell bodies without drilling or clamping their flexures [3].

Load path and clearance



Two sliding C-shaped guides

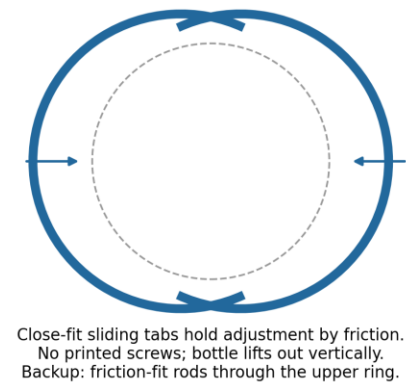


Figure 3. Dimensioned mechanical concept and the selected ring adjustment. The final cell-seat profile follows the delivered SC928NB drawing. The fixed frame is the printed chassis.

Table 2. Mechanical requirements and verification.

ID	Requirement	Verification and pass criterion
M1	Two demonstration bottles spanning 60–65 and 95–100 mm diameter shall fit with 2–5 mm radial clearance. A 0.2 mm strip shall pass vertically at four directions under 1 and 3 kg loads; adjustment shall not shift by >1 mm after ten lifts.	Measure diameter and four gaps using calipers. Test both bottles at 1 and 3 kg; all 16 strip checks must pass. Mark guide positions, lift each bottle ten times, and remeasure; pass both with ≤ 1 mm shift.
M2	At a 3 kg centered load, platform clearance from the fixed frame and stops shall be ≥ 0.5 mm at four sides. Each cell shall produce a positive calibrated response ≥ 20 g in at least two of three placements of 100 ± 2 g above its seat; $\geq 10/12$ placements shall pass overall.	Hold 3 kg for 60 s and check four gaps with a 0.5 mm gauge. Apply/remove the reference mass three times above each cell after settling; pass $\geq 10/12$ correctly signed responses ≥ 20 g, with at least two passes per cell.
M3	The combiner shall match Figure 4 with no short between E+ and E–, and shall produce a positive ≥ 30 g estimate for a central 50 ± 2 g step in $\geq 4/6$ trials without ADC saturation.	Unpowered DMM: identify all C/P/N leads, record both resistance halves and verify the four joined lead pairs. Check resistance E+–E– against the mapped bridge ($\pm 10\%$). Power through a current-limited supply; repeat the step six times and retain all records. No sample may equal ADC full-scale code.
M4	Base and platform widths and seat spacing shall match their stated dimensions within ± 1 mm; ring height shall be 120 ± 10 mm.	Measure both base/platform axes and adjacent cell-seat spacings with calipers; measure ring height from the platform with a ruler. Record each value; all must satisfy its tolerance.

Number cells 1–4 around the platform. C is each midpoint lead; P is the outer lead whose resistance to C increases under the intended load, and N is the decreasing-resistance lead. Identify these by measurement rather than wire color. Connect C1=E+, C3=E–, C4=A+, C2=A–; join P1–P2, N2–N3, P3–P4 and N4–N1. Each bridge leg contains two gauge elements. The combiner uses four three-wire solder-pad inputs and one four-wire solder-pad output with strain relief, so no detachable input connectors are required.

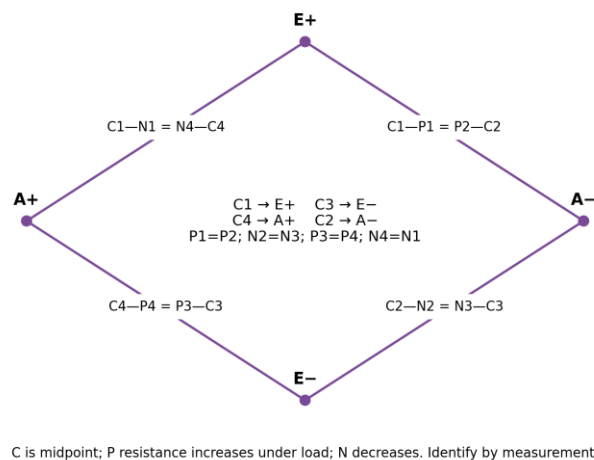


Figure 4. Exact combiner wiring. Each labelled branch contains two resistive elements; joined outer leads are shown by “=”.

2.4 HX711 analog subsystem

Inputs are regulated 3.3 V and bridge A+/A–; outputs are signed 24-bit DOUT samples clocked by PD_SCK. The bare SOP-16 HX711 and team-assembled board support HL1. RATE is grounded for nominal 10 samples/s. Firmware uses 25 clocks per conversion to select channel A at gain 128, keeps clock-high pulses within 1–10 μ s, and rejects codes 0x800000 and 0x7FFFFFFF as saturated [4].

The submitted HX711 layout is not yet the finished 3.3 V assembly. Its 20 k Ω /8.2 k Ω feedback divider requests approximately 4.30 V. We will use the external-supply configuration instead: omit Q1 and R3; jumper Q1 pads 2–3 while leaving pad 1 open; populate R4 and R5 with 0 Ω . This supplies VSUP, DVDD, AVDD and E+ from 3.3 V, grounds VFB, and leaves BASE open. Retain supply bypass capacitors. Figure 10 shows the first-round circuit and the explicit rework locations; the main system has one selected 3.3 V configuration [4], [10].

Table 3. Analog requirements and verification

ID	Requirement	Verification and pass criterion
H1	The controller shall receive ≥ 480 valid samples in 60 s at nominal 10 samples/s. Valid means DOUT-ready, a complete 24-bit read with 25 clocks, and a nonsaturated code.	Use a logic analyzer on DOUT/SCK and a timestamped serial log during a stationary load. Count samples, inspect pulse timing, and confirm no DOUT stall > 2 s. Pass ≥ 480 valid samples.
H2	At 1, 2 and 3 kg stationary loads, the filtered stream shall reach STABLE within 30 s in at least two of three placements at each load.	For each load, place the bottle or dry fixture centrally three times. Log filtered samples and first STABLE time. Pass $\geq 2/3$ per load using the defined 20 g/5 s criterion. Also report 30 s peak-to-peak noise as a diagnostic, without a separate accuracy claim.
H3	AVDD, DVDD and E+ shall be 3.1–3.5 V; both INA inputs shall lie between AGND+1.2 V and AVDD–1.3 V at gross loads of 1, 2 and 3 kg.	After unpowered rework continuity checks, measure supplies and INA+/INA– with a DMM at all three loads. Check DOUT/SCK with a scope; pass stated limits and no saturated plateau.

2.5 Controller subsystem

The ESP32-S3-WROOM-1-N16 module receives HX711 samples and button inputs, drives the OLED, and implements the event state machine for all three high-level requirements. The Rev B board provides native USB and exposed GPIO headers. Its USB-only supply uses LD1117, a 22 μ F ceramic output capacitor and C6 10 μ F tantalum. JP1 is a 0603 zero-ohm link, not a switch: fitted for USB-only operation; open when the external power PCB supplies 3.3 V. The two regulator outputs must never be paralleled. Figures 8–9 show the supplied schematic and layout [5], [11], [12].

Table 4. Controller requirements and verification.

ID	Requirement	Verification and pass criterion
C1	With JP1 fitted and external power absent, USB shall enumerate, flash/verify firmware and boot in three consecutive cold starts.	Use a data-capable C-to-C cable and laptop. Disconnect/reconnect three times; save enumeration, flash verification and boot messages. Pass all three.
C2	With JP1 open and USB power absent, external 3.3 V shall boot the controller three times without reset loops; after the initial power-on ramp, J2 pins 2/1 shall remain at 3.1–3.5 V.	Check the open link and polarity with an unpowered DMM. Use a current-limited source and scope the final harness during three boots; pass all three and the rail limits.
C3	GPIO4/5, GPIO8/9 and GPIO15/16/17 shall operate with all peripheral headers loaded; USB enumeration and flash from C1 shall still succeed.	Connect final HX711, OLED and buttons. Log ADC reads, an I ² C screen update, and one recognized press per button. In USB-only power mode, repeat one enumerate/flash/boot cycle with peripherals connected; pass every listed operation.

2.6 Subsystem

Inputs are USB 5 V and a protected Adafruit 2011 1S 2000 mAh LiPo; output is regulated 3.3 V to all loads. BQ24074 provides charging and power-path management; TPS63001 supplies 3.3 V through a 2.2 μ H SRN4018 inductor. R_{ISET}=2.21 k Ω sets nominal fast charge near 0.403 A, with the configuration checked against a 0.450 A limit. The power switch controls converter EN. A thermistor is electrically insulated and coupled to the battery pouch; the board-mounted thermistor position alone does not monitor pack temperature [6]–[8]. Figures 6–7 identify the charger, converter, battery socket and output connection.

The first-round POWER board has no dedicated output connector. We will attach a strain-relieved two-wire cable at the converter 3.3 V output node and ground return. Bring-up uses a bench source and electronic load before connecting the battery. USB charging and controller programming use separate ports; JP1 isolates the controller USB regulator in battery mode.

Table 5. Power requirements and verification.

ID	Requirement	Verification and pass criterion
P1	Across the expected battery-voltage range of approximately 3.3–4.1 V and representative system loads up to 500 mA, the converter shall maintain the 3.3 V rail between 3.1 and 3.5 V, with no more than 150 mV peak-to-peak ripple.	With the cell disconnected, use a current-limited bench supply to simulate battery inputs of 3.3, 3.7, and 4.1 V. At each input voltage, apply representative loads of 100 and 500 mA for at least 60 s. Measure the output voltage with a DMM and the peak-to-peak ripple with an oscilloscope using a short ground connection and a 20 MHz bandwidth limit. The rail shall remain within 3.1–3.5 V and ripple shall remain ≤ 150 mV for all tested conditions.
P2	The battery-powered assembly shall run ≥ 120 min without reset or loss of the total, with the system rail at 3.1–3.5 V.	After approved supervised charging, disconnect USB. Run OLED/HX711 continuously; record pack/rail voltage and total every 30 min. Remove a 100 ± 2 g dry mass at each checkpoint. Pass at 120 min with retained accepted events and no reset.
P3	Fast-charge current shall be ≤ 450 mA; charging shall be inhibited at thermistor equivalents of -5 and 55 °C, and enabled at 25 °C. Battery polarity shall match BAT/GND.	Before using a cell, connect a battery simulator and resistance decade box using the selected NTC curve. Test each temperature equivalent for 30 s; cold/hot current < 5 mA, 25 °C charging ≤ 450 mA. Check connector polarity with a DMM and record TA safety review.

2.7 Firmware and user interface

Firmware converts counts into grams with an empty-platform offset and a known-mass scale factor. It first ignores absent (< 200 g) and unsettled readings, then compares stable plateau medians. Removal adds to the displayed total and restarts the reminder timer; refill only updates the baseline. A subthreshold change does not update the stored baseline, allowing small changes to accumulate until they cross 30 g. Returning an unchanged bottle does not itself create an event. Figure 5 defines the core flow.

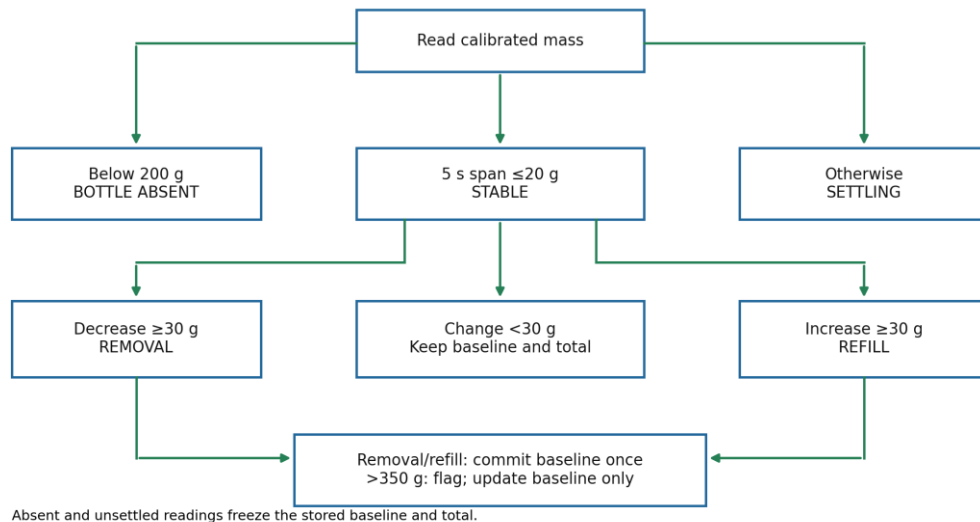


Figure 5. Core mass-based state flow. The first settled bottle establishes a baseline. Optional accelerometer readings do not participate in core acceptance.

Table 6. Integrated mass-event requirements and verification.

ID	Requirement	Verification and pass criterion
F1	Meet HL1: $\geq 18/24$ water-removal trials within ± 50 mL; $\geq 4/6$ at each size; each pass commits ≥ 30 mL.	At 20–25 °C, test 50, 100, 200 and 300 mL. For each size, run two trials at gross starts of 1.35 ± 0.03 , 2.00 ± 0.03 and 2.97 ± 0.03 kg, never exceeding 3.00 kg. Lift the bottle ≥ 50 mm, pour into a separately weighed cup, and return within 25 mm of center. Reference removal is grams/0.998, measured to ≤ 2 g uncertainty. Use the actual reference, targeted to 50–53, 97–103, 197–203 or 297–300 mL respectively. Final gross mass must stay ≥ 1.00 kg. Record reference, estimate, sign, error and settling time. A trial is considered successful if the system produces an estimate within the stated accuracy criterion after reaching a stable reading. Settling time shall be recorded for characterization. Retain all 24 outcomes.
F2	At least 80% of representative unchanged-mass motion trials shall produce no removal event, and at least 4 of 5 representative refill trials shall be classified as REFILL without increasing the accumulated removed-volume total.	At approximately 2 kg gross mass, perform 20 unchanged-mass motion trials, including bottle lifts and lateral repositioning representative of normal use. Return the bottle to the weighing platform and allow the system to settle after each trial. Record whether any removal event is committed; at least 16 of 20 trials shall produce no false removal event. Then perform five settled mass-addition trials of approximately 100 g; at least 4 of 5 shall be classified as REFILL without increasing the removed-volume total.
F3	A valid accepted removal event shall update the displayed total within 3 s of STABLE in at least 5 of 6 trials, without duplicate accumulation.	Perform six representative removal events of approximately 100 mL. Record the STABLE timestamp and the first corresponding OLED update using serial logs and synchronized video. At least 5 of 6 trials shall update within 3 s, and no passing trial shall increase the total more than once for the same stable event.
F4	The 1.00 and 3.00 kg operating boundaries shall accept at least two of three ≥ 30 mL removal events each for 50 ± 2 g steps.	Run three $1.05 \rightarrow 1.00$ kg and three $3.00 \rightarrow 2.95$ kg dry-mass steps, using a reference balance. Require settling ≤ 30 s and $ \text{estimate} - \text{reference} \leq 50$ g for $\geq 2/3$ at each boundary. These are additional boundary checks, outside F1's 24 water trials.
F5	Absent readings shall freeze the total and baseline; changes smaller than the configured event threshold shall not be committed as removal events. Changes within the valid operating range shall be classified according to sign, while changes substantially outside the expected removal range shall be flagged without accumulating into the removed volume total. Reset requires a 2 s button, hold then confirmation; reminder persists until acknowledged.	Replay independent episodes initialized at a 2 kg baseline for 150 g absent, stable 29/31/–31/–349/–351 g changes, and duplicate plateaus. Require expected state/total for every case. Test reset hold 1 s (no reset), hold 2.1 s + button 3 (reset), and a reminder held 60 s before acknowledgment. Also inject a 10 ms button pulse (ignored) and a 50 ms pulse (one action) to verify 30 ms debounce. These logic tests supplement physical trials. The initial firmware configuration will use a nominal 30 g event threshold and a nominal 350 g upper bound. Boundary tests will be performed immediately below and above the configured thresholds.

Three buttons select a 1000–4000 mL goal in 200 mL steps and a 10–120 min reminder interval in 10 min steps. Button 1 enters/selects the menu; buttons 2 and 3 increase/decrease. A 2 s button-1 hold requests total reset, confirmed by button 3. All buttons use 30 ms debounce. The persistent visual reminder is sufficient; there is no required buzzer, wireless link or activity classifier [14].

Table 7. U1 is core; A1 and A2 are optional and excluded from HL1–HL3.

ID	Requirement	Verification and pass criterion
U1	The display should clearly present the removed-volume estimate, selected goal, and reminder interval under typical indoor viewing conditions at approximately 0.5 m. Users shall correctly identify at least 80% of displayed information, and each control shall respond correctly to at least 90% of deliberate button presses. The interface shall allow the goal and reminder interval to reach their specified minimum and maximum settings.	Test the display at approximately 0.5 m under typical indoor illumination of roughly 300–700 lux. Each teammate shall read the total, goal, and reminder interval in three representative screen states, for 18 combined field readings; at least 15 of 18 shall be correct. Test each button with 10 deliberate presses separated by at least 0.5 s; at least 9 of 10 presses per button shall be recognized correctly. Verify the minimum, an intermediate value, and the maximum setting for both goal and reminder interval. Configure a 10 min reminder and verify that it appears within ± 2 min of the expected time.
A1	A separate ADXL343 carrier shall return device ID 0xE5 at address 0x53 while the OLED remains accessible at 0x3C.	Use an I ² C scanner and device-ID read on GPIO8/9 at 100 kHz; require both addresses, expected ID and a screen update. Failure does not fail HL1–HL3.
A2	Tilt $\geq 20^\circ$ for 2 s shall raise a tilt indication; after return within 5° of level, indication shall clear within 10 s in $\geq 5/6$ cycles.	Use a $0^\circ/10^\circ/25^\circ$ jig and six $0 \rightarrow 25 \rightarrow 0^\circ$ cycles held ≥ 5 s at each position. Require indication within 3 s at 25° and clearing within 10 s of level for $\geq 5/6$. A 10° hold must not trigger. Test tilt separately from water removal.

The optional bare Analog Devices ADXL343BCCZ-RL uses a team-made carrier with CS=3.3 V, ALT ADDRESS=GND, local $1 \mu V / 0.1 \mu F$ bypassing and the shared I²C bus. Static tilt is $\theta = \text{atan2}(\sqrt{a_x^2 + a_y^2}, a_z)$ with z normal to the base. This is a later orientation enhancement, excluded from the core success criteria [15].

2.8 Tolerance analysis

The most demanding function is detecting a 50 g change while carrying a 1–3 kg bottle. We use the lower published SC928NB sensitivity of 0.60 mV/V and a conservative 20 kg aggregate reference (four 5 kg cells). The supplier’s sensitivity convention for the assembled bridge must be confirmed by calibration; the half-sensitivity case is included below [3].

$$\Delta V_{out} = S V_{exc} \left(\frac{\Delta m}{M_{FS}} \right) = 0.00060 \times 3.0 \times \left(\frac{0.050}{20} \right) = 4.5 \mu V \quad (2-1)$$

where S is the rated bridge sensitivity in V/V , V_{exc} is the bridge excitation voltage, Δm is the applied mass change, and M_{FS} is the assumed full-scale reference mass of the load-cell assembly. The 3.0 V calculation is conservative relative to the required ≥ 3.1 V assembled excitation. If effective sensitivity is half the assumed value, the 50 g signal is $2.25 \mu V$. HX711 differential full scale at AVDD=3.0 V and gain 128 is ± 11.72 mV; even a conservative 3 kg load signal plus published zero offset remains well inside it [3], [4].

$$V_{FS} = \pm \frac{0.5 V_{AVDD}}{G} = \pm 0.5 \times \frac{3.0}{128} = \pm 11.72 \text{ mV} \quad (2-2)$$

HX711 typical input noise at 10 samples/s is 50 nV RMS. Using 0.50 μV rms as an unmeasured assembled-noise scenario gives single-sample SNR=9 (or 4.5 at half sensitivity). Forty independent samples would give 0.079 μV rms, equivalent to 0.88 g or 1.76 g; two independent plateau averages differ by approximately 1.24 g or 2.49 g RMS. This is a mean-based analytical comparison, not a claim about the actual median filter or correlated mechanical noise [4].

Table 8. Provisional error allocation. Values are allowances, not measurements or additional acceptance requirements.

Source	Model allowance	At 50 g	At 300 g
Gain/calibration	2% of step	1.0	6.0

Source	Model allowance	At 50 g	At 300 g
Reference mass	2 g	2.0	2.0
Placement/load-path change	15 g	15.0	15.0
Plateau noise/repeatability	12 g	12.0	12.0
Short-term drift/creep	8 g	8.0	8.0
1 g/mL approximation	0.2% of step	0.1	0.6
Worst-case linear sum	Design allocation	38.1	43.6

Both sums fit the ± 50 g accuracy target. The 50 g event has only 20 g margin above the 30 g threshold, so the worst-case allocation does not guarantee every smallest event is detected. As a numerical feasibility check, 100,000 synthetic trials per size with independent uniform placement ± 15 g, noise ± 12 g and drift ± 8 g, uniform gain $\pm 2\%$, reference ± 2 g and density $\pm 0.2\%$ predict the pass fractions below. This assumes distributions, does not replace measured data, and is consistent with requiring four of six successes per size rather than every trial.

Table 9. Synthetic pass probability under the stated allocation model.

True step g	Predicted successful event
50	95.0%
100	100.0%
200	100.0%
300	100.0%

The classifier accepts candidate removal/refill changes up to 350 g, providing a 50 g guard band around the largest required reference step. Above 350 g it flags OUT OF RANGE without accumulating. With that guard band, the stated synthetic model predicts approximately 95% success at 50 g and 100% at the other sizes. These predictions only demonstrate feasibility under the assumed allocation. F1 establishes compliance; stationary noise, placement and 3 min drift logs will replace the assumptions.

2.9 Risk analysis and procurement contingencies

The hardest requirement is HL2: returning a bottle at a different position can change the measured load path. We address this with ring clearance, repeatable seating, filtered plateau comparison and the 30 g deadband; M1/M2 and F2 isolate mechanical and event-classification behavior. Noise or drift that prevents stable plateaus is investigated with raw-count logs before changing calibration. A rail or communication failure is isolated through P1, C1 and H1 before integration.

Table 10. Main choices and conditional replacements. Only one configuration is operated at a time.

Main choice	Trigger and date	Replacement and reason
Four SC928NB 5 kg half bridges	Submit supplier order by Oct 5; obtain committed arrival by Oct 12; delivery go/no-go Oct 16.	First use the same SC928NB 3 kg version if it can arrive by Oct 23. Capacity is per cell; system range stays 1–3 kg. Recalibrate.

Main choice	Trigger and date	Replacement and reason
SC928NB shipment from China	Neither capacity can arrive by Oct 23.	Activate the Amazon two-bar full-bridge set [9] on Oct 16 after checking seller rating, drawing, excitation and ETA. Shipping delay is the trigger. Replace the entire mount/combiner with two bars and two custom HX711 channels; sum calibrated masses and repeat core tests. No supplied HX711 breakout is used.
UCTRONICS U602602 OLED	No confirmed delivery by Oct 16.	Use Adafruit 326 SSD1306 OLED after checking 3.3 V pinout/address. Same user interface and tests.
Two sliding C guides	Print coupon cannot hold setting or pass M1.	Friction-fit rods through the upper ring; preserve clearance and repeat M1.

3 Cost and schedule

3.1 Parts and fabrication

Table 11 is one completed main prototype, including the corrected HX711 population and combiner. Dollar amounts are planning estimates from the reconciled purchasing list [17], not checkout quotations. Course-stock parts have \$0 team expenditure; listed MPNs specify compatible equivalents to confirm against supplied stock. Optional ADXL343 and contingent replacements are excluded. No machine-shop work is planned (0 quoted hours); printed seats and guides use course printing [16], [18]. Lab instruments are borrowed at \$0 incremental cost. Reference prefixes identify the board.

Table 11. Main prototype bill of materials. Linked source names open the purchasing or stock route.

Reference	Manufacturer and part specification	Qty	Line cost	Source
ESP U2	Espressif ESP32-S3-WROOM-1-N16	1	\$0.00	ECE Shop
ESP U3	ST LD1117S33CTR / E-Shop LD1117-3.3, SOT-223	1	\$0.00	ECE Shop
ESP J1	HRO TYPE-C-31-M-12, 12-pin USB-C	1	\$0.90	Keebio
ESP SW1,SW2	XUNPU TS-1088-AR02016, 4 × 3 mm tactile	2	\$0.16	LCSC
ESP R1,2,4–6	Yageo RC0603FR-075K1P, 5.1 kΩ 0603	5	\$0.20	DigiKey
ESP R3; JP1	Yageo RC0603FR-0710KL 10 kΩ; RC0603JR-070RL 0 Ω, 0603	2	\$0.00	ECE Shop
ESP C1,C4	Samsung CL10A106MQ8NNNC 10 μF 6.3 V X5R 0603	2	\$0.00	ECE Shop
ESP C2	Samsung CL10A226MQ8NRNC 22 μF 0603	1	\$0.40	DigiKey
ESP C3,C5	KEMET C0603C104K4RACTU 0.1 μF; Samsung CL10B105KA8NNNC 1 μF, 0603	2	\$0.00	ECE Shop
ESP C6	KYOCERA AVX TACR106K010RTA 10 μF 10 V 0805 tantalum	1	\$2.30	DigiKey
ESP D1–D3	Lite-On LTST-C190EKT/GKT/TBKT red/green/blue 0603	3	\$0.00	Self service
ESP J2,J3	Samtec TSW-120-07-G-S equivalent 1×20 2.54 mm male	2	\$0.00	Self service
POWER U1	TI BQ24074RGTR, 16-pin charger/power path	1	\$2.80	DigiKey
POWER U3	TI TPS63001DRCR 3.3 V buck-boost	1	\$2.60	DigiKey
POWER L1	Bourns SRN4018-2R2M, 2.2 μH	1	\$0.85	DigiKey
POWER F2	Bourns MF-MSMF050-2, 1812 resettable fuse	1	\$0.45	DigiKey
POWER SW2	C&K JS102011SAQN slide switch	1	\$0.80	DigiKey
POWER J1	GCT USB4105-GF-A-060 USB-C charge receptacle	1	\$0.00	ECE Shop
POWER J2	JST B2B-PH-K-S vertical 2-pin battery connector	1	\$0.30	DigiKey

Reference	Manufacturer and part specification	Qty	Line cost	Source
POWER R1,R2,R8,R10	Yageo RC0805FR-075K1L ×2; RC0805FR-071K1L; RC0805FR-07100KL	4	\$0.00	ECE Shop
POWER R3	Yageo RC0805FR-072K21L, 2.21 kΩ	1	\$0.04	DigiKey
POWER R4,R5	Yageo RC0805FR-073K16L, 3.16 kΩ	2	\$0.08	DigiKey
POWER R6	Yageo RC0805FR-07100RL, 100 Ω	1	\$0.04	DigiKey
POWER R7	Yageo RC0805FR-0749K9L, 49.9 kΩ	1	\$0.04	DigiKey
POWER C1,C3–5,C10–11	Samsung CL21A106KPFNNNE 10 μF 10 V X5R 0805	6	\$0.00	ECE Shop
POWER C2,C9; D1	KEMET C0603C104K4RACTU ×2; Lite-On LTST-C170GKT LED	3	\$0.00	ECE Shop
POWER TH1	TDK B57861S0103F040 10 kΩ NTC; remote insulated pack attachment	1	\$0.65	DigiKey; validate TS curve
POWER BATT	Adafruit Product 2011 protected 1S 2000 mAh LiPo	1	\$12.50	Adafruit
HX U1	Avia HX711 SOP-16 bare IC, LCSC C43656	1	\$0.85	LCSC
HX R1,R2	Yageo RC0603FR-07100RL, 100 Ω	2	\$0.08	DigiKey
HX R4	Yageo RC0603JR-070RL, 0 Ω 0603 (VFB ground)	1	\$0.00	Course stock
HX R5	Yageo RC0603JR-070RL, 0 Ω 0603 (excitation link)	1	\$0.00	Course stock
HX C1,C3–5; C2,C6	KEMET C0603C104K4RACTU ×4; Samsung CL31A106KAHNNNE 10 μF 1206 ×2	6	\$0.00	ECE Shop
HX K1–K3	Samtec TSW-105/102/104-07-G-S equivalent 2.54 mm male	3	\$0.00	Self service
MECH 4 cells	Sensor and Control SC928NB four-cell 5 kg set	1	\$18.00	Supplier
PCB ESP	Team 41 controller board 29 ×51.9 mm	1	\$8.00	Course PCB service
PCB POWER	Team 41 power board 80 ×50 mm	1	\$10.00	Course PCB service
PCB HX	Team 41 HX711 board approximately 22 ×22 mm	1	\$6.00	Course PCB service
PCB BRIDGE	Team 41 passive combiner, 4×3 + 1×4 solder pads	1	\$6.00	Course PCB service
MECH print	PLA filament for base, platform, guides and retained seats	1 lot	\$4.00	Course printing
HARNESS	22–26 AWG insulated wire, heat-shrink and strain relief	1 lot	\$3.00	Course stock
MECH fit	Friction-fit tabs/rod material and insulating mounts	1 lot	\$3.00	Course printing/stock
UI OLED	UCTRONICS U602602, SSD1306 128 × 64 I ² C	1	\$9.00	Amazon
UI UI×3	TE Connectivity 1825910-6 normally-open tactile switches for the separate user interface	3	\$0.00	Self service
BUS RPU1/RPU2	Yageo RC0603FR-074K7L 4.7 kΩ pull-ups to 3.3 V; fit only if OLED lacks them	2	\$0.00	Course stock

Main parts and fabrication total: \$93.04. Shipping allowance: \$15.00. Tax allowance: 8% of parts = \$7.44. Estimated cash expenditure: \$115.48. The Q1 pad jumper uses harness wire. The optional carrier adds approximately \$8.50 (ADXL343 \$3.50 and PCB \$5.00; stock passives/header \$0). If activated, the two-bar contingency adds one HX711 channel and revised mount costs, priced before purchase; it is not added to the main configuration.

3.2 Labor

We estimate 160 hours per teammate: design/documentation 40 h, fabrication/assembly 35 h, firmware/integration 45 h, and verification/reporting 40 h. A planning wage of \$45/h corresponds to \$93,600/year at 2080 h/year; it is an assumed entry-level engineering rate, not student wages. The course requires the 2.5 overhead multiplier [20].

Table 12. Equal estimated labor and total project cost.

Item	Calculation	Total
Lawrence Cheng	$160 \text{ h} \times \$45/\text{h} \times 2.5$	\$18,000.00
Shengyuan Wang	$160 \text{ h} \times \$45/\text{h} \times 2.5$	\$18,000.00
Combined labor	$320 \text{ h} \times \$45/\text{h} \times 2.5$	\$36,000.00
Grand total	Labor + main parts + shipping + tax	\$36,115.48

3.3 Schedule

Table 13 assigns one primary deliverable to each teammate per week. The first-round controller/POWER/HX submissions are complete; later PCB rounds are available for corrections and the passive combiner. Procurement gates in Table 10 occur before the progress demo. Test work is spread across October and November rather than concentrated before fall break [19].

Table 13. Weekly deliverables and division of labor.

Week	Lawrence Cheng	Shengyuan Wang
Sep 28–Oct 4	Freeze the design document and objective core tests.	Record the submitted first-round board revision and write the design document.
Oct 5–11	Complete the SC928NB order and print-fit coupon.	Complete the documented HX711 assembly correction.
Oct 12–18	Release the ring/platform fabrication drawing and delivery decision.	Demonstrate separate power/controller bring-up.
Oct 19–25	Complete the mechanically isolated sensor mount.	Complete bridge/HX711 assembly and signed raw-count logging.
Oct 26–Nov 1	Complete calibration and the first 12 water trials.	Complete converter/harness and charger-simulator verification.

Week	Lawrence Cheng	Shengyuan Wang
Nov 2–8	Demonstrate integrated tracking and complete the other 12 water trials.	Complete the 120 min battery run after safety review.
Nov 9–15	Complete 20 motion and five refill trials.	Complete UI/timing/firmware-boundary verification.
Nov 16–22	Complete mock-demo rehearsal and failed-test corrections.	Complete spill/tip checks and optional standalone ADXL tests.
Nov 23–29	Close any remaining calibration or mechanical test failure.	Close any remaining assembly or power test failure.
Nov 30–Dec 6	Deliver the bottle-use demonstration and measured results.	Deliver the hardware-mode demonstration and as-built circuit record.
Dec 7–10	Complete the final paper figures and measured R&V results.	Complete the final BOM and notebook hardware evidence.

4 Ethics safety and standards

The device supports voluntary awareness and reminders, but neither mass loss nor a displayed goal establishes medical need or actual drinking. Goals remain user-selected, and the screen labels the total as an estimate. We will report every verification outcome and attribute the Soldered HX711 and atomic14 controller reference designs [10], [11]. Honest limitations, accurate records, public safety and credit to prior work follow the IEEE and ACM codes and course ethical guidance [26]–[28].

Local operation avoids account requirements and collection of drinking histories. Reusing an existing bottle reduces the need to replace a container; course-stock parts and repairable separate boards limit cost and waste. Small display size remains an accessibility limitation, addressed by U1 rather than an unsupported universal-readability claim. Keep battery replacement possible and send depleted or damaged lithium cells to the university-approved battery recycling stream, never ordinary trash. Foreign component supply creates lead-time and transport impacts; Table 10 defines a practical procurement response.

Electrical and battery controls. Use protected 1S cells, verified JST polarity, insulating mounts, strain relief and an accessible power disconnect. Obtain required course/TA battery approval, attach the remote NTC to the pack with electrical insulation, and pass P3 before charging a real cell. Charge supervised in the course-prescribed safety bag on a nonflammable surface. Record voltage, current and pack temperature every 5 min; stop for swelling, odor, pack temperature $\geq 40^\circ\text{C}$ or a rise $\geq 10^\circ\text{C}$, or cell voltage above the approved 4.20 V limit. End discharge at 3.0 V. Confirm charger/instrument tolerance with the TA. No unattended charging or exposed pouch contact with sharp printed edges [6], [8], [13], [29].

Spills and mechanical stability. Electronics and battery sit in a separate insulated enclosure beside the base during the first prototype, outside the bottle footprint; route cables with drip loops. A later enclosure under the platform requires a removable splash shield. Before live use, test the chosen enclosure unpowered with a 20 mL spill on the platform; absorbent witness paper at electronics/battery must remain dry. With a sealed bottle at 1 and 3 kg, tilt the supporting surface to 10° in four directions; the base must neither tip nor slide. Use a spotter and repeat any failed enclosure/foot change. The device makes no waterproof claim. Keep platform gaps guarded against fingers, rounded exposed edges and bottle use on a level desk.

Table 14. Applicable standards and design implications. Referenced safeguards do not claim certification.

Reference	Application
USB Type-C Cable and Connector Specification Release 2.5, 2026 [21]	5.1 k Ω CC sink pull-downs, verified receptacle pinout, and separate charging/programming ports. USB current depends on the source advertisement; use a qualified 5 V charger for charge tests.
IEC 62133-2:2017 + AMD1:2021 [22]	Portable lithium battery safety informs protected-cell selection, thermal monitoring and handling.
IEC 62368-1:2023 [23]	Electrical/thermal safeguard principles inform insulation, enclosures and access to disconnect.
47 CFR Part 15 and FCC module integration guidance [24]	Preserve module antenna clearance; radios disabled in core testing. No final-product authorization claim.
OSHA 29 CFR 1910 Subpart S and course safety rules [13], [25], [29]	Current-limited bring-up, insulating benches, guarded hot tools and supervised lithium-battery work.

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Appendix A POWER schematic and layout

Figure 6 is rendered from the submitted POWER.kicad_sch. U1 is the BQ24074 charger; U3 is the TPS63001 converter; J1 accepts charging USB; J2 connects the protected pack. TH1 will be mounted remotely at the pack. The regulated output cable attaches to the 3.3 V output node and GND. References here carry the POWER prefix in the BOM.

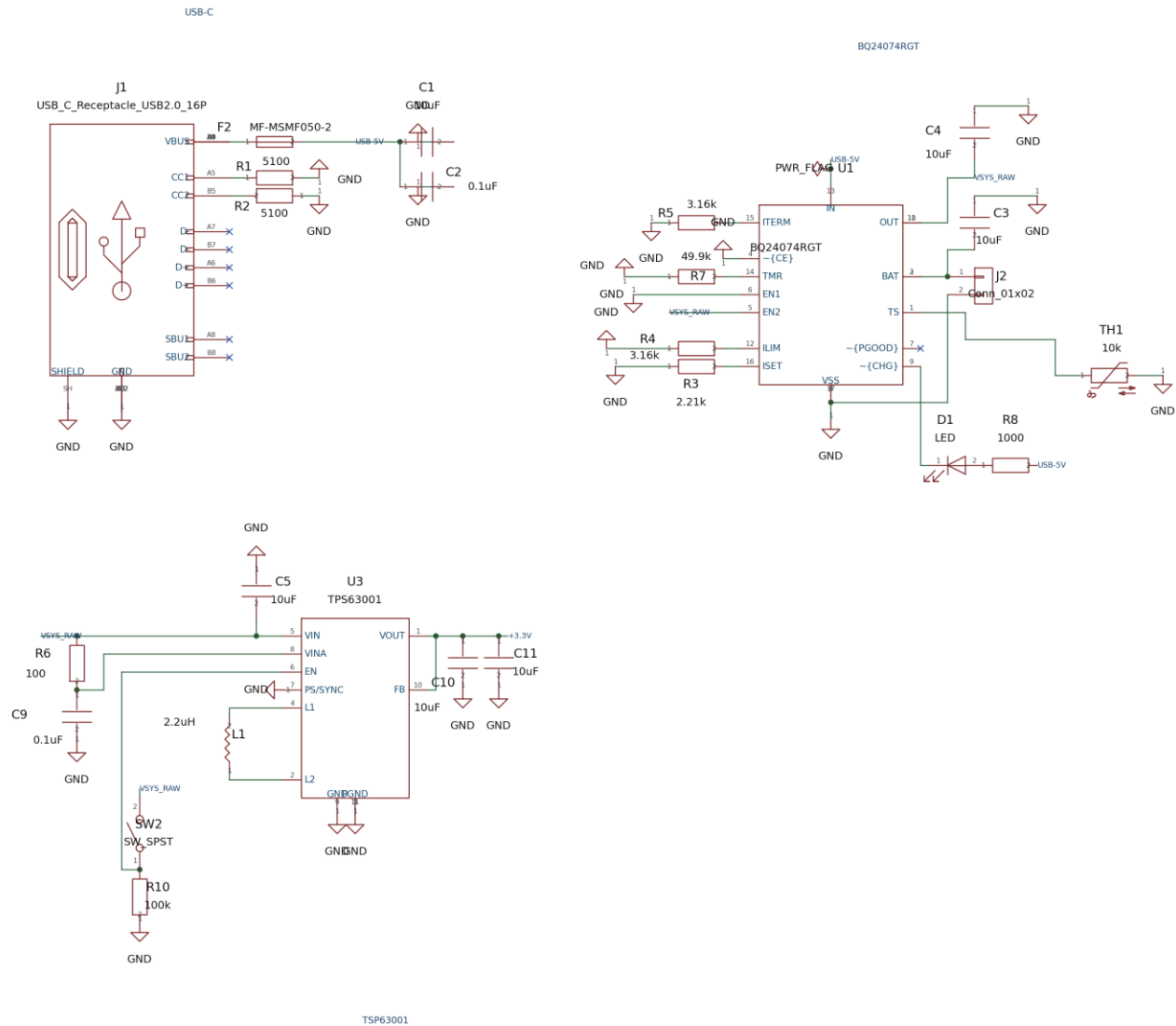


Figure 6. First-round POWER schematic. Upper left: USB sink input. Upper right: charger/power path. Lower left: 3.3 V buck-boost and enable switch.

POWER PCB layout

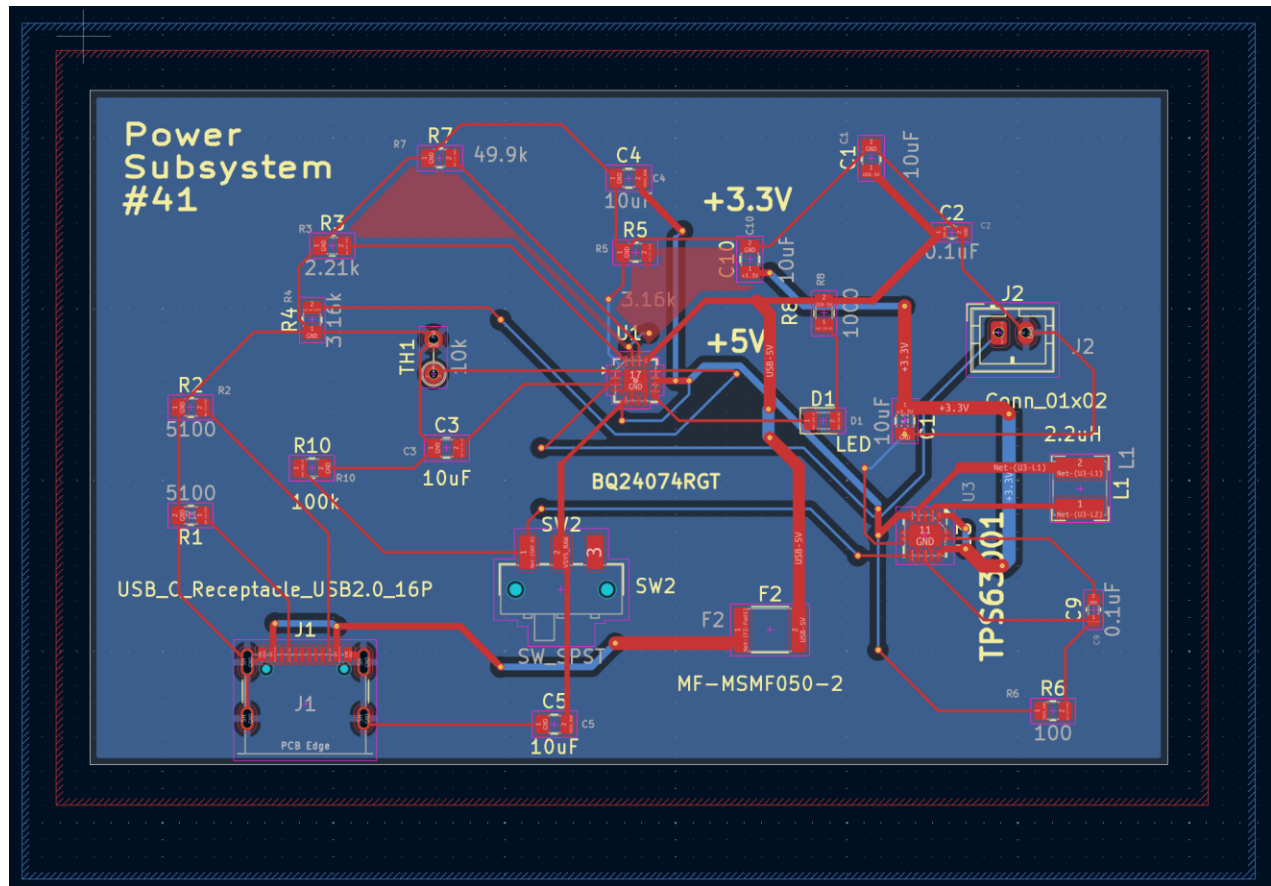
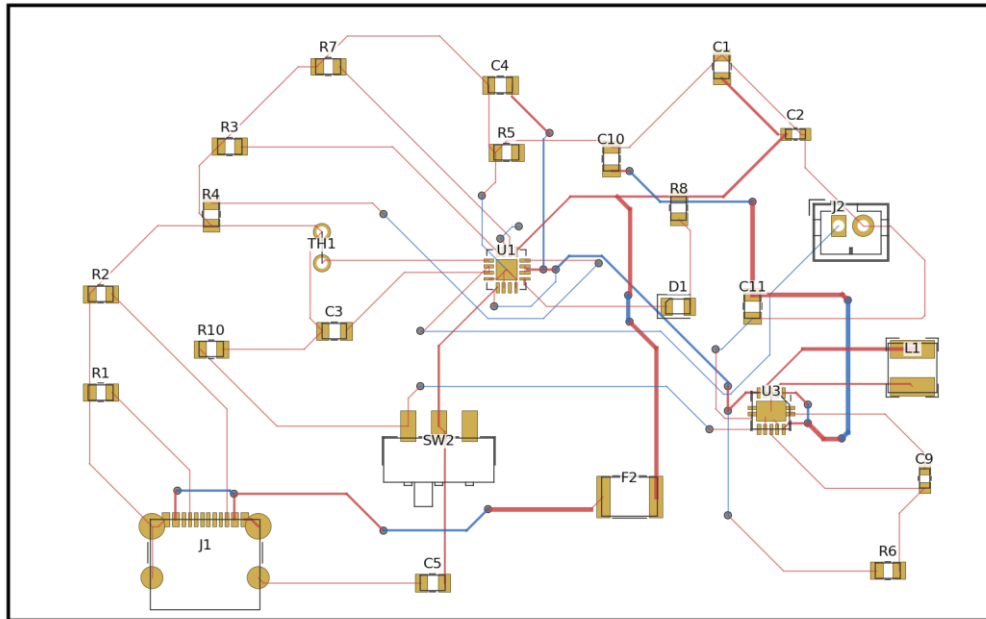


Figure 7a and 7b. Submitted 80 × 50 mm POWER board. Red shows front copper tracks, blue back copper tracks, gold pads and gray vias. Copper pours are omitted for component/track visibility; this view is not an ERC/DRC result.

Readout labels: J1 USB charging input; J2 battery; U1 charger; U3 converter; L1 2.2 μ H inductor; SW2 power enable. Attach and strain-relieve the output harness at the converter's output capacitor positive node and ground. Inspect joints and verify P1/P3 before integrating a real cell.

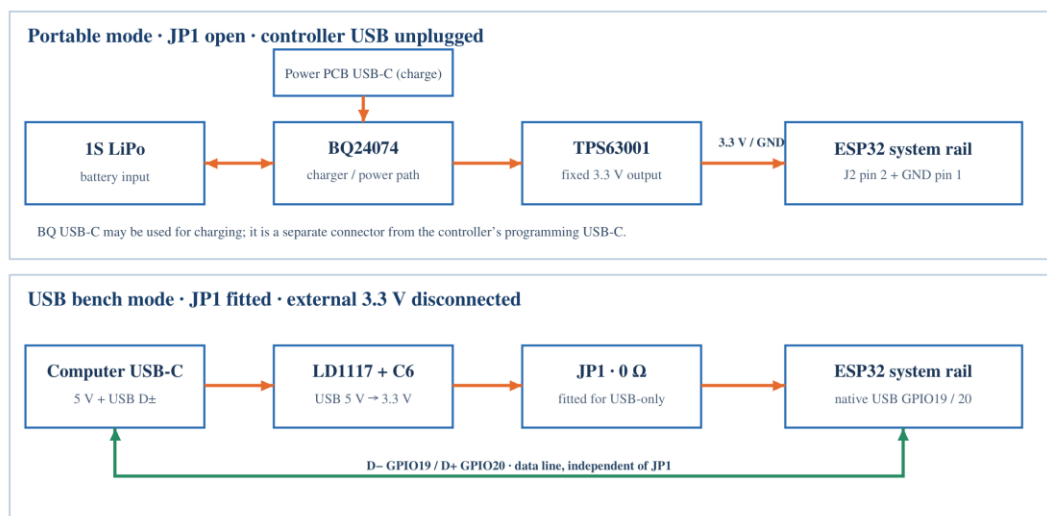


Figure 7c. Selected power modes. Battery mode uses JP1 open; USB-only bench mode uses JP1 fitted and external 3.3 V disconnected.

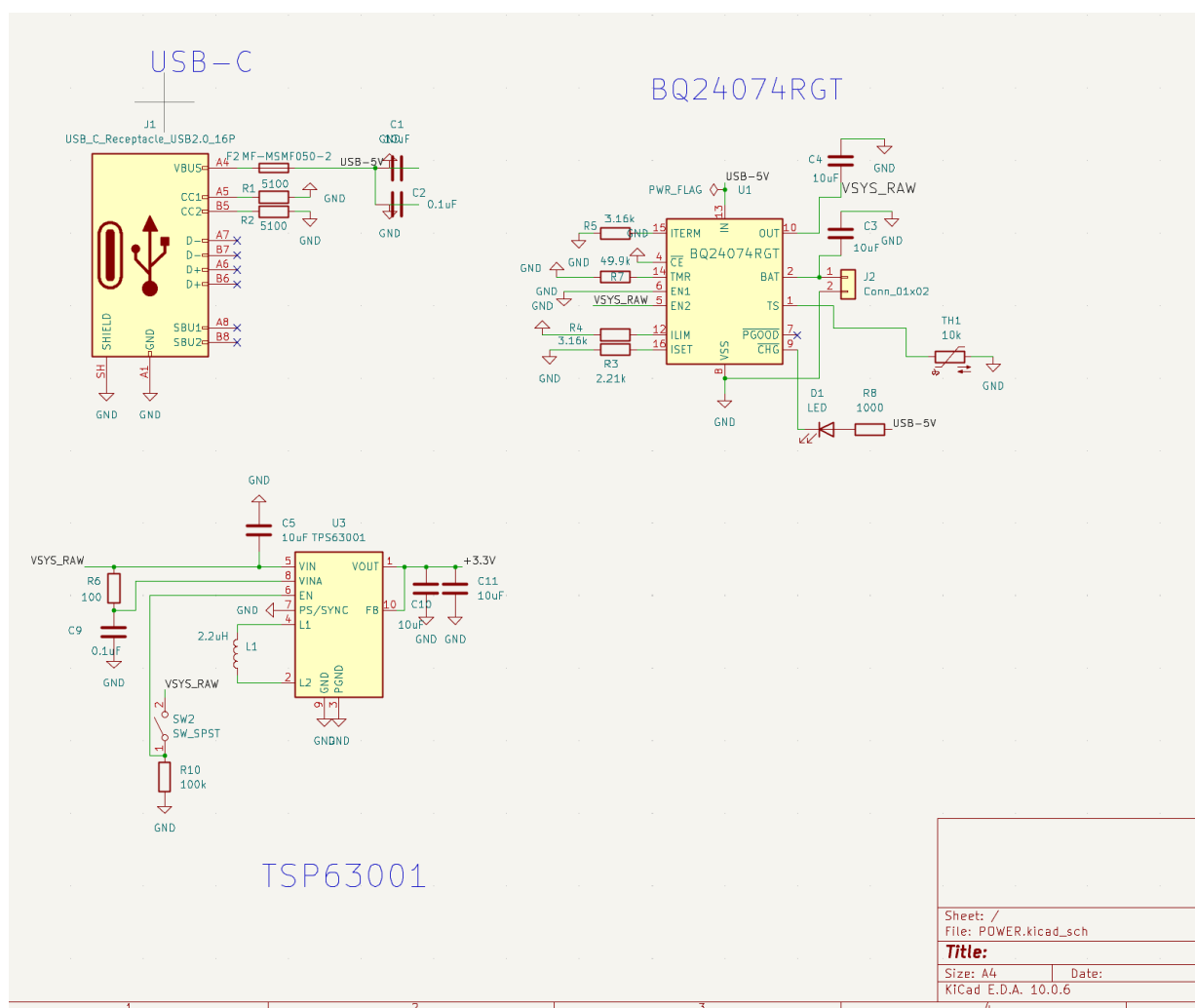


Figure 7d: Kicad Schematic for Power Subsystem

Appendix B ESP32 Rev B schematic

Figure 8 is rendered from Team41_CupBase_ESP32S3_RevB(1).kicad_sch. U2 is the N16 module; J1 is native USB; SW1 reset and SW2 boot. U3 is the USB-only regulator. JP1 separates USB_LDO_3V3 from the external system rail; C6 is the added tantalum output capacitor.

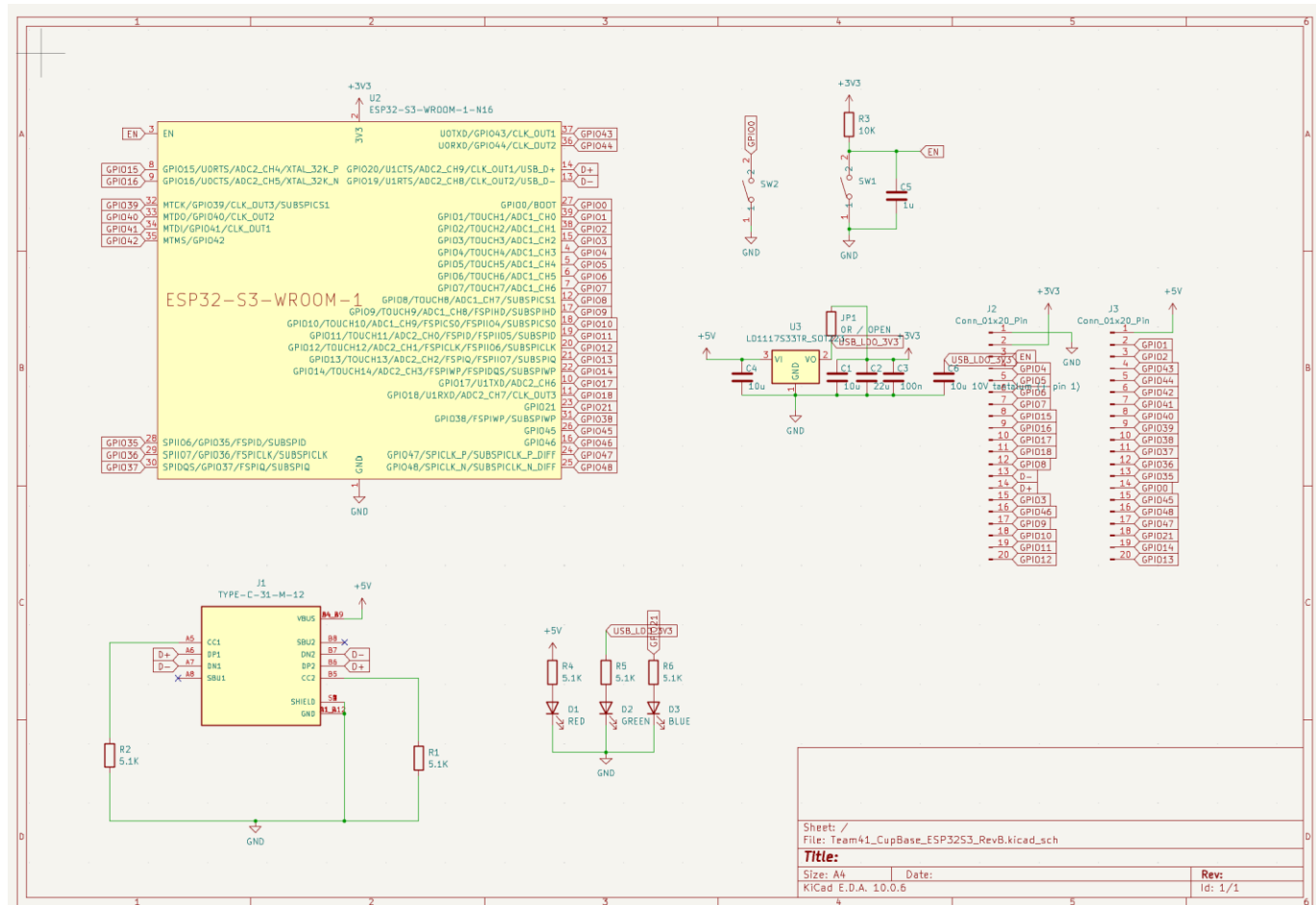
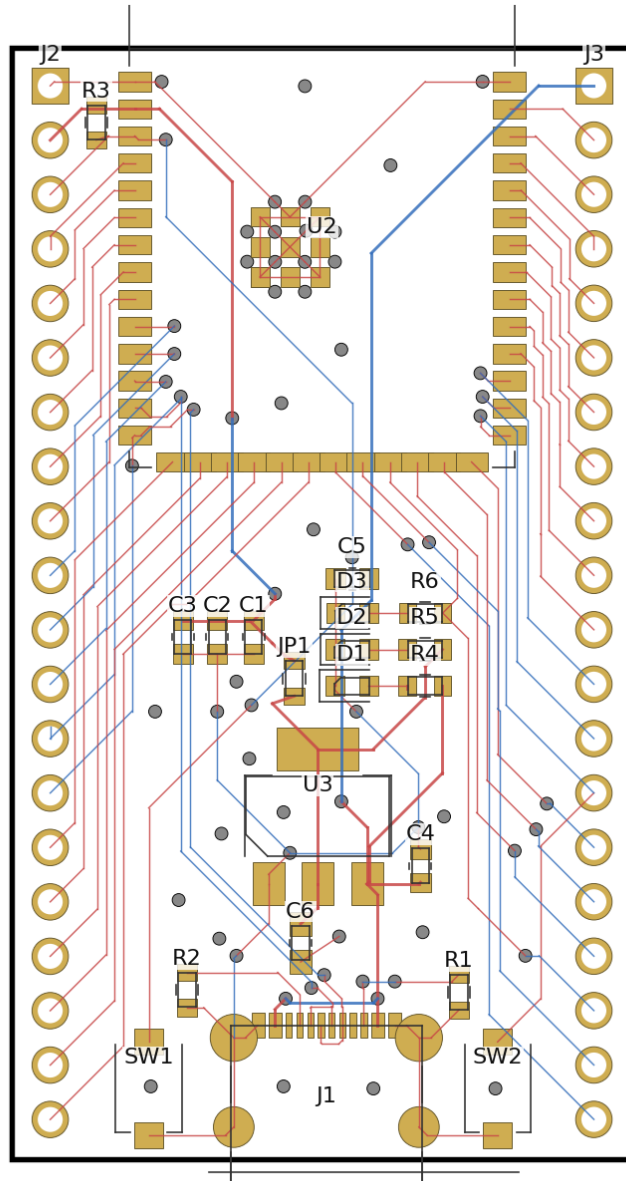


Figure 8. Submitted controller Rev B schematic. GPIO mapping is defined in Table 1; unused module alternate functions are not required by the prototype.

ESP32 Rev B PCB layout



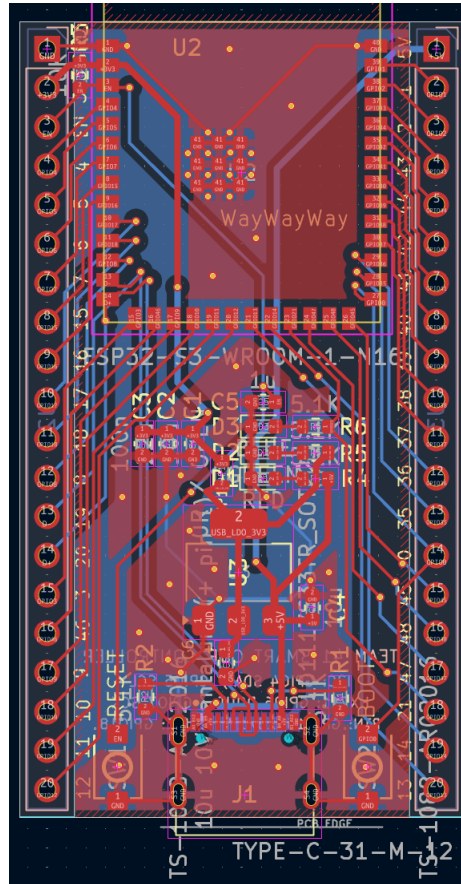


Figure 9 [part 1 and 2]. Submitted controller layout, 29 × 51.9 mm. The same copper/pad colors as Figure 7 apply; pours are omitted. J2/J3 are the peripheral headers; antenna clearance is retained at the module end. Higher level schematics and PCB included

Assembly labels: J1 USB; U2 ESP32-S3; U3 LD1117; JP1 power link; C6 tantalum; SW1/SW2 reset/boot. J2 supplies the named core interfaces. Verify EN continuity between the reset network and module before C1; if the first-round trace is incomplete, repair that net with a short insulated jumper and record the as-built change.

Appendix C HX711 first round and planned completion

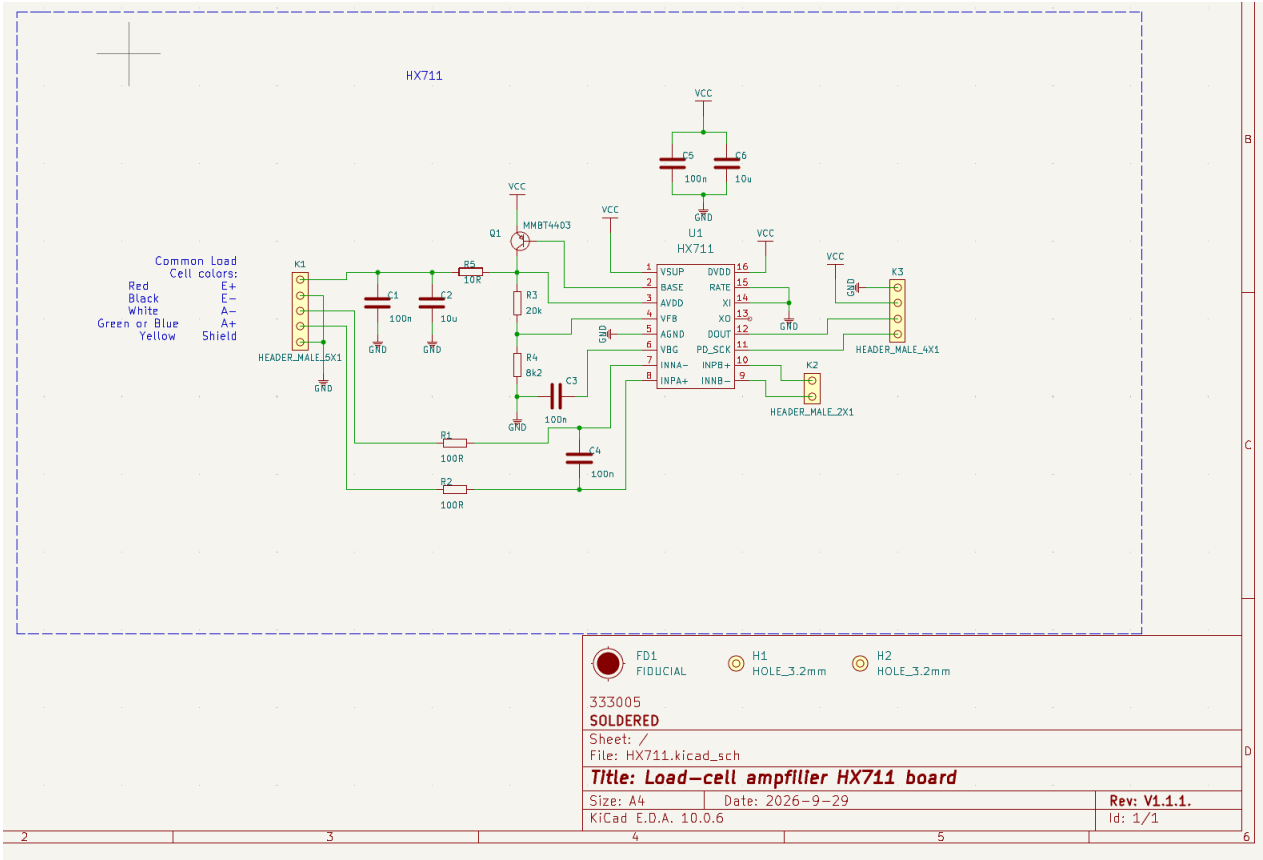
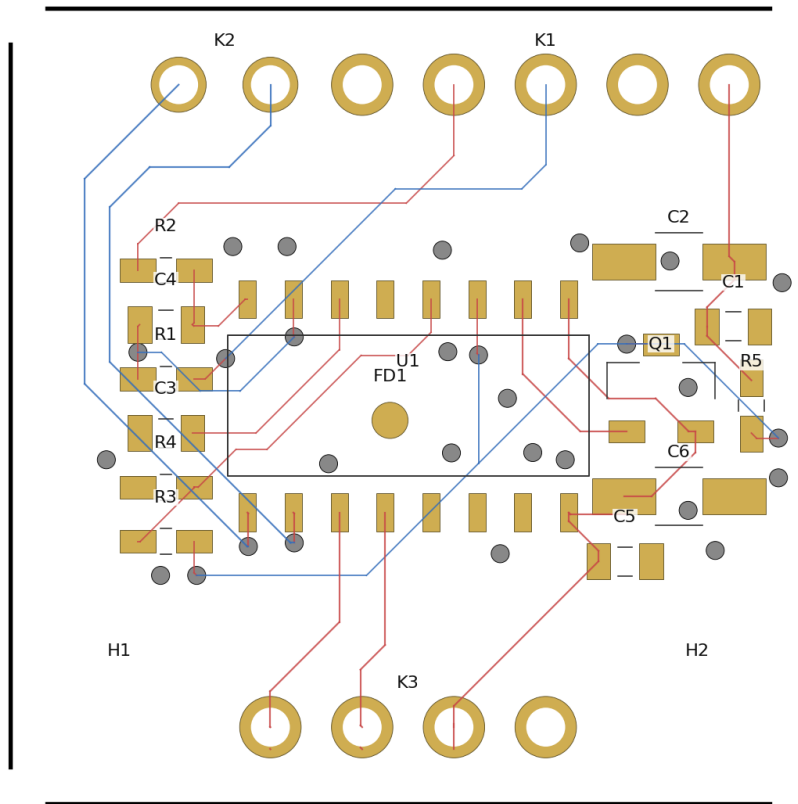


Figure 10. Submitted HX711 circuit before completion. The Q1/R3/R4 regulator is replaced by the explicit 3.3 V assembly changes below; the ordered PCB is retained.

Table 15. Exact first-round HX711 assembly changes.

Location	Final assembly
Q1	Omit transistor; bridge pads 2 and 3 only. Pad 1 remains open.
R3	Omit 20 kΩ resistor.
R4	Fit 0 Ω instead of 8.2 kΩ: VFB to GND.
R5	Fit 0 Ω instead of 10 Ω: E+ follows AVDD.
U1 and supply bypassing	Retain HX711 and supply capacitors; verify VSUP/DVDD/AVDD=3.3 V and BASE open.

HX711 PCB and bring up checks



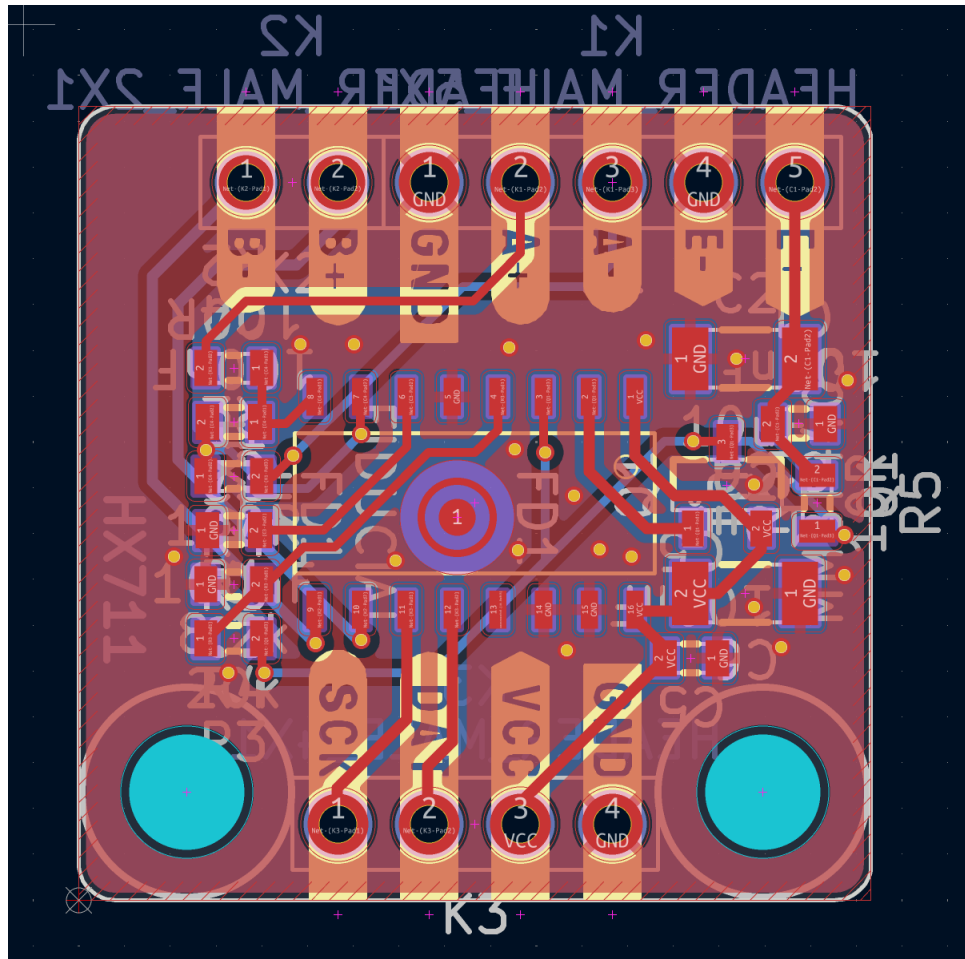


Figure 11[part 1 and 2]. Submitted approximately 22 × 22 mm HX711 layout. R3/R4 are at the left of U1; Q1/R5 are at the right. Use Table 15, not the original populated regulator values. Higher level schematics and PCB included

K3 carries SCK, DOUT, VCC and GND. K1 carries ground, A+/A− and E+; map it received-board pin numbers to the nets before wiring rather than assuming cable colors. K2 is the unused channel B interface. Unpowered: check the Q1 jumper, open BASE, grounded VFB and no 3.3 V short. Then use current-limited 3.3 V and pass H1/H3 before attaching the bottle platform. No assembled-board test result is claimed.