Grab an attendance sheet

Lecture 7

March 3, 2026

THIS WEEK

What happened in the past…and what can we learn from it?

- Retrospective on prior year designs
- Enclosure design
- Design for success

We are going to be discussing things that didn't work well last year. This isn't meant to insult to last year's teams…

…but we want to build on their work

Next year we'll be doing the same for your teams…

6.900 2025 Projects

- Two projects, five teams
- **MITOS**
  - Stationary weather station to be deployed in various parts of campus
  - Monitor local heat environment
  - Primary requirements
    - **Accurate** air temperature measurement
    - More **robust comms**
    - **Interact** with users
- **City of Cambridge Bike Lane Monitor**
  - Count bike usage in separated bike lanes
  - Primary requirements
    - **Accurate** bike detection
    - Works **anywhere** in Cambridge
    - **Privacy-**preserving

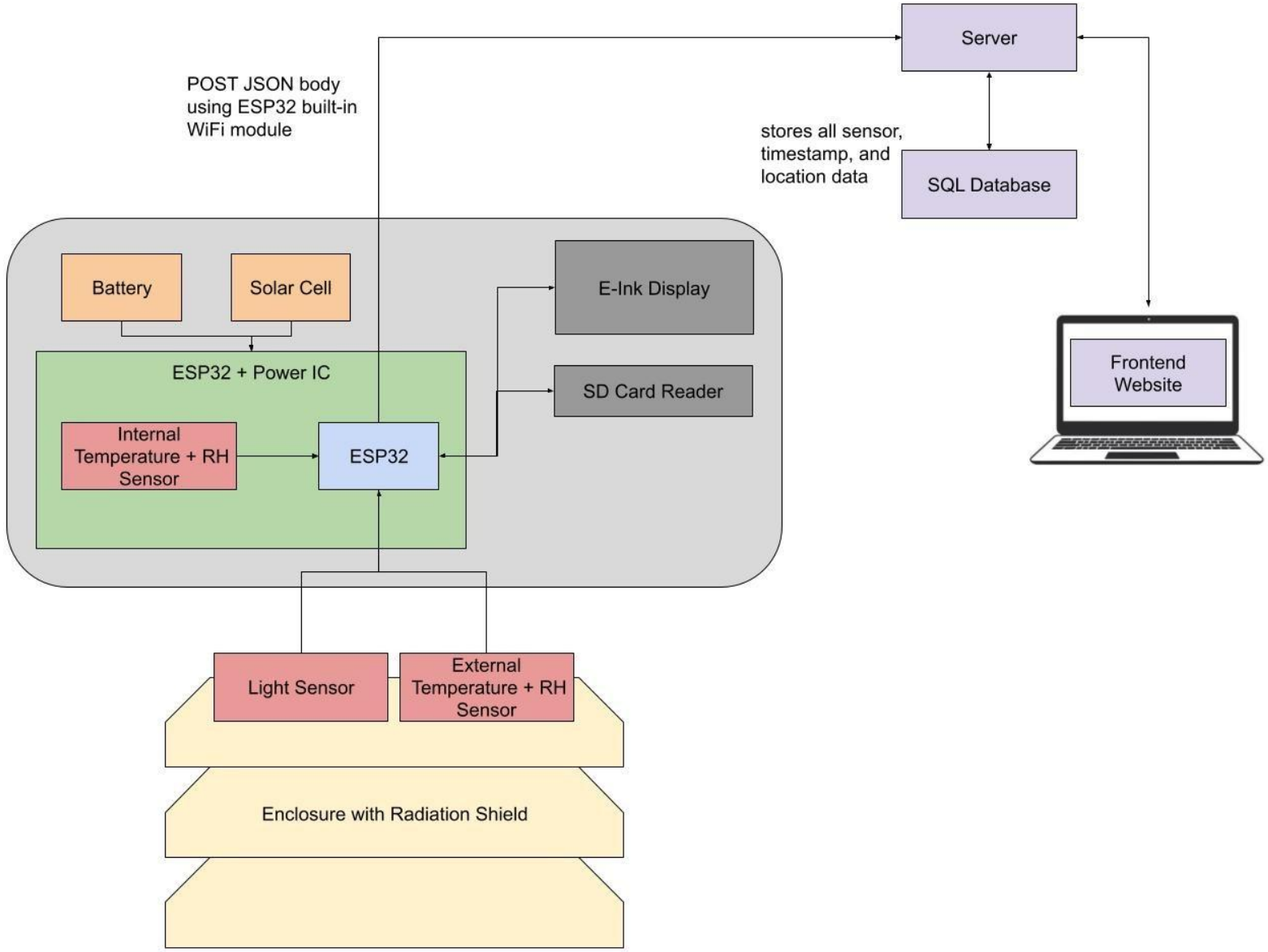
6.900 2025 Projects

- Some class-wide differences last year
  - We used Arduino
    - No more this year
  - We allowed teams wider latitude in industrial design, 3DP, front end
    - Logistically insane with little-to-no benefit
    - This year we tightened down

MITOS project – team 1

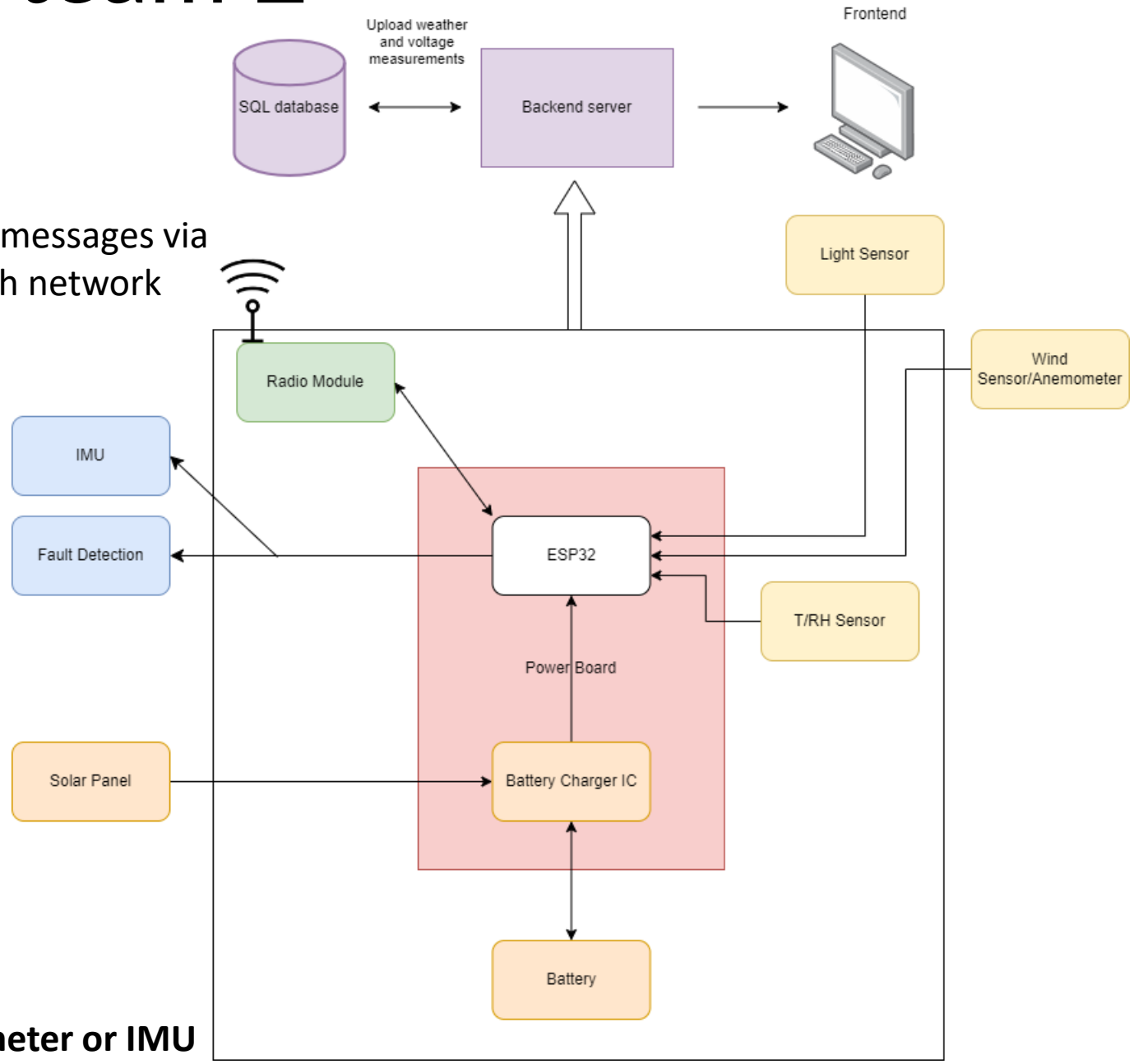
Collects **temperature**, **humidity** and **lux** data every **five minutes** and posts it to the website every **hour**

Displays **current temperature** and **website QR code** on an **e-paper display** for community engagement



MITOS project – team 2

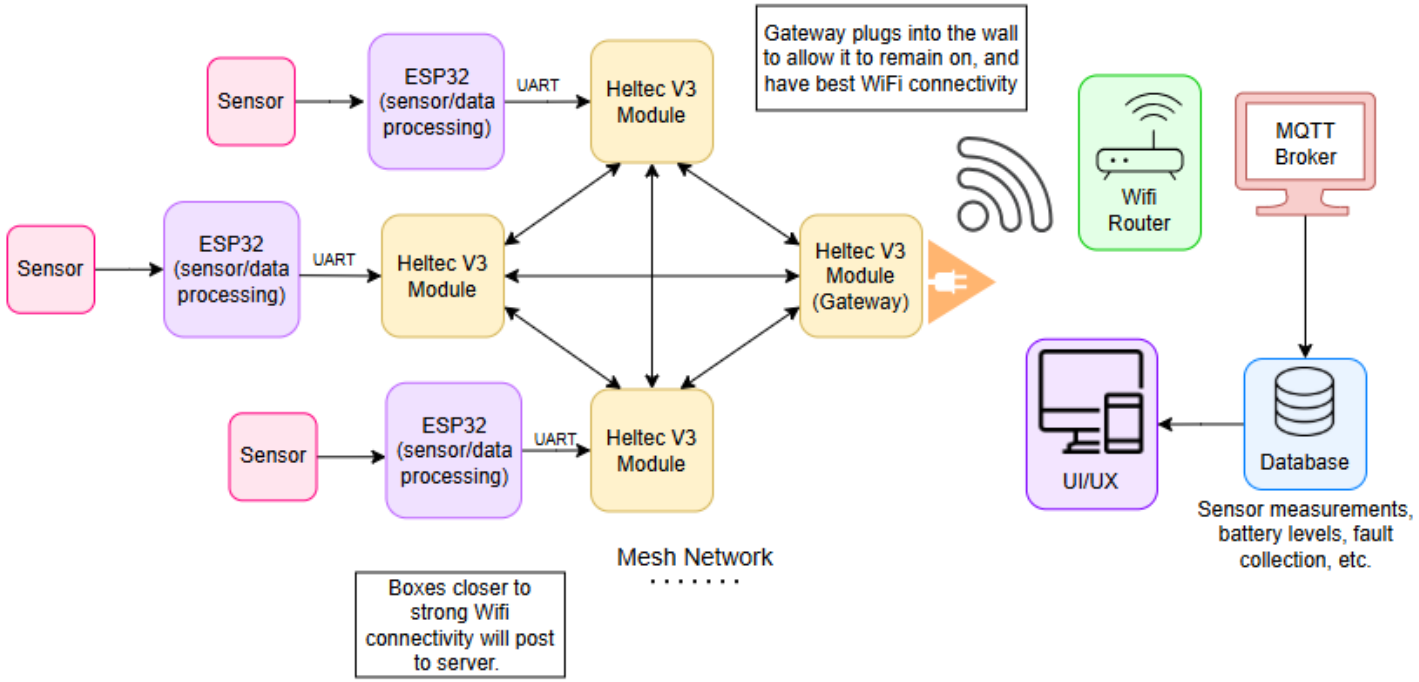
Use LoRa to send messages via MQTT across mesh network



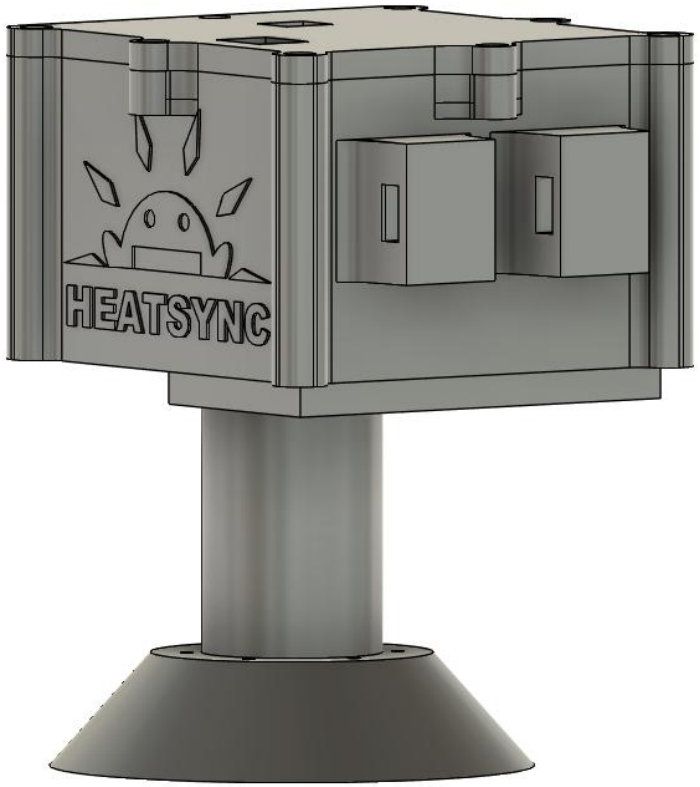
Did not implement anemometer or IMU

MITOS project – comms strategy – team 2

- Heltec V3 LoRA Module connected to each sensor node configured as ‘client’
- Gateway-configured LoRA module connected to the wall
  - Sends all data seen in the communication channel between all nodes onto the server
- All nodes are ‘subscribed’ to the same channel



MITOS project – industrial design - team 1



MITOS project – industrial design – team 2

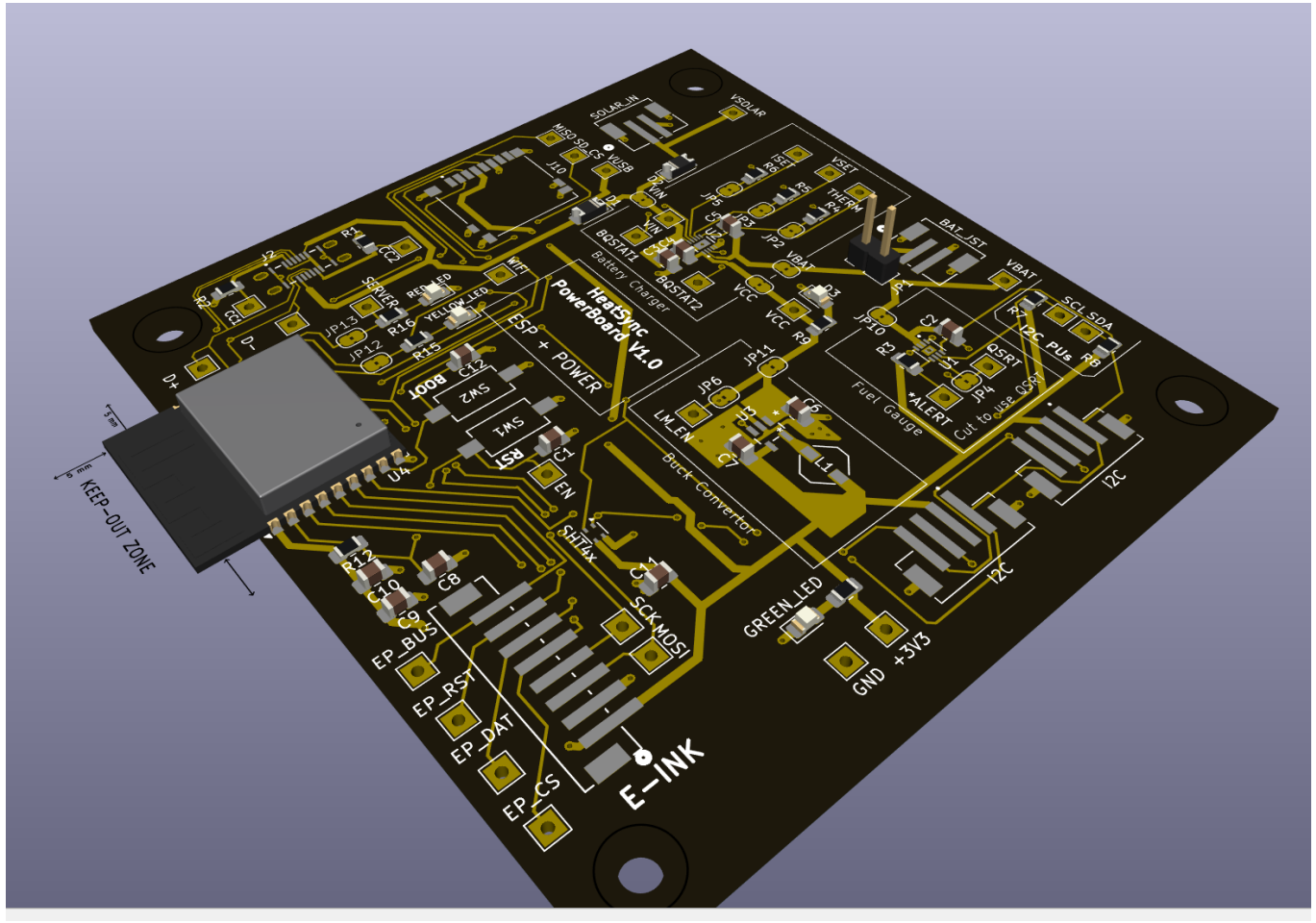
Use gasket for weather-proofing
Waterproof cable penetration with epoxy

Industrial design notes

- Radiation shield
  - Both used 3DP design
  - Assembly of the bits and pieces can be time-consuming
- Teams return again and again to hose clamps
  - Metal zip ties are also a good option (but one-time use)
  - Need to ensure your enclosure attachment points are strong
- E-ink displays
  - Had last-minute issues with sourcing and size changes

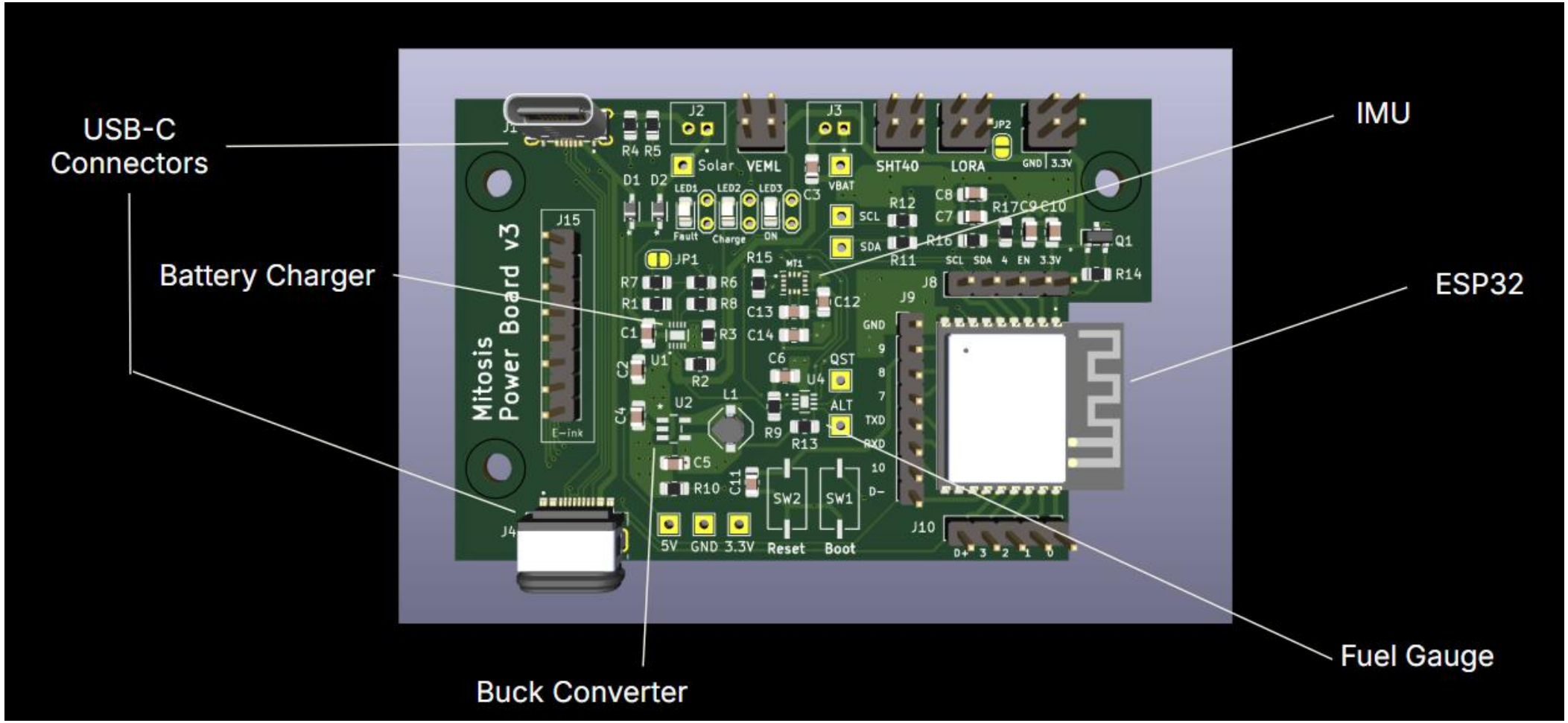
MITOS – sensors & electronics – team 1

- One main board w/ ESP32, power, etc.
- Two simple daughter boards with RH/T, lux
  - To bring sensors to edge of enclosure
- RH/T board conformal coat for weather-proofing
  - More on that later



MITOS – sensors & electronics – team 2

- Similar physical partition
- Use load switch to turn off LoRa module → conserve power

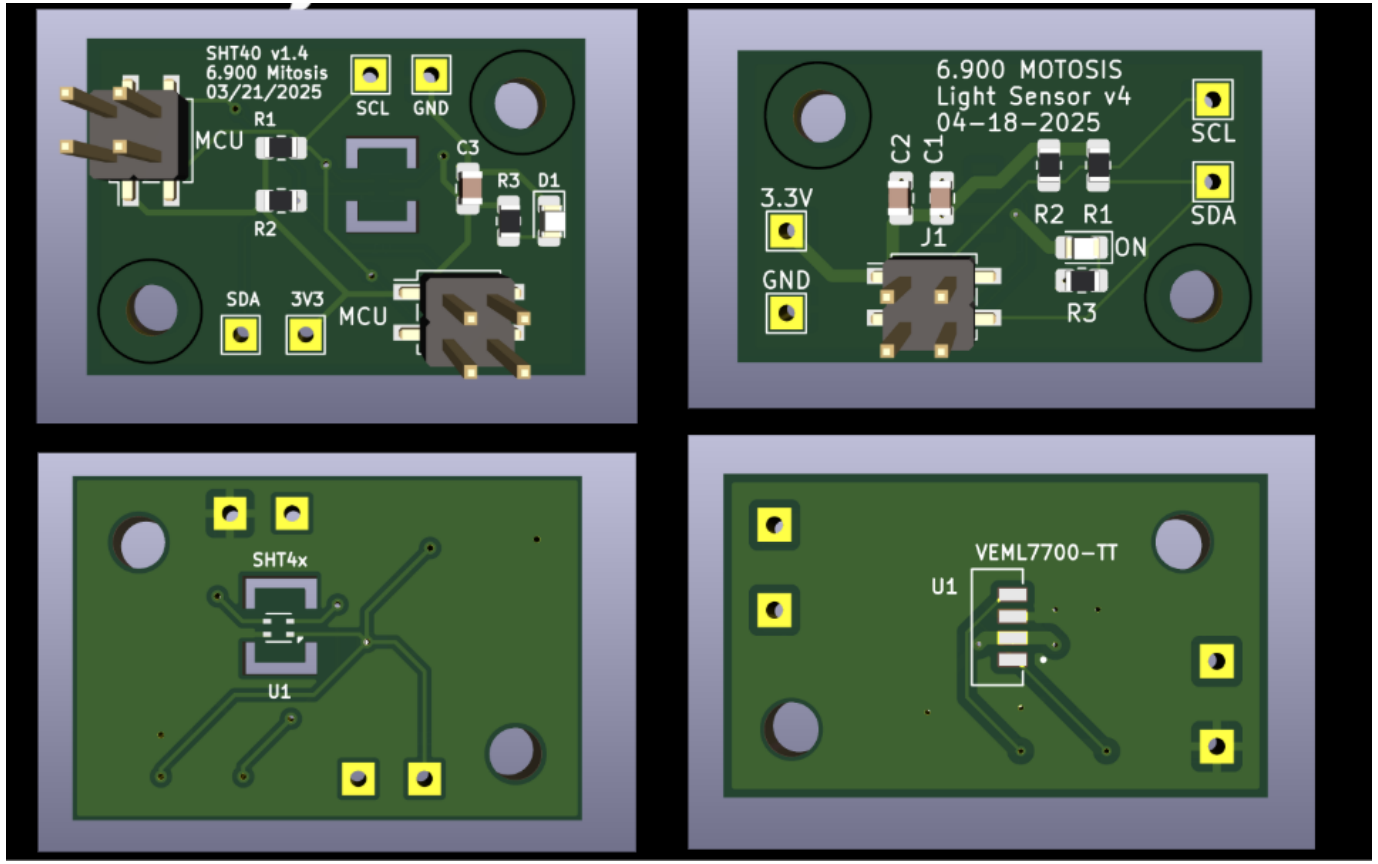


Very useful to have 3D models in KiCAD and Fusion360

MITOS – sensors & electronics – team 2

- RH/T and Lux boards

Boards with components on both side → harder to assemble



MITOS – sensors & electronics

- All used
  - SHT4x sensors
    - Team 1 had additional internal SHT sensor so used variant with different I2C address
  - VEML7700 light sensors
    - These have a weird footprint and are big and kinda pricey
  - Battery monitor ICs
    - Unclear if this is a big win over just measuring voltage
- Industrial design necessitated parts on both sides of board
  - This is always a PITA
- Did not use proper connectors
  - Non-polarized, non-locking
  - *You'll do better this year…*

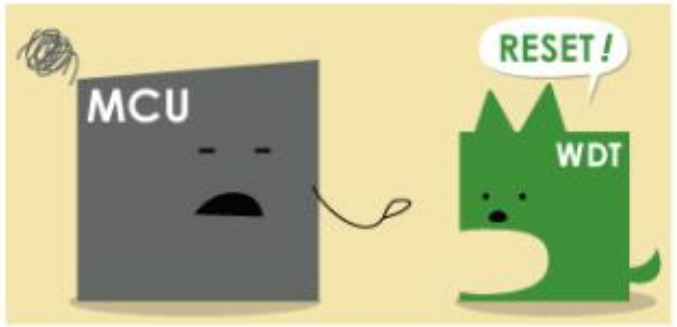
MITOS – power budget – team 1

- Display updates are pricey (in power)
- Deep sleep current was ~0.5 mA
  - Not sure why this is so high
  - Should be able to get this much lower
- Power hogs: Display > Deep sleep > Comms > everything else
- If you are using a display, start on it soon in order to maximize efficiency

	Operating Current(mA)	Duration (ms)	Current Consumed(maH)
Sensor Collection	36.038	80	0.0008
Data Processing	36.035	1200	0.0120
Comms Connection	404.531	400	0.0449
Comms Transmission	550.053	200	0.0306
Deep Sleep	0.5322	3,598,120	0.5322
Battery Lifetime (days)	235.010		
Lifetime with e-ink(days)	14.427		
Lifetime with Solar and e-ink	indefinite	Assuming 100 mW input for 8 hours	

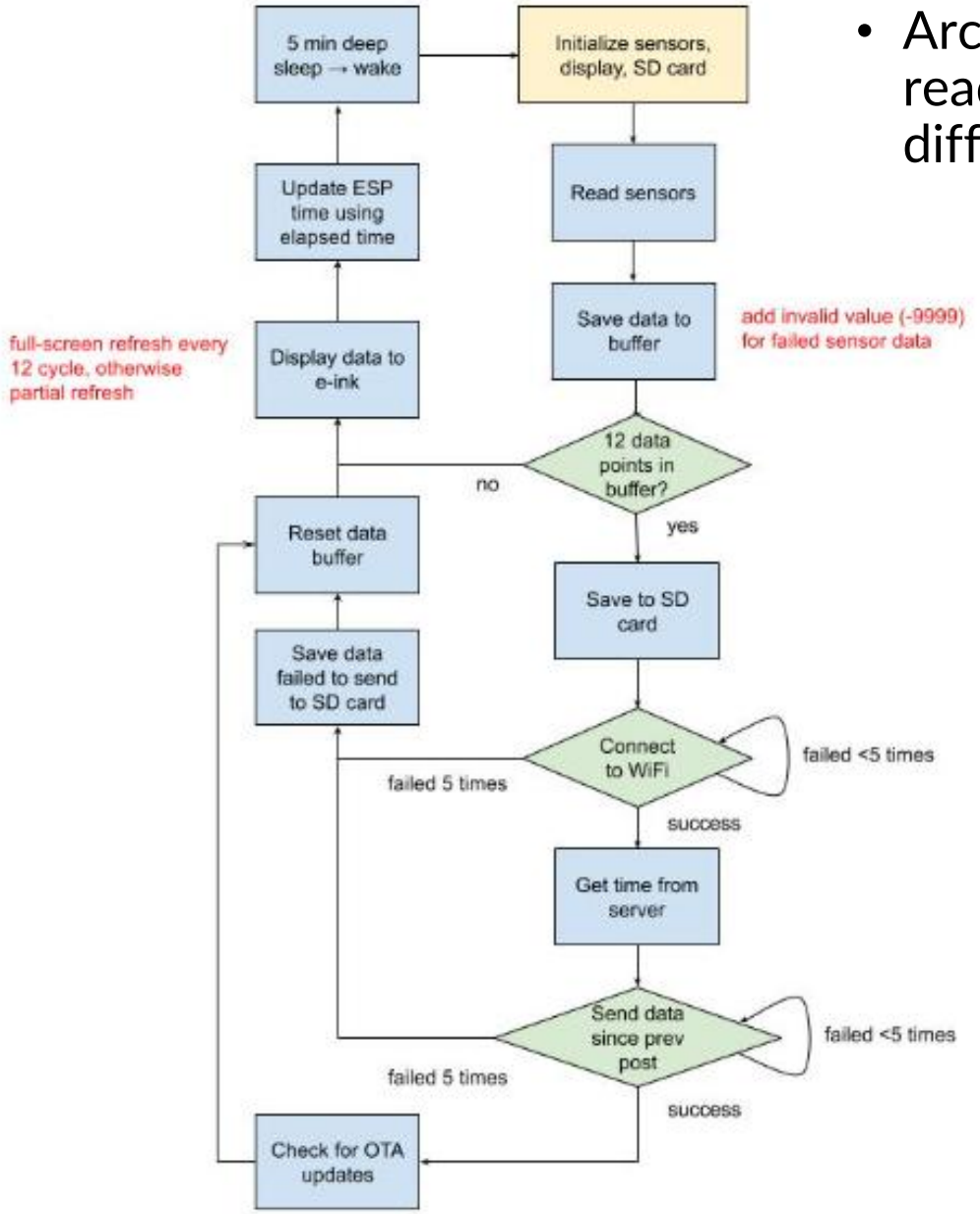
MITOS – FW – team 1

- Using cycles vs. time can lead to issues estimating time later on
- Architecture does not allow reading different sensors with different cadences



40 seconds WDT

Connects to strongest WiFi signal from given list

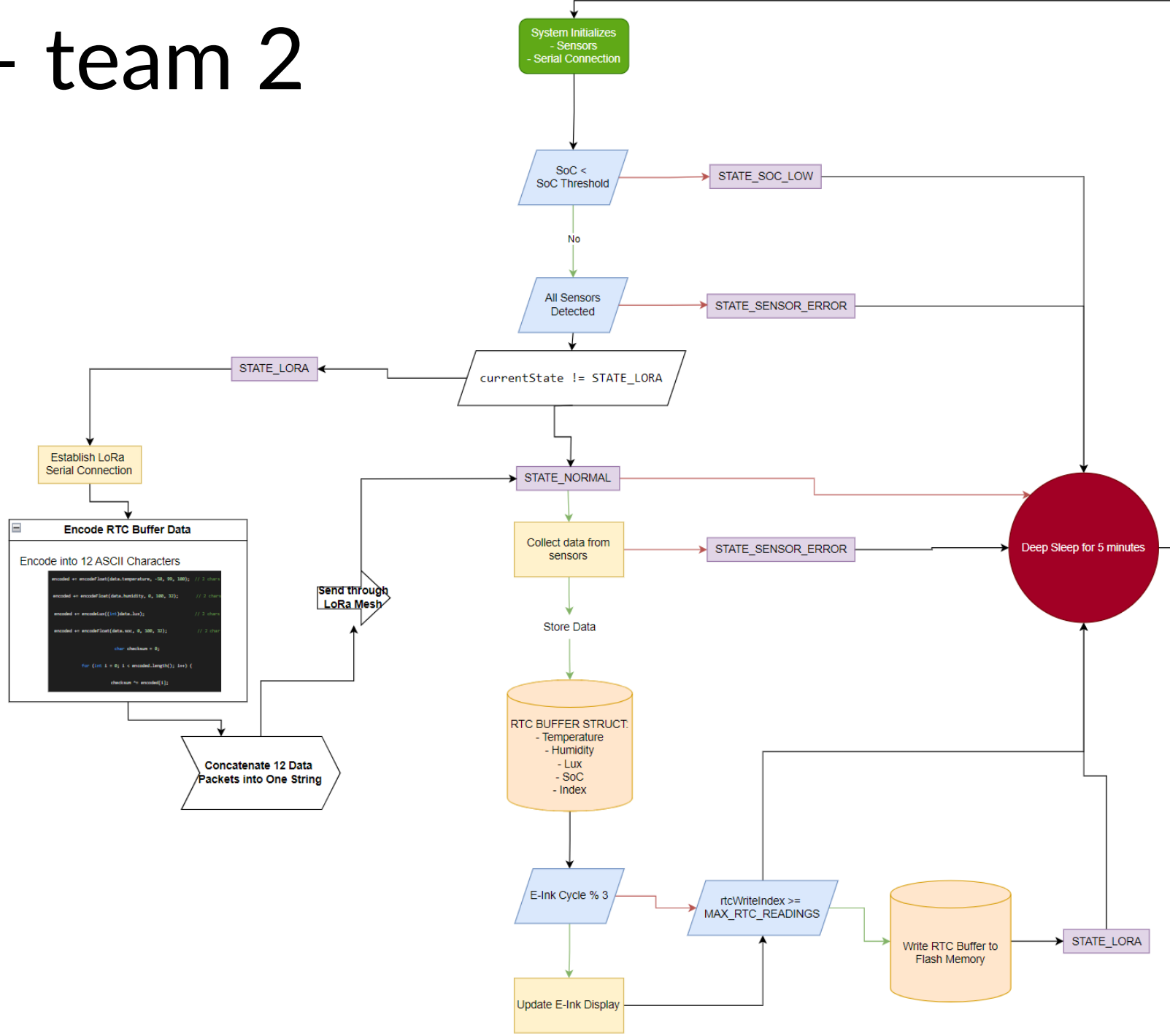


Data collection every 5 minutes

Minimum hourly data upload

Report data which failed to send using SD card data

MITOS – FW – team 2



MITOS – FW notes

- Some keys to success
  - For WiFi, scan for the strongest AP
    - It will change over time, even if your system is not moving
    - Multiple APs may broadcast the same SSID, so you need to choose the strongest MAC, not just strongest SSID
  - You WILL have comms failures (WiFi, cellular, LoRa, etc.)
    - Have a way of buffering up the data
  - Consider logging data and messages to SD Card
    - Easy to re-direct ESP_LOG messages to SD
    - Doesn’t consume a lot of power
    - Logs make debugging easier
    - Increases cost and complexity of system
    - Requires more GPIOs b/c SD cards use SPI

MITOS – Fault reporting – team 1

Temperature + Heat Index

WiFi connectivity indicator

Server status

Battery charge indicator

Website QR code

- **Debug mode:** posts and refreshes e-paper every 5 seconds
- **Normal mode:** collects data and refreshes e-ink every 5 minutes, posts data every hour
- In both modes, **all data and error messages are logged to the SD card**

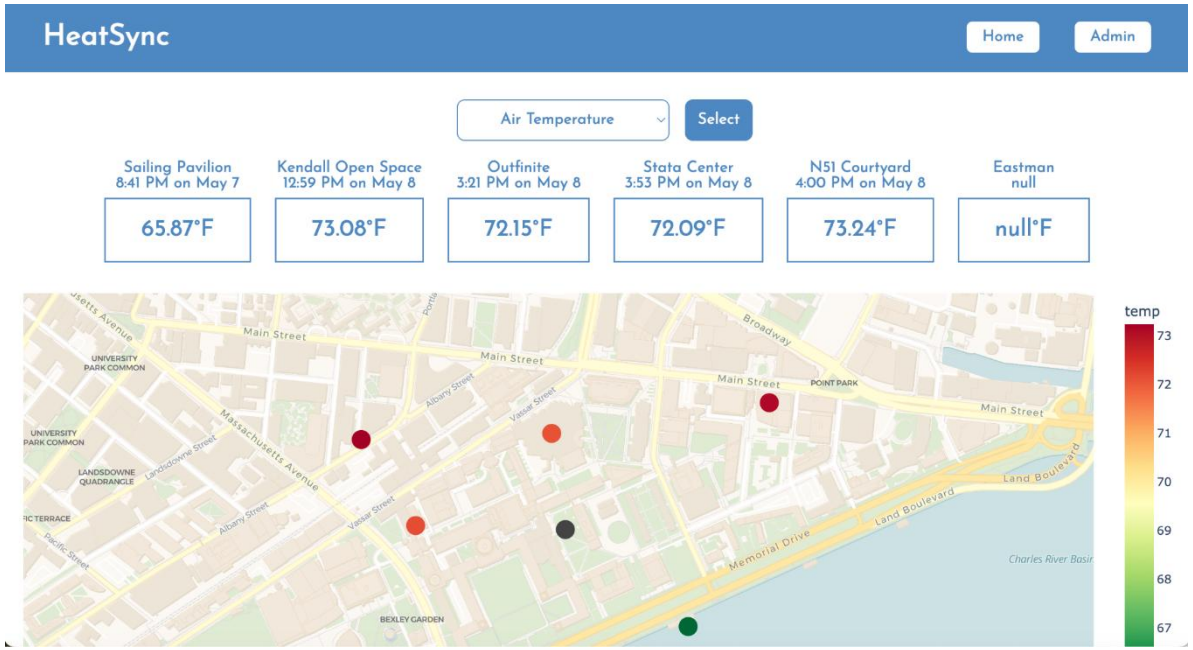
One thing that's missing from display: some sense of time

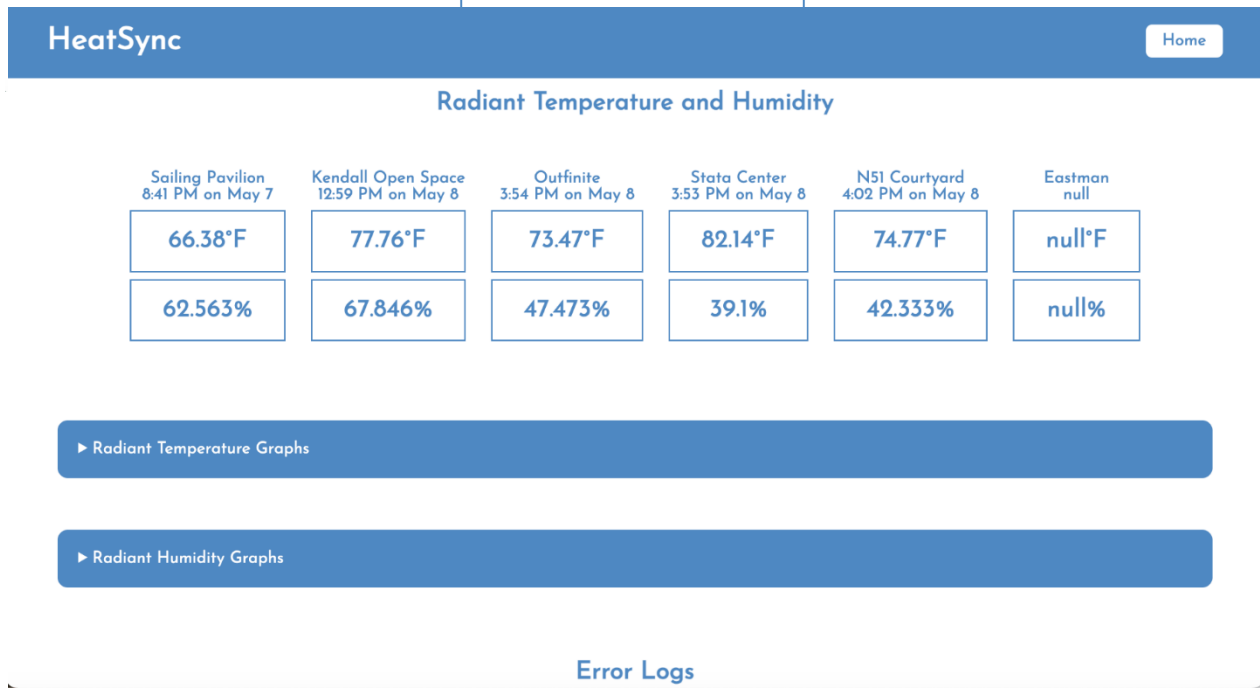
MITOS – Fault reporting – team 2

- On-board status LEDs
  - These may only be visible internally
  - Green LED - The system is on.
  - Orange LED - The system’s battery is charging. This LED will blink rapidly when there is no battery plugged in.
  - Red LED - Battery charger fault, which includes:

Not exactly sure if they did this or if they ended using only display for status reporting

MITOS – dashboard – team 1

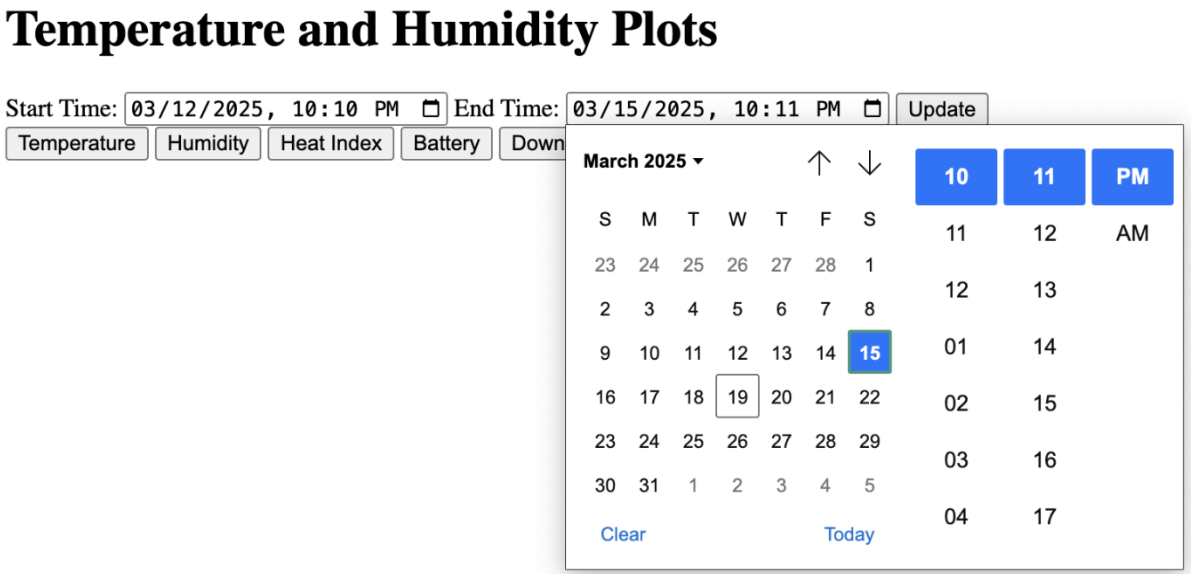




- I like
  - Displays last update time/date → know which devices are active
  - Has error logging table (not shown)
- I don't like
  - No way to "move" a device
  - ID is not linked to MAC address
  - Too many significant digits reported
  - Every piece of data is on its own plot…cumbersome to visualize…not possible to compare plots across devices…or to plot multiple quantities on same plot…or plot specific date ranges, etc.

MITOS – dashboard – team 2

- I like
  - Can set specific date ranges
- I don’t like
  - Single plot…same issues as team 1

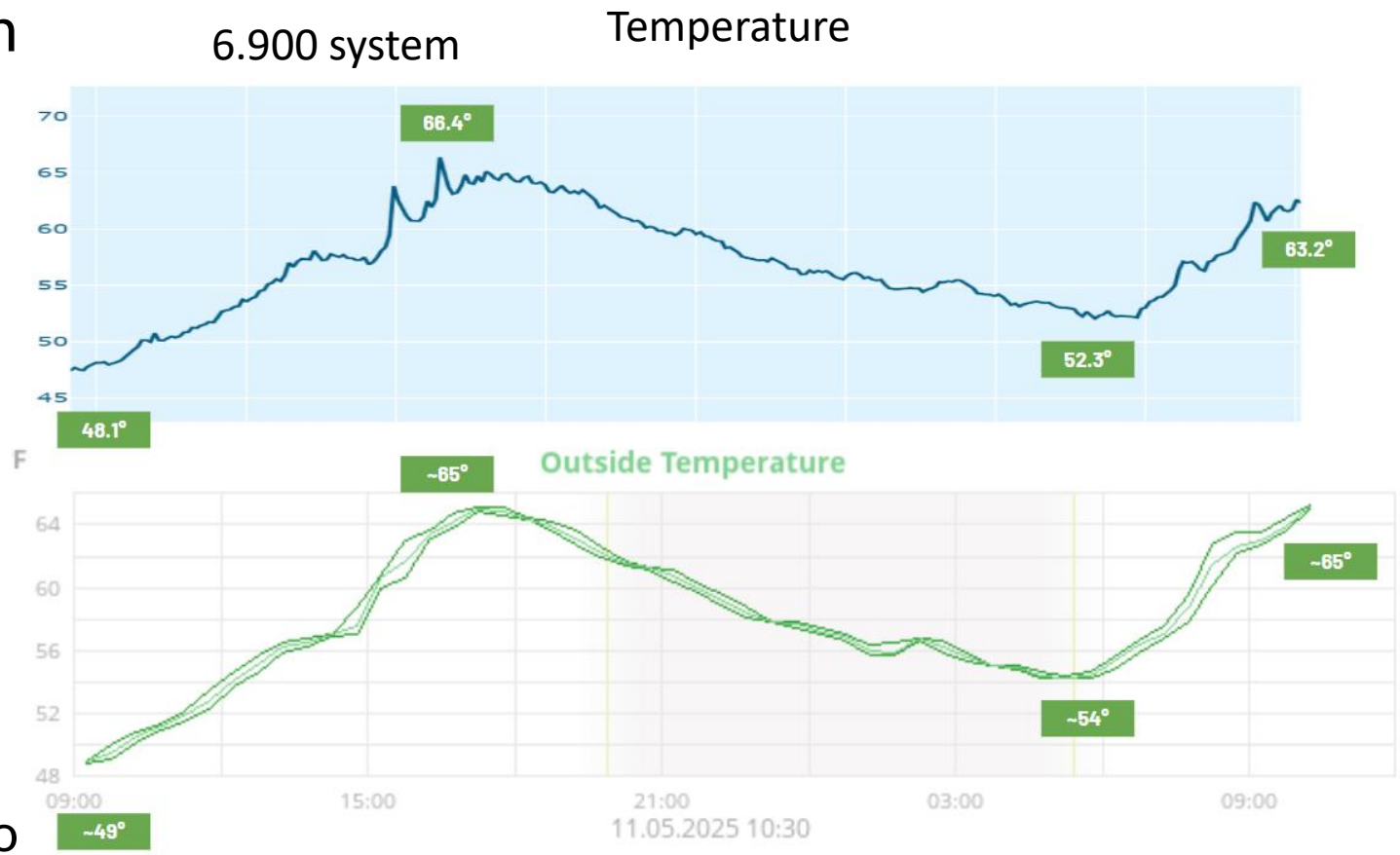


MITOS - cost

- Team 1
  - BOM: $96
  - Assembly: $60 (3h@$20/h)
  - COGS: $156
  - Cost drivers
    - E-ink display: $16
    - Battery: $9
    - Solar panel: $8
    - Enclosure material: $10
- Team 2
  - BOM: $102
  - Assembly: not sure
  - COGS: not sure
  - Cost drivers
    - E-ink display: $17
    - Battery: $10
    - Solar panel: $12
    - LoRa radio: $18
    - Enclosure material: not sure

MITOS – accuracy – team 1

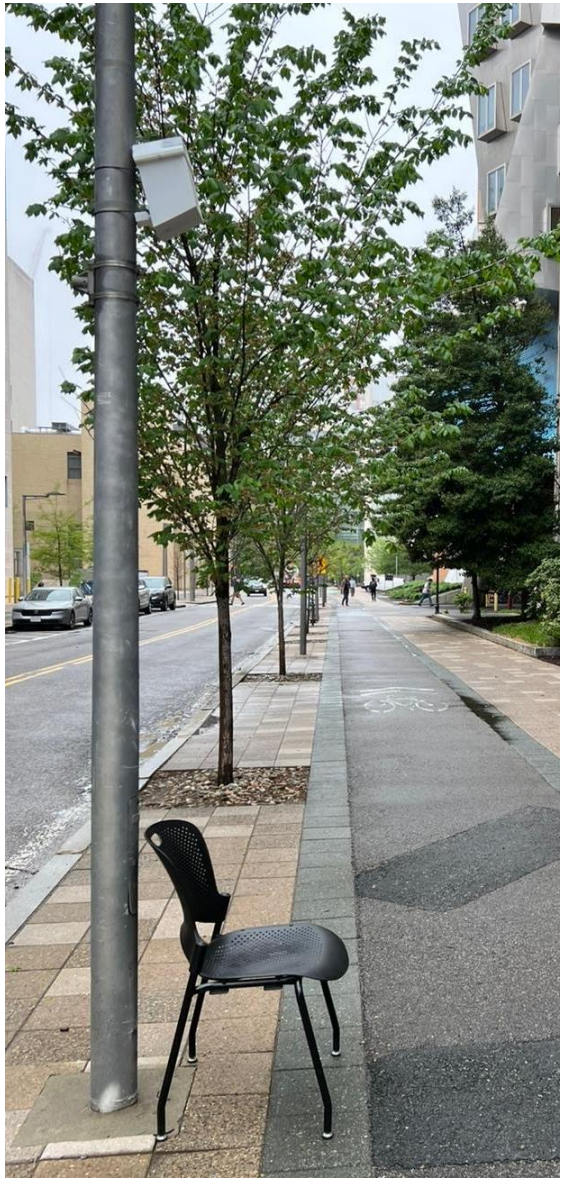
- Did comparison to weather station at sailing pavilion
  - Obtained similar results for humidity
- Obtaining accuracy is hard because
  - You need to compare with a more accurate system
  - The two options nearby are sailing pavilion and Green building
  - Neither easily provide raw data for comparison
  - Need to perform comparison on warm sunny day cause sun is going to major cause of inaccuracy



Weather station at sailing pavilion

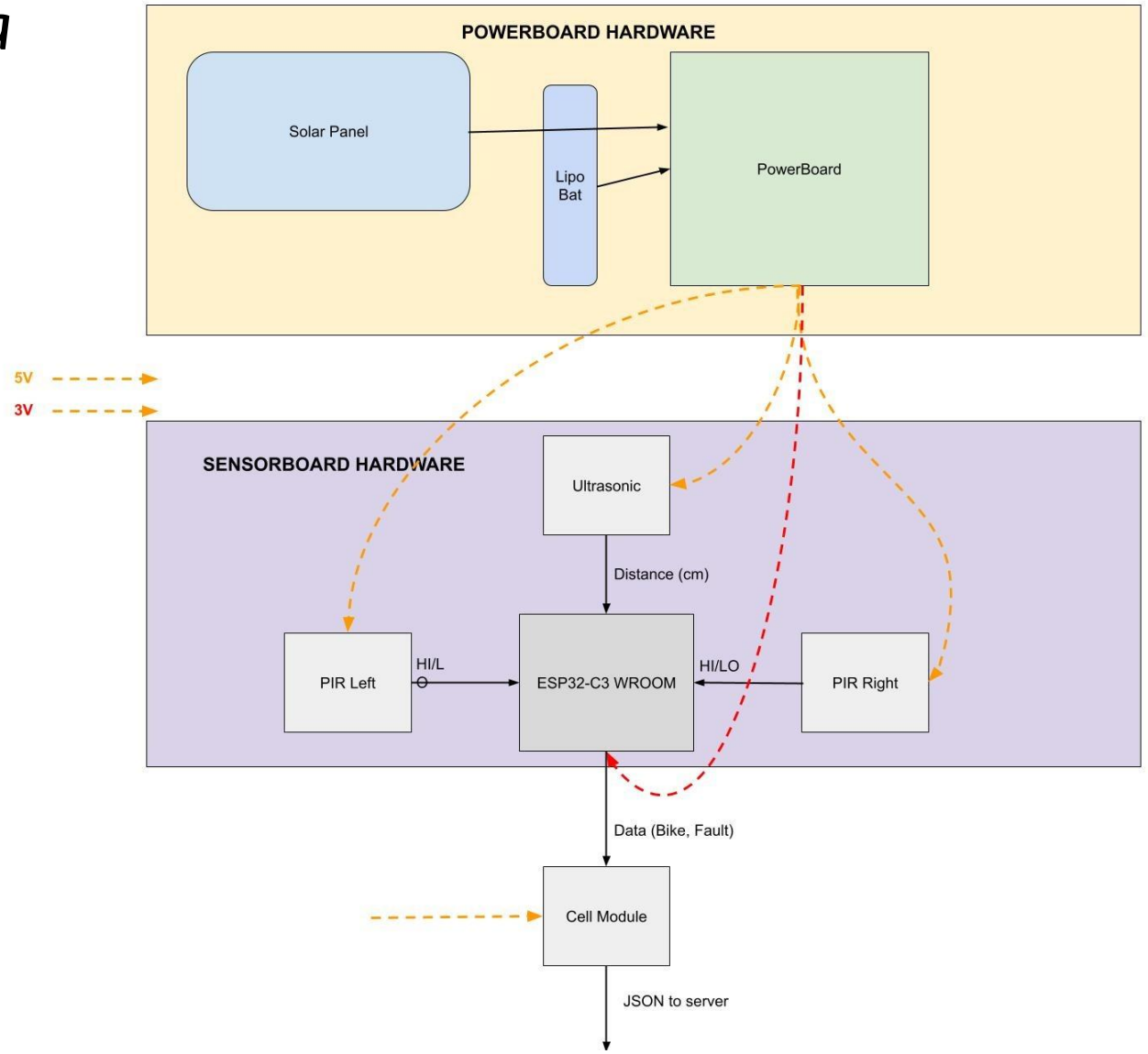
Bike Lane – overall concept - Team 3

- Sense bikes using mmWave radar
- Transmit periodically over cellular
- Use solar panel + battery + sleep for power management



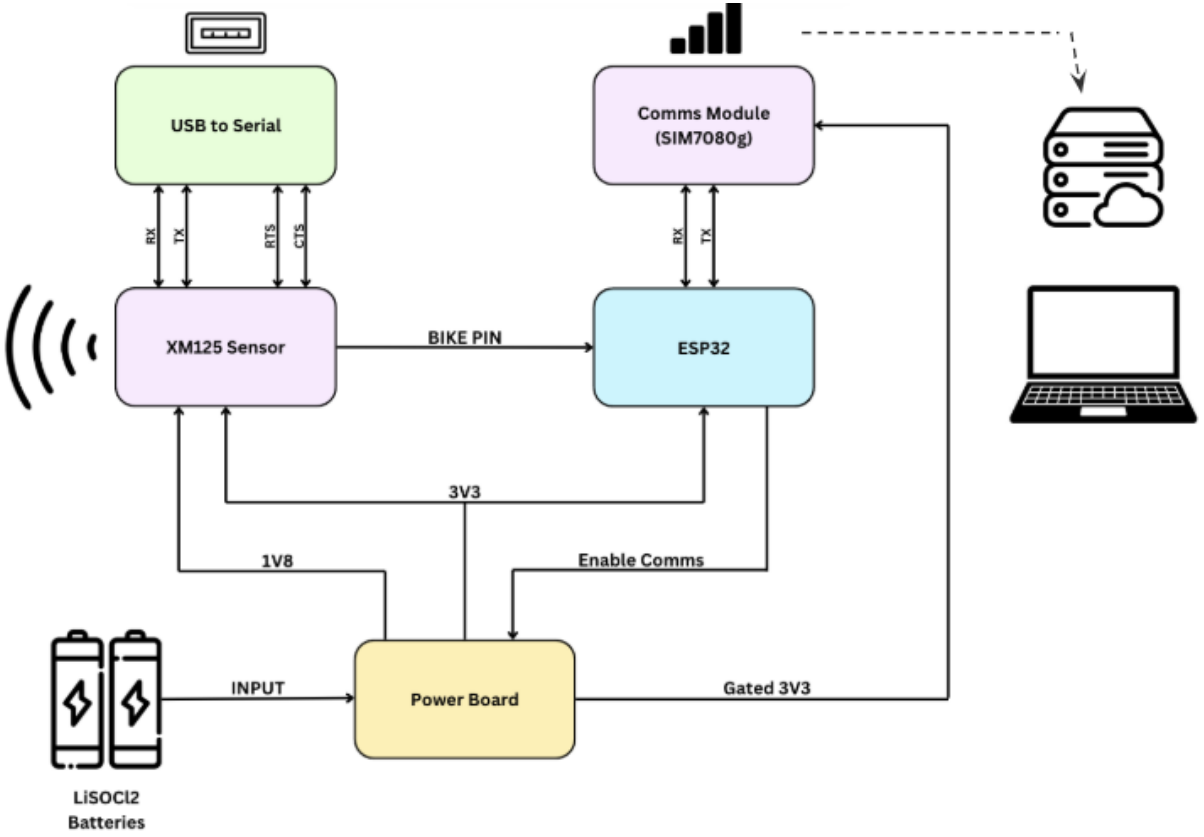
Bike Lane – overall concept - Team 4

- Use PIR to detect objects (*aka* tripwire)
  - Low power
- Use ultrasonic sensor to confirm detection
  - Ensure it is in bike lane
  - Decrease false-positive rate
- Transmit periodically over cellular
  - Every 3 minutes
- Use solar panel + battery + sleep for power management
  - Asleep 1am to 6 am

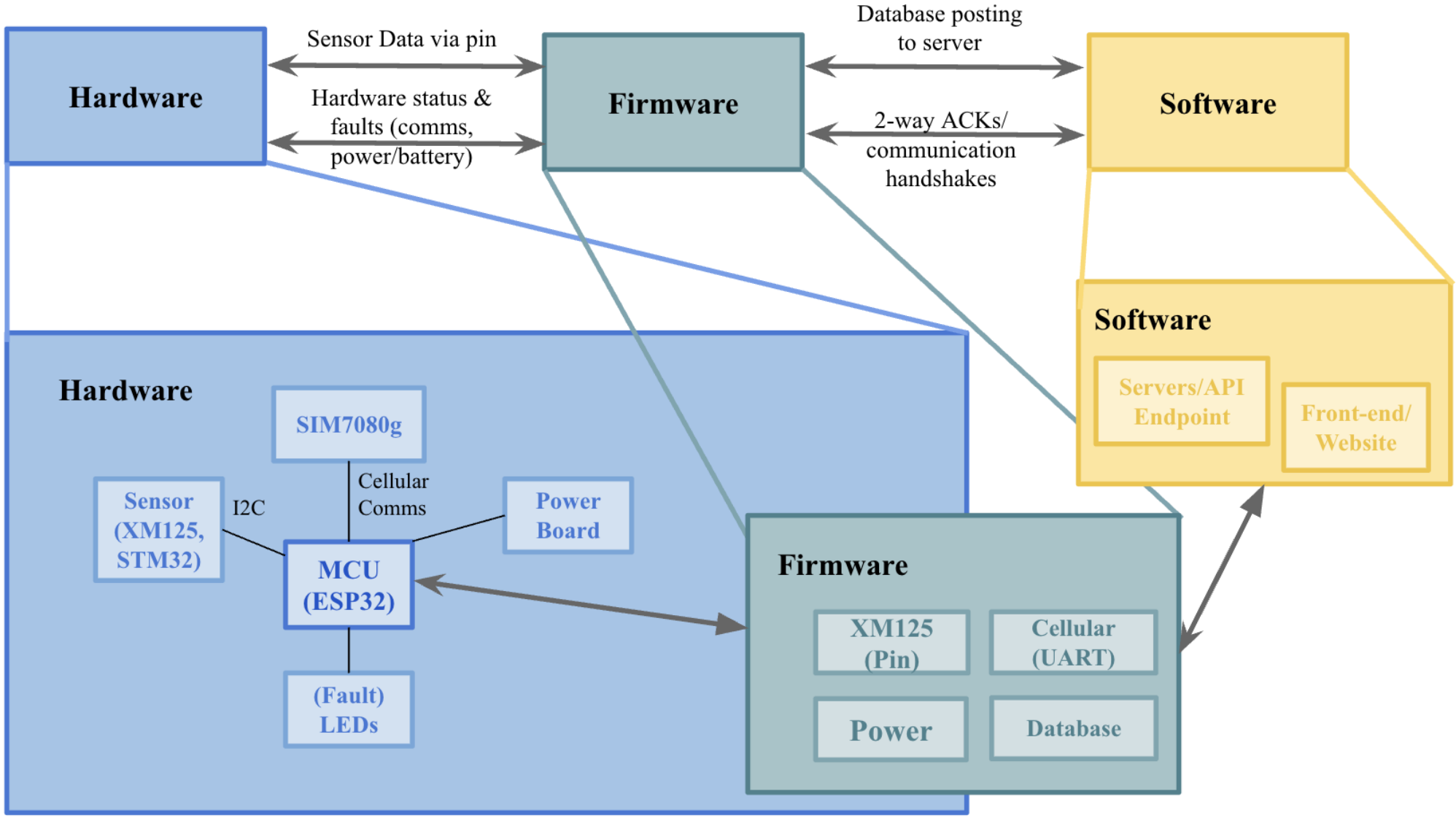


Bike Lane – overall concept - Team 5

- Use XM125 mmWave radar to detect objects
- Transmit periodically over cellular
- Use primary cell + sleep for power management

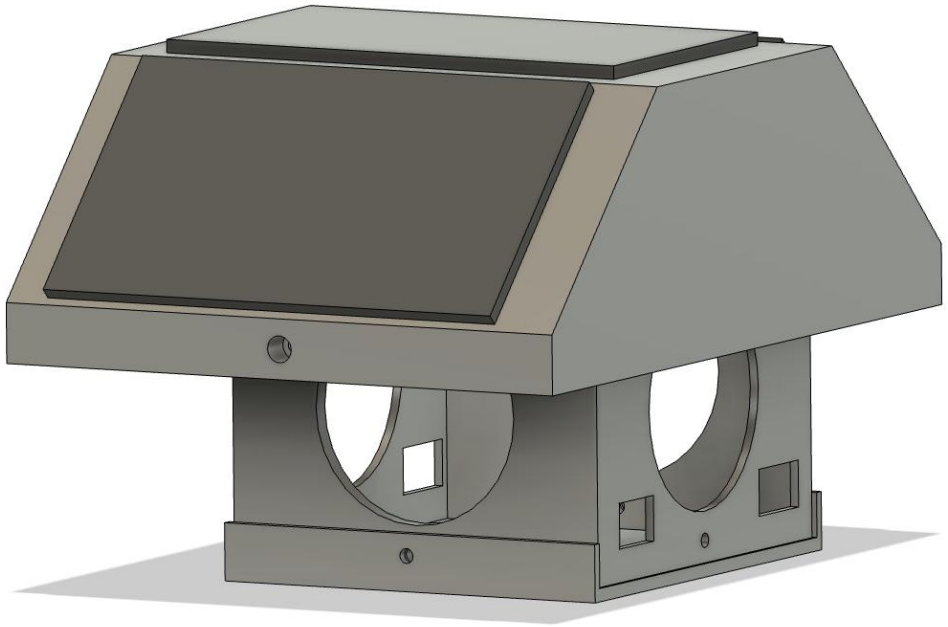


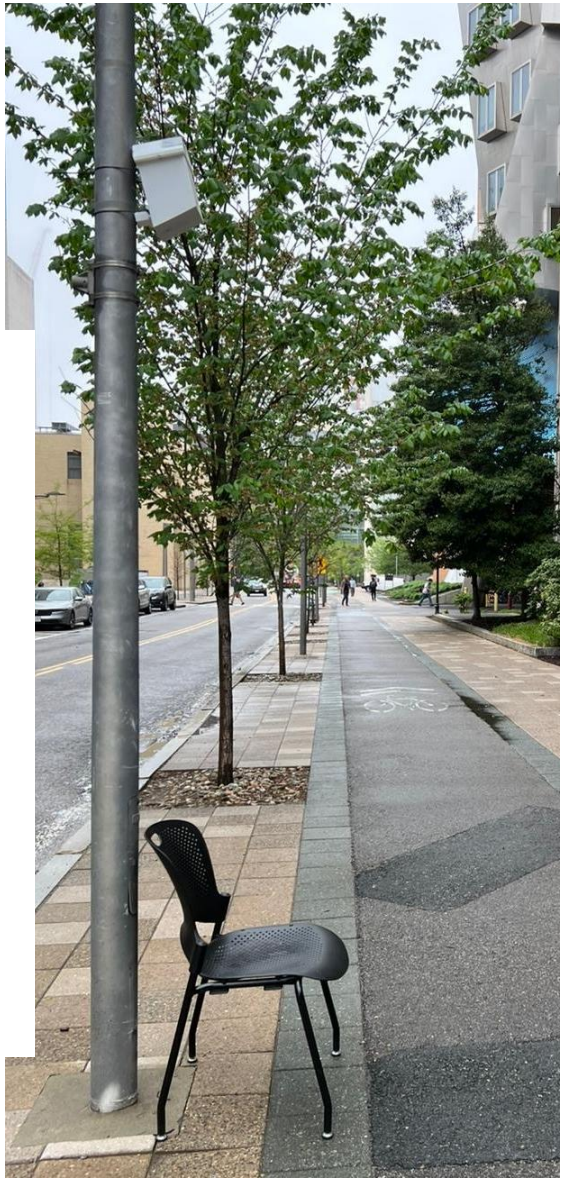
Bike Lane – system diagram - Team 5

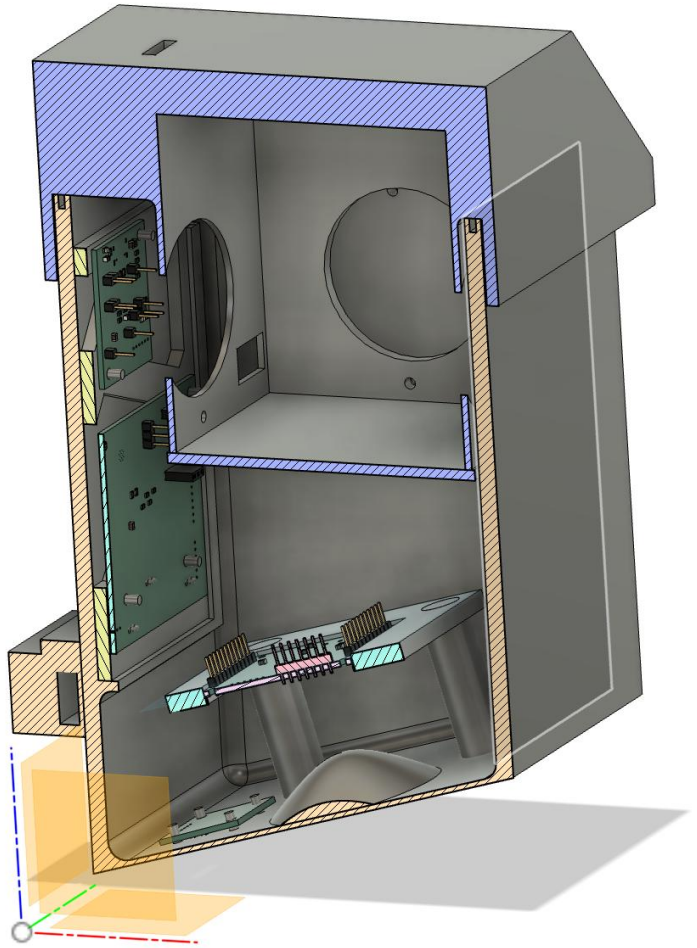


Bike Lane – ID - Team 3

- Mounted high
- Aims down and over



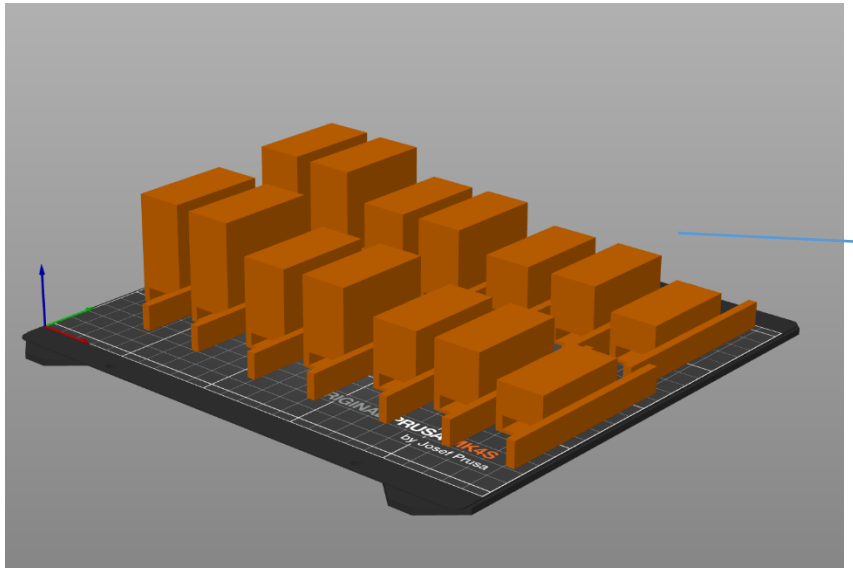


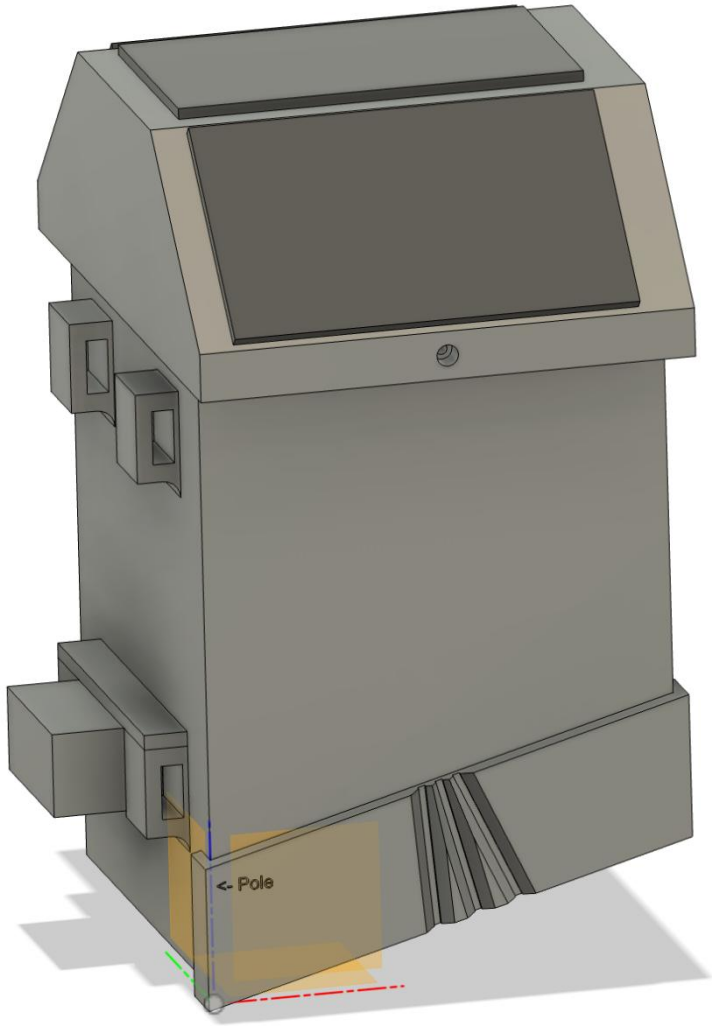


Lid attachment w/o sealing is a bit scary

Bike Lane – ID - Team 3

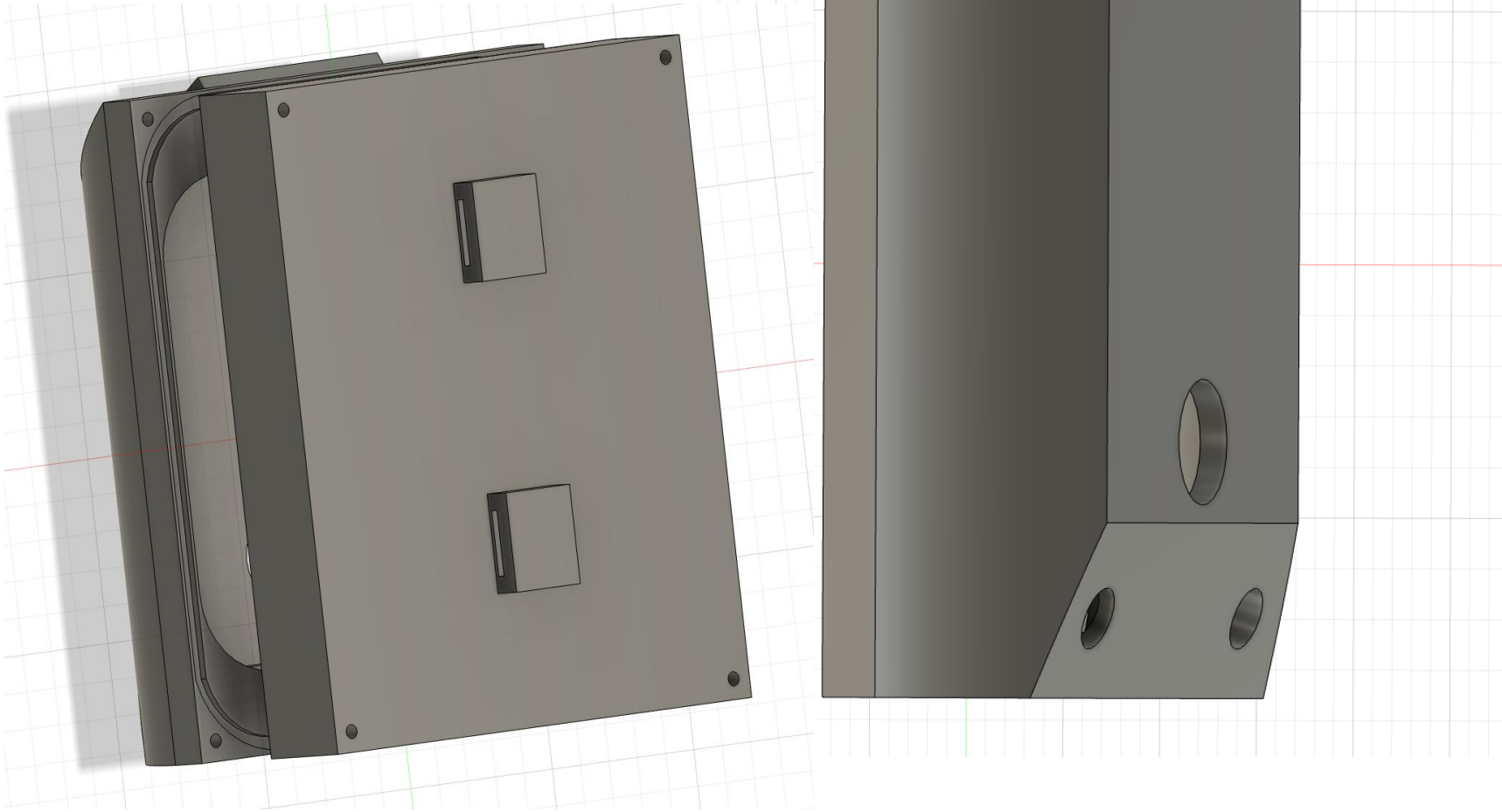
- Alignment blocks for easy alignment





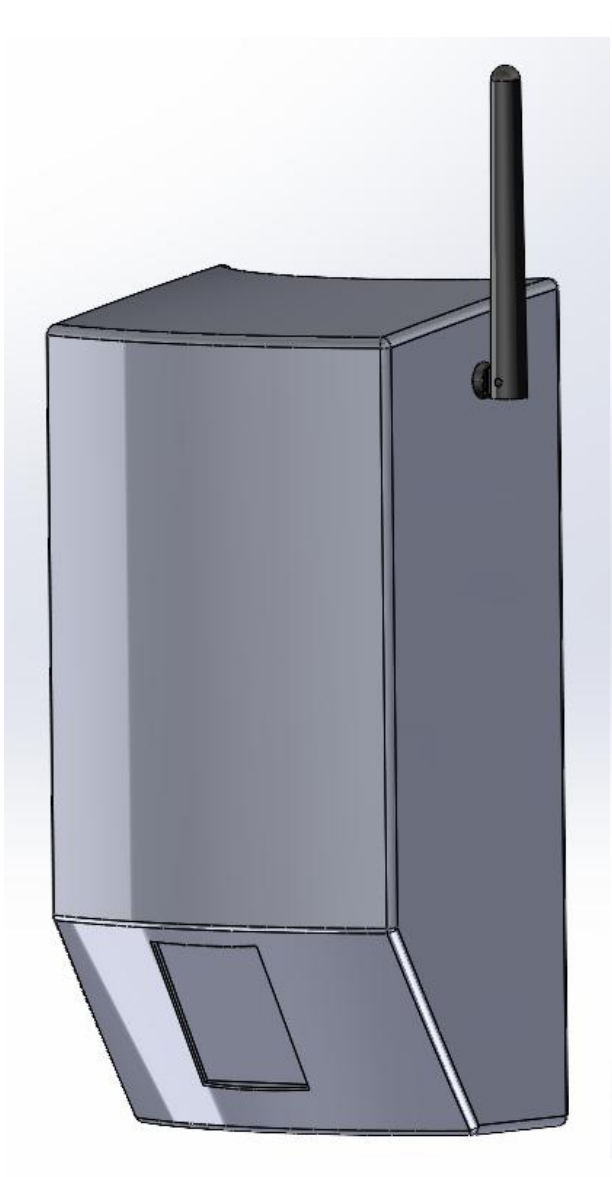
Bike Lane – ID - Team 4

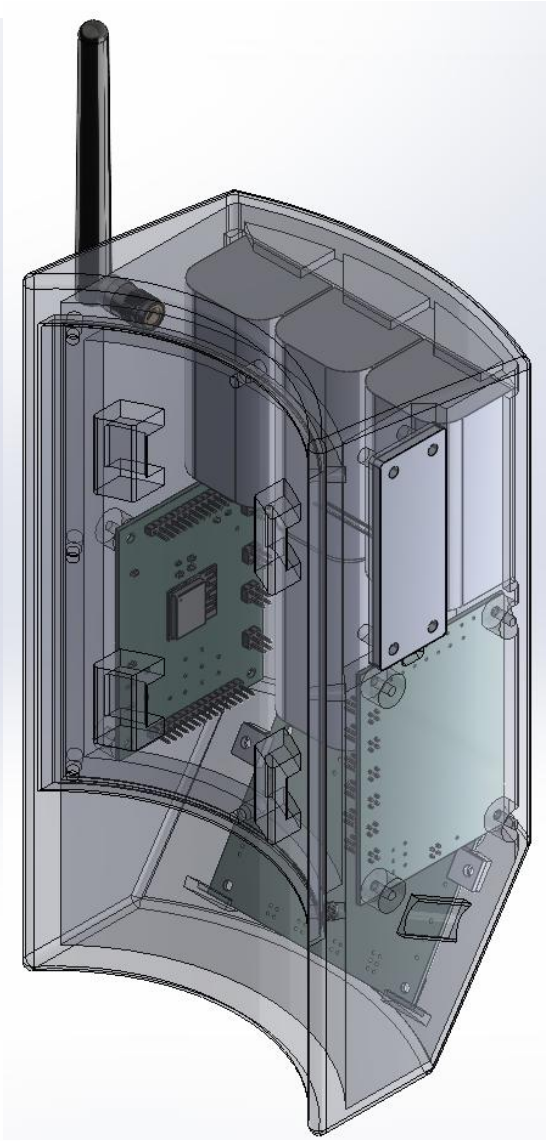
- Use hose clamps at back
- Mounted lower than other teams

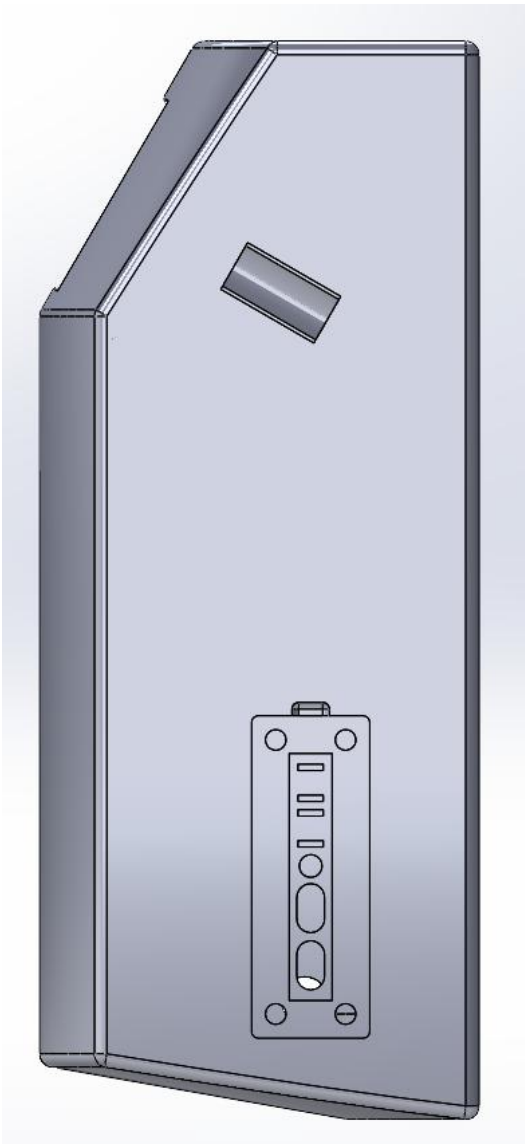


Bike Lane – ID - Team 5

- Parametric design allows easy dimensional change
- Curved back for pole mounting
- Side access panel for USBC, debug LED
- Back panel access to batteries
  - Not so easy to access & change

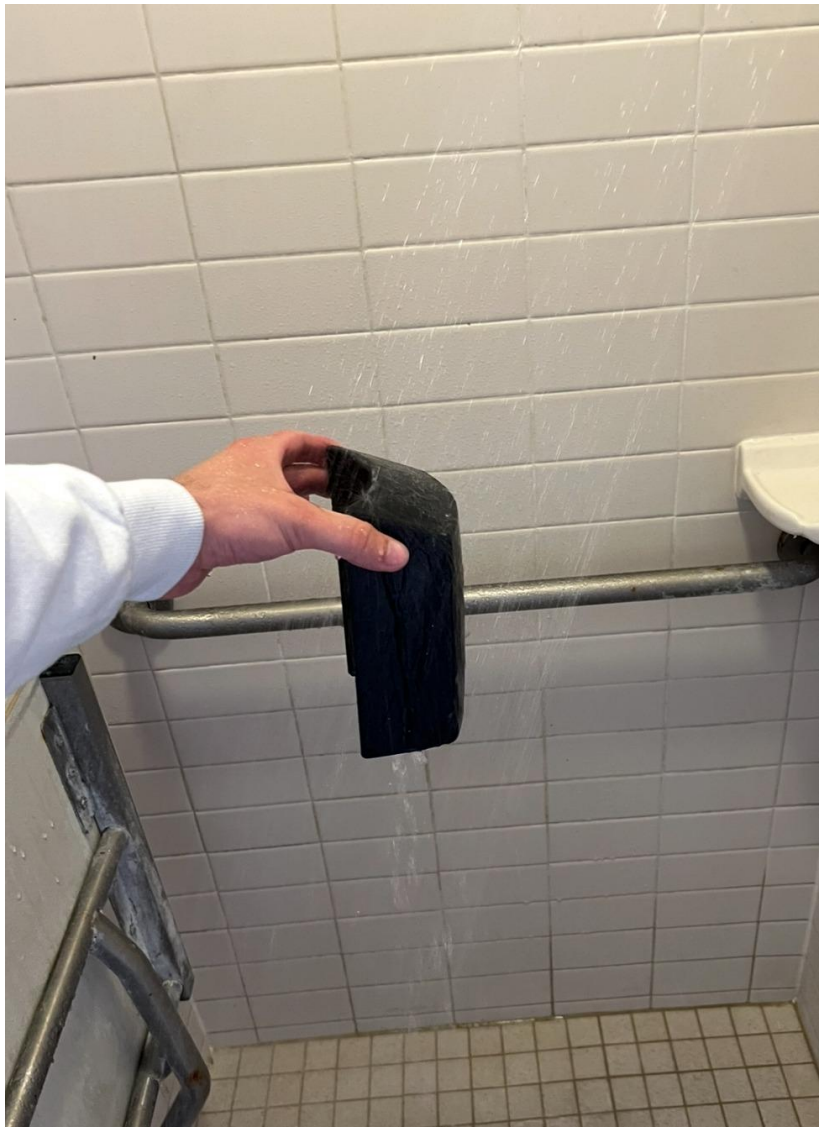






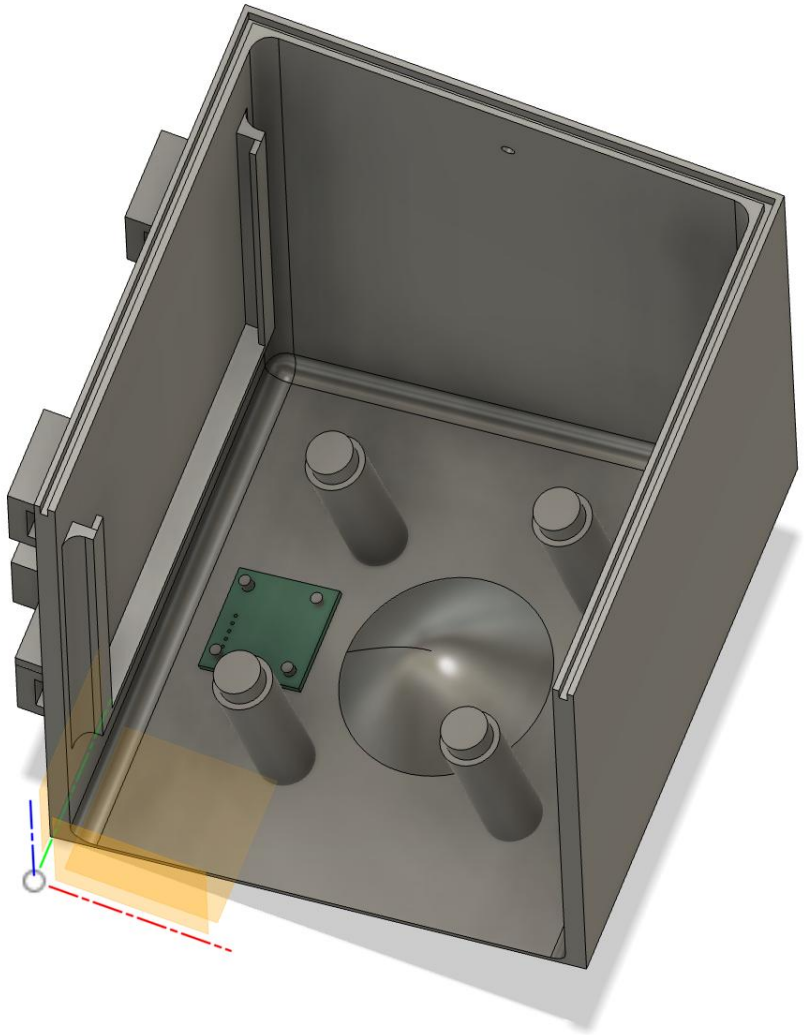
Bike Lane – ID - Team 5

- Waterproofing via
  - Gaskets at openings
  - FlexSeal coating
  - Washers on screws



Bike Lane – sensors - Team 3

- Evaluated several strategies
  - Cameras, PIR, U/S
  - Pivoted to mmWave radar near the end
  - XM125
    - One advantage: does not need window or other external access
    - Uses its own STM32 MCU, so two pieces of FW to deal with
  - Pivoting late caused headaches
  - **De-risk high-risk aspects of your approach early on**
  - **This includes getting substantial data. Early on. Outdoors. In real setting.**



Bike Lane – sensors - Team 4

- Two PIRs + one U/S
  - Pretty low power b/c U/S used intermittently
  - Adds three penetrations in enclosure
- PIR as trip-wire, then confirm w/ U/S and second PIR
  - Can establish direction
- Finding a weatherproof U/S sensor took a bit of work
- Though they didn’t get this approach to work…I think it could work
- Sensing was a high-risk aspect of this project that they didn’t derisk early enough!

Bike Lane – sensors

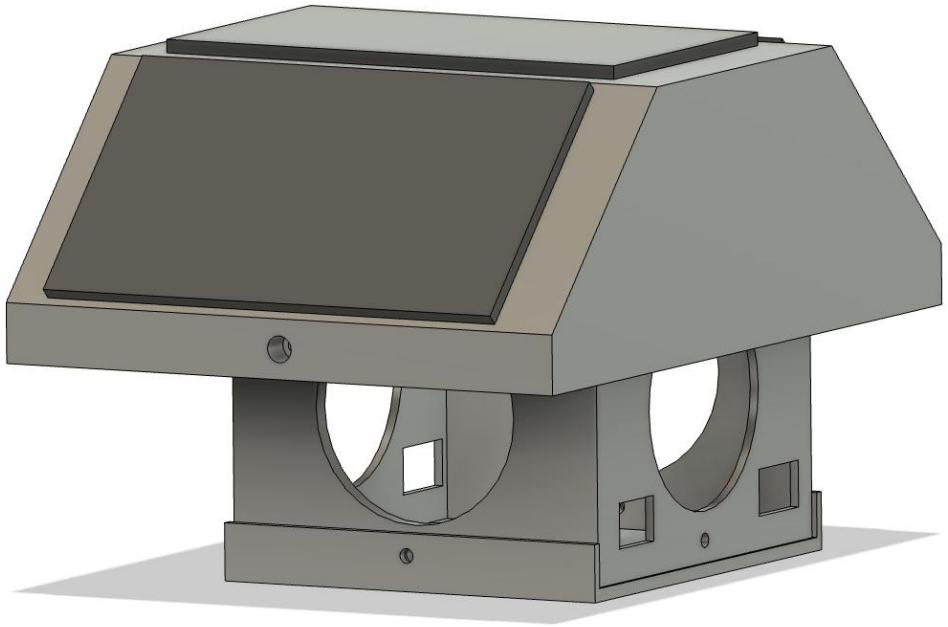
- At least one team evaluated cameras and TOF sensors
- TOF sensors don’t work well outdoor and with necessary distance
  - E.g., VL53L5CX range limited to 2.2m in sunlight
    - Frame rate needed for bike detection draws ≈ 300 mA
- Cameras have power, compute, and privacy challenges

Bike Lane – power - Team 3

- Solar panels + batteries
- Allowed either battery or solar+battery operation

•We chose the ESP32-S3 to utilize more advanced power saving features

•**Ultra-Low Power Coprocessor** handles sensor reading to minimize power consumption: 100 uA vs. 30 mA



Easily accessible battery compartment

Bike Lane – power - Team 3

- Main power drivers
  - Comms: 7 mW average (1x/hr)
  - Compute: 2 mW average
  - Sense: 33 mW average (on continuously) – **not sure what happened to power gating**
  - LEDs: 11 mW average – **Don’t use an always-on LED to report status!**

Bike Lane – power - Team 4

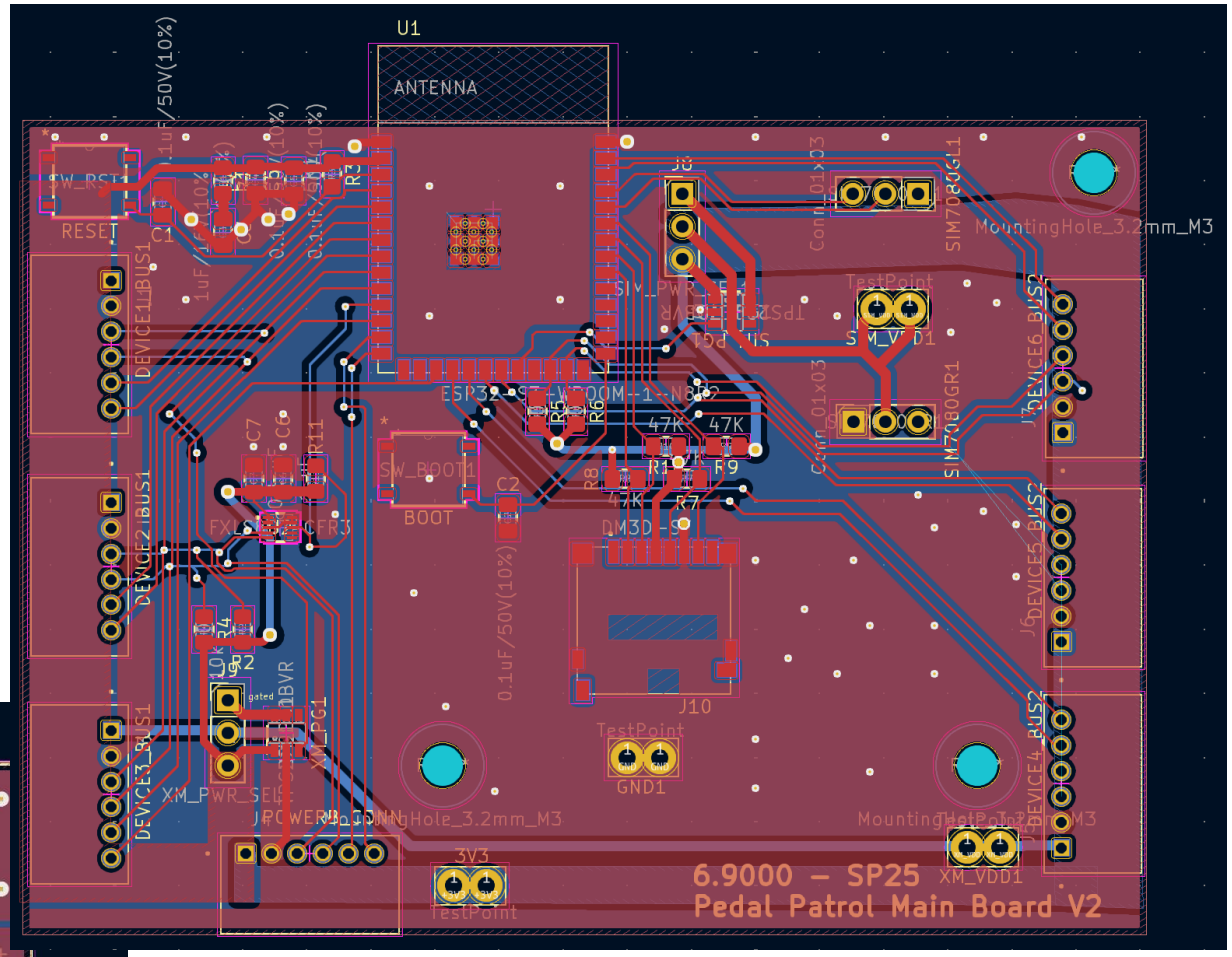
- Similar to team 3, but only one panel
- Don’t have complete power budget, so difficult to draw conclusions as to main drivers

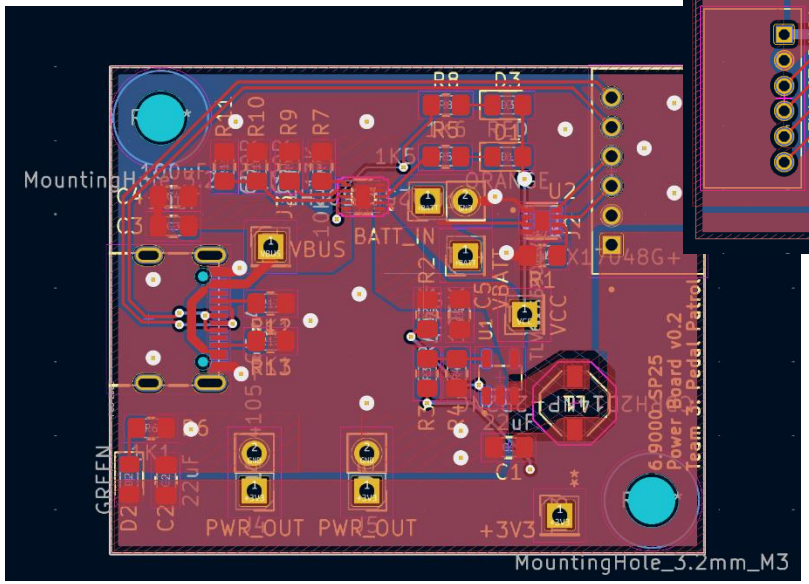
Bike Lane – power - Team 5

- Used primary Li-SOCL2 cells
  - Work well in cold temp (as opposed to Li-Ion, alkaline)
  - 2S2P configuration (I believe)
  - Need to be “burned in” to get started
- Created 3V3 and 1V8 with converters
  - 1.8V for XM125

Bike Lane – electronics - Team 3

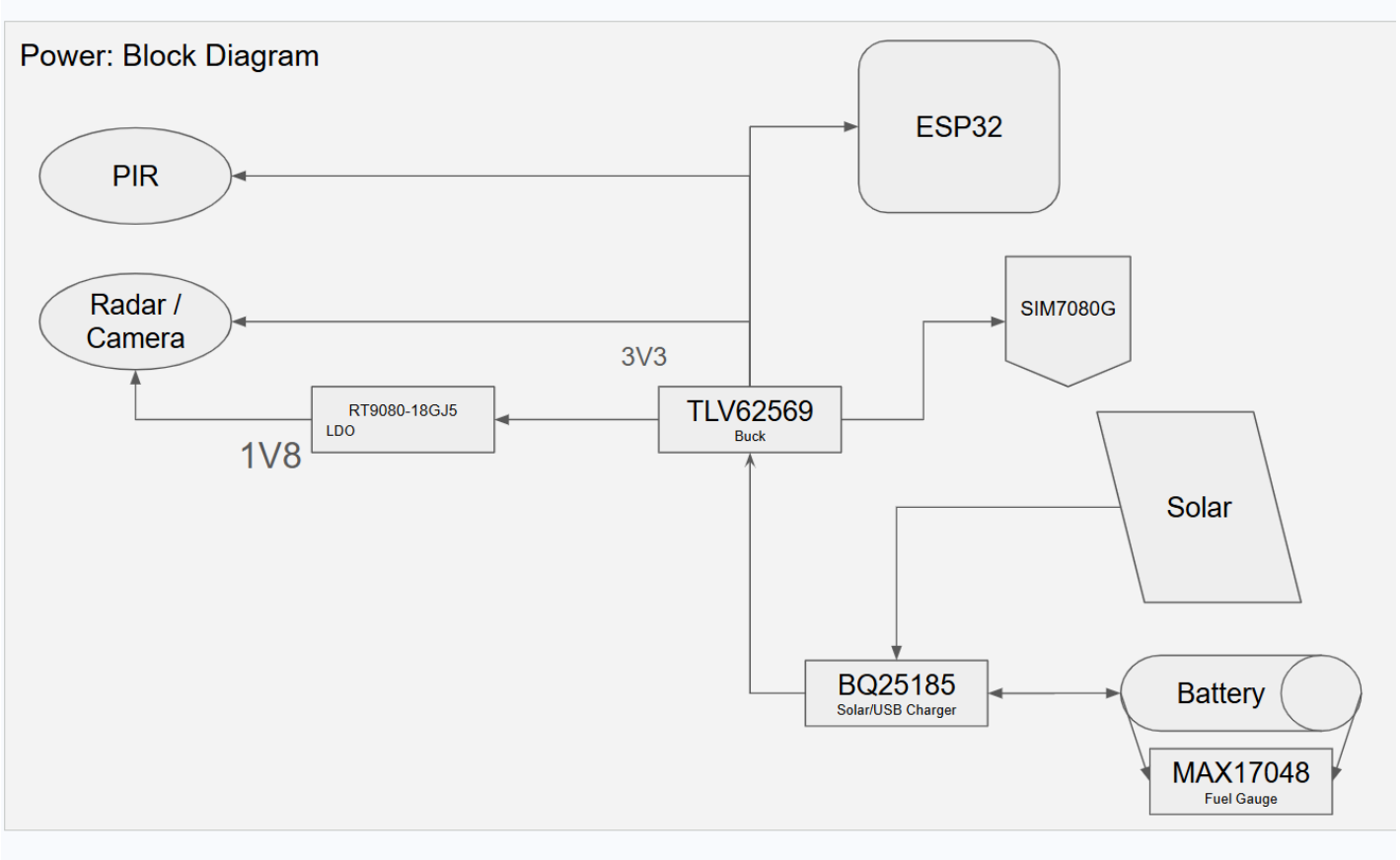
- Main board
  - ESP32S3
  - Load switches
  - Connectors
- Power board
  - USB/solar in
  - Generate various voltages
- XM125 sensor board





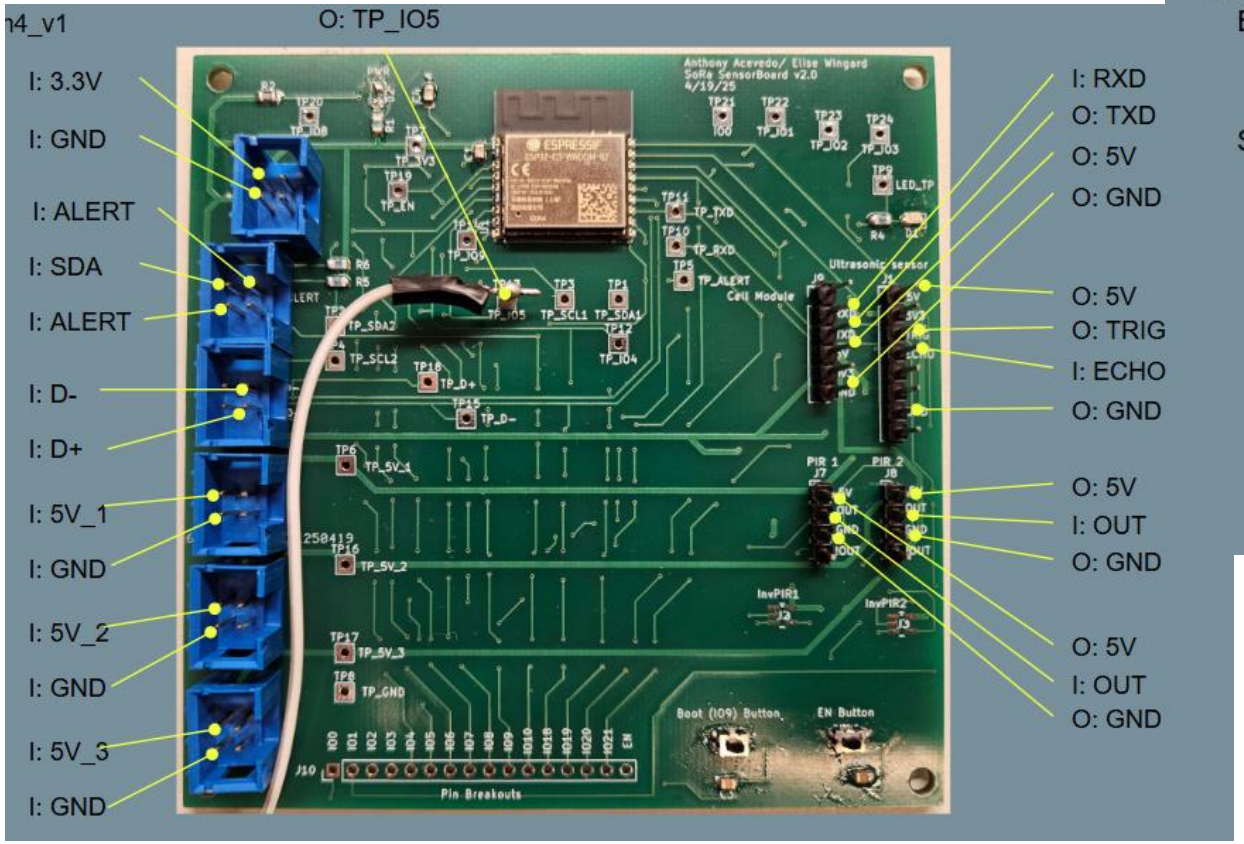
Bike Lane – electronics - Team 3

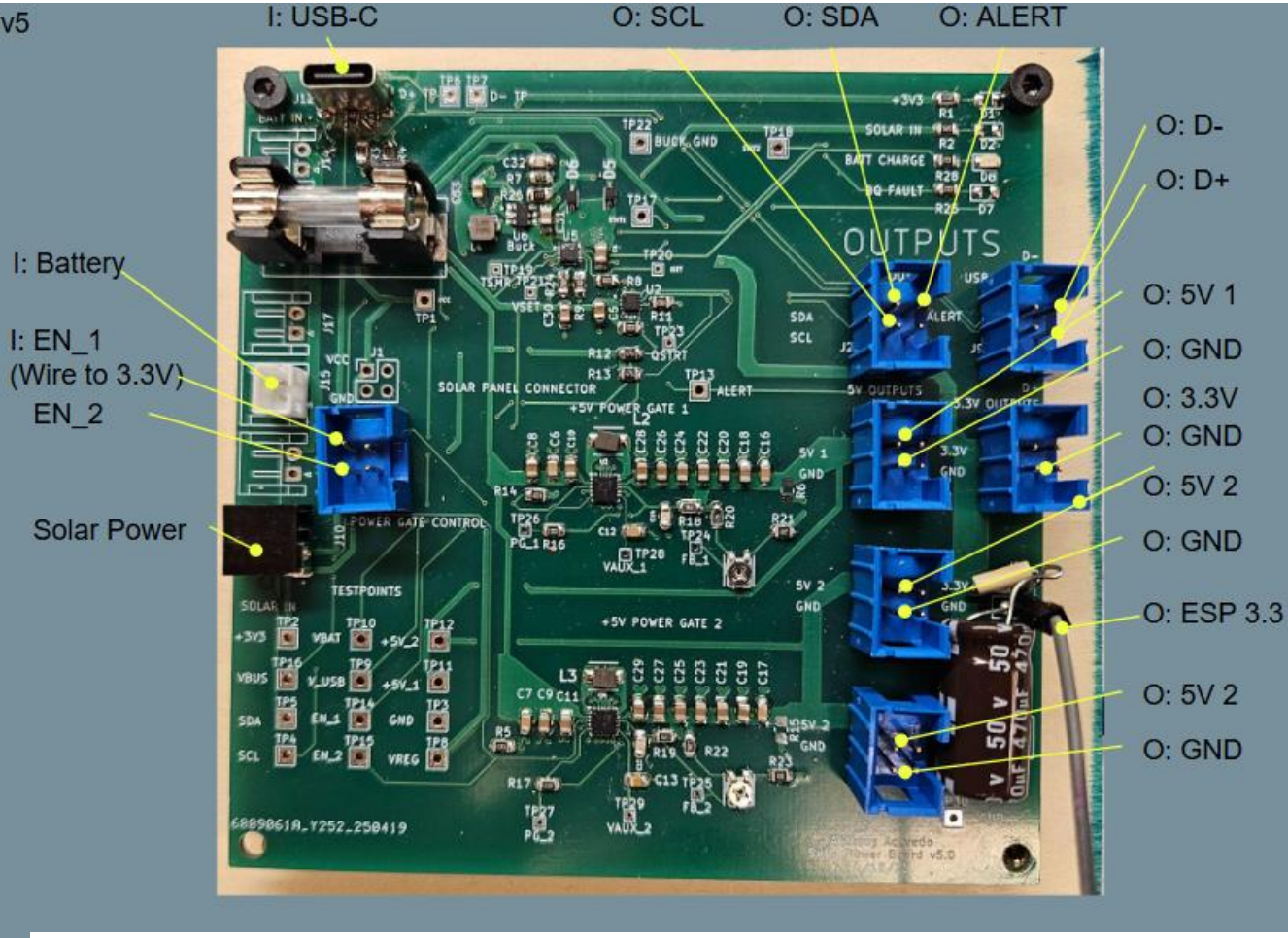
- Load switch for cellular and for XM125 boards
  - Sleep modes/pins not exposed
- XM125 also needs 1.8V



Bike Lane – electronics - Team 4

- Two PCBs
  - One w/ ESP32, connectors
  - One for power management
  - Cellular module just hanging out

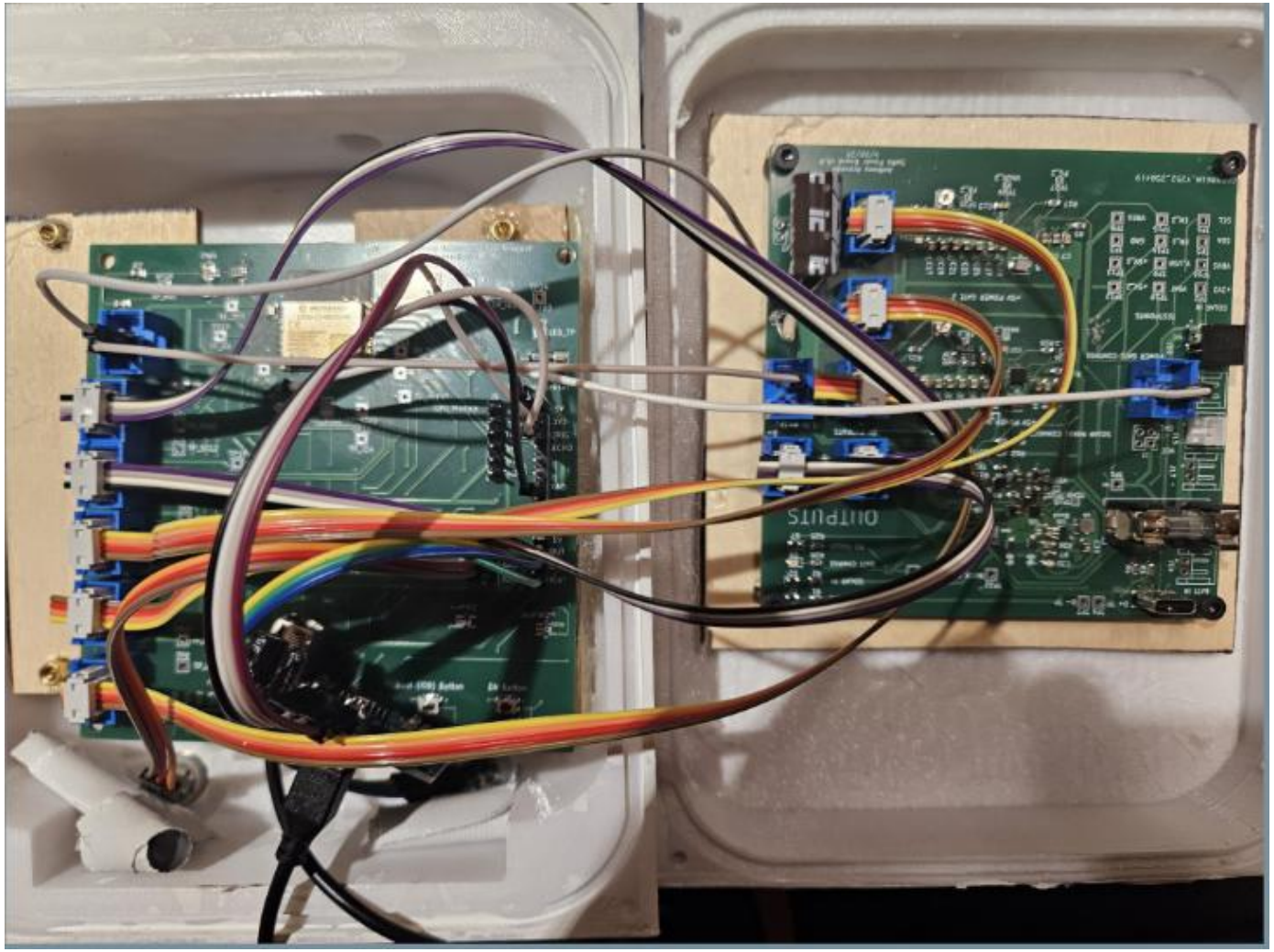




These boards could be a lot smaller

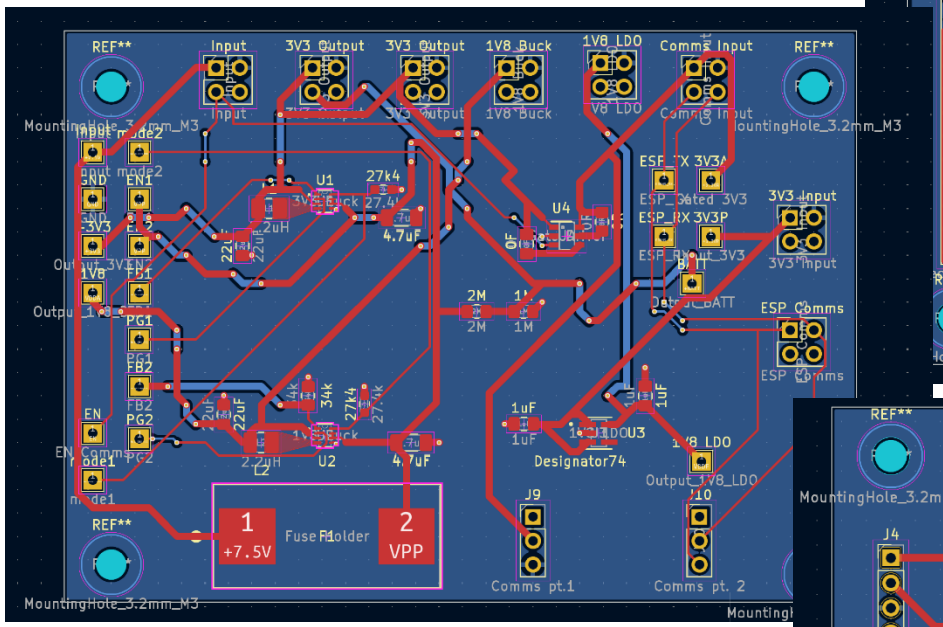
Bike Lane – electronics - Team 4

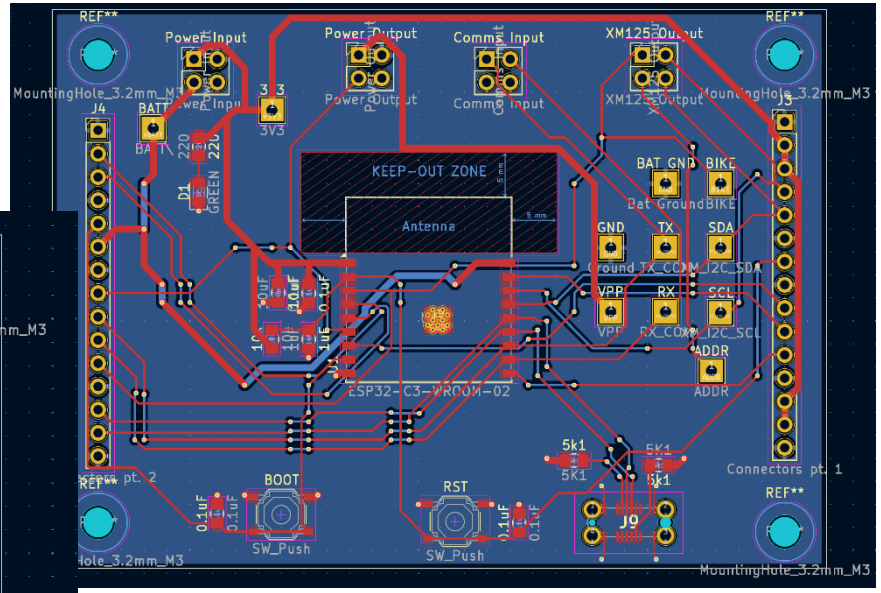
- Good that they used IDC cables
  - Polarized
- Bad that they used wood
- Complicated assembly, everything stuffed in there
- They should have partitioned their electronics differently
  - One cable in-between
  - Mounts for battery, cellular module

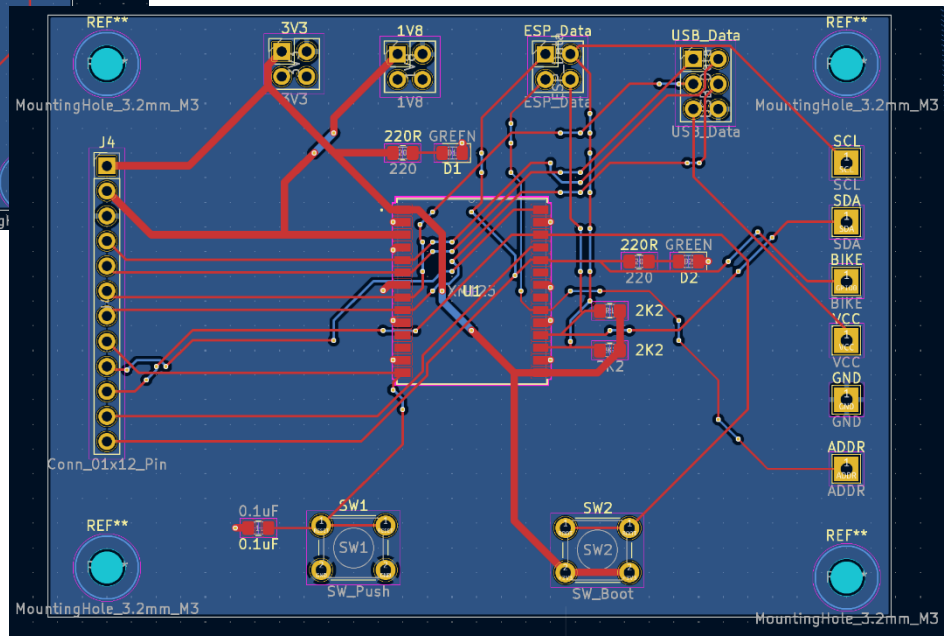


Bike Lane – electronics - Team 5

- Power board
  - Bunch of buck/LDO converters
  - They didn't know which would work
- Sensor board
  - For XM125
- ESP32 board
- These boards are bigger than they need to be
- Did not pay attention to connector pinout…and had issues at final build…had to use individual jumper wires and glue







These boards could also be a lot smaller

Bike Lane – comms

- All teams used cellular modem due to placement in Cambridge where WiFi was not necessarily available
- Some teams initially explored LoRa but not for very long

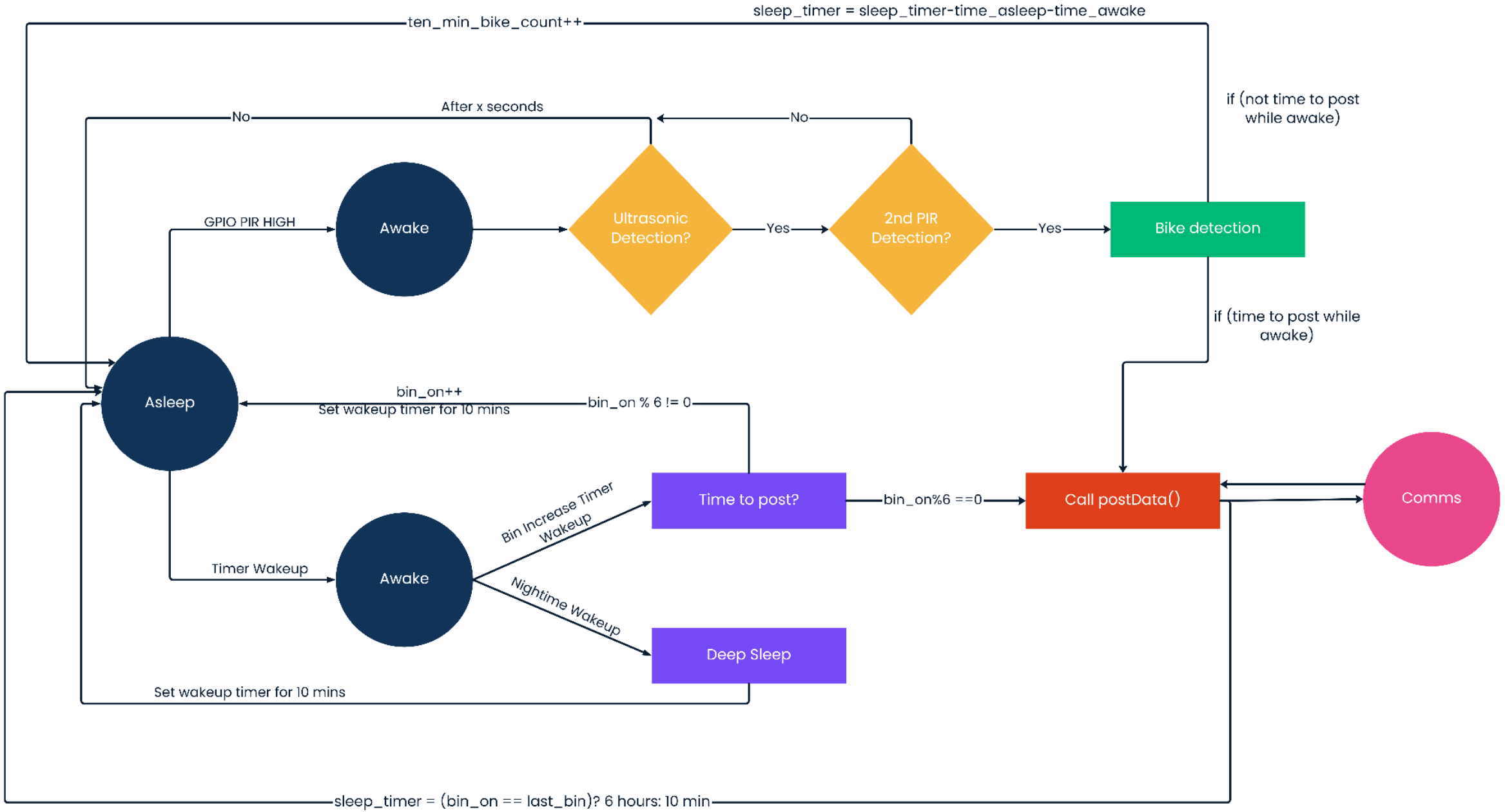
Bike Lane – Cost

- Team 3
  - BOM: $166
  - COGS: $211
  - Cost drivers
    - XM125: $22
    - Solar panels (3): $42
    - Battery: $15
    - Cell module: $39
    - USB-C cable: $8
    - Fuel gauge: $5
    - SIM card: $5
- Team 4
  - BOM: $75
  - COGS: $175
  - Cost drivers
    - U/S module: $16
    - PIR sensors (2) : $6
    - Cell module: $17
- Team 5
  - BOM: $177
  - COGS: $228
  - Cost drivers
    - XM125: $14
    - Batteries (4): $44
    - Cell module: $39
    - USBC connector: $8
    - ASA filament: $17
    - SS tamper-resistant screws (12): $5
    - Flexseal: $7

Bike Lane – FW – team 3

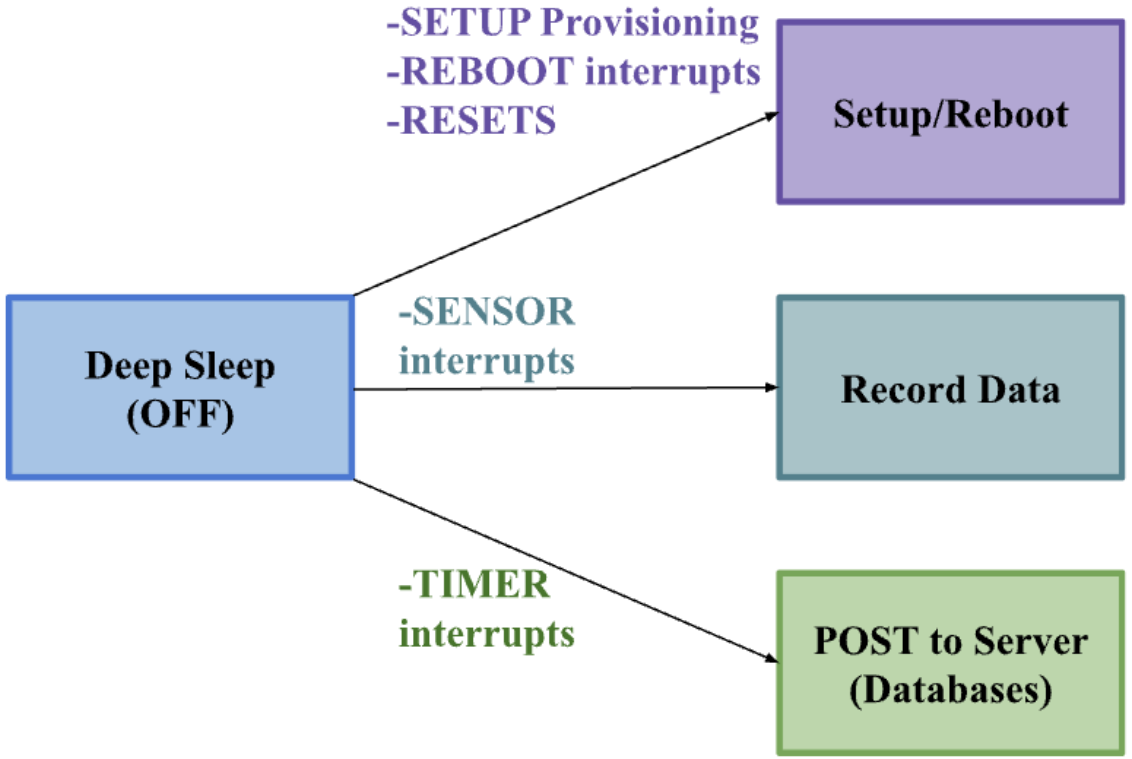
- Couldn’t find…

Bike Lane – FW – team 4



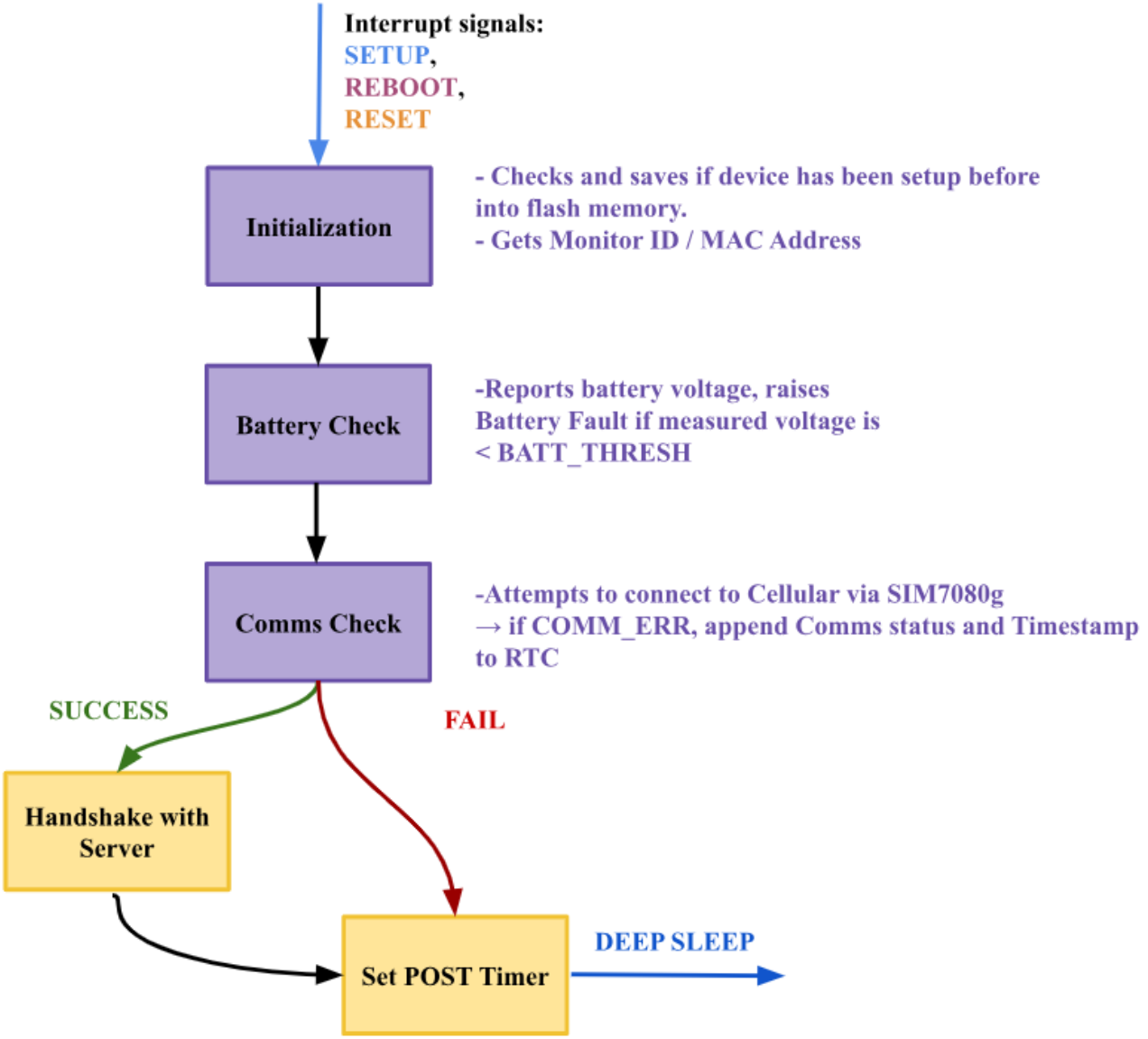
Bike Lane – FW – team 5

- Deep sleep
- Interrupt-driven architecture



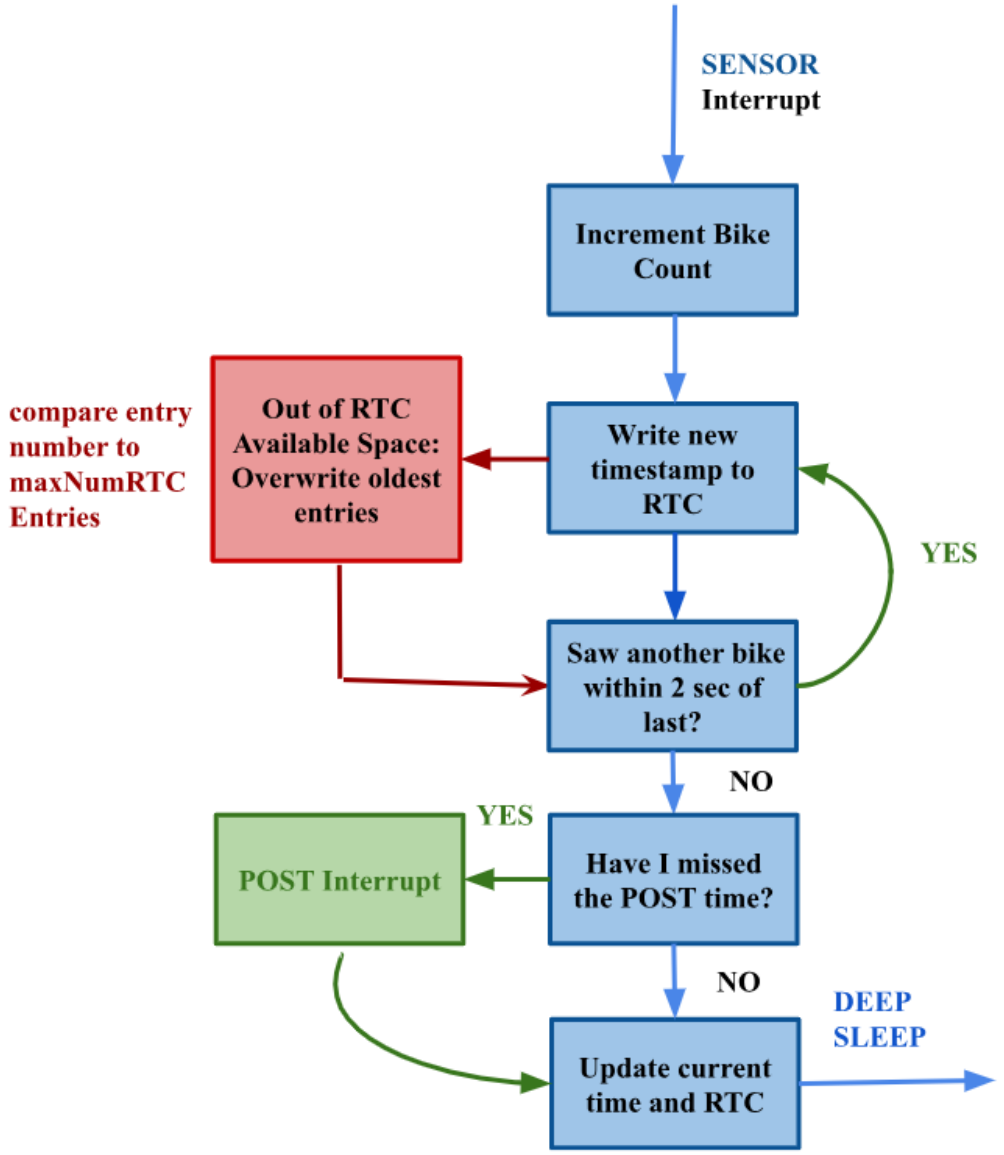
Bike Lane – FW – team 5

- Deep sleep
- Interrupt-driven architecture



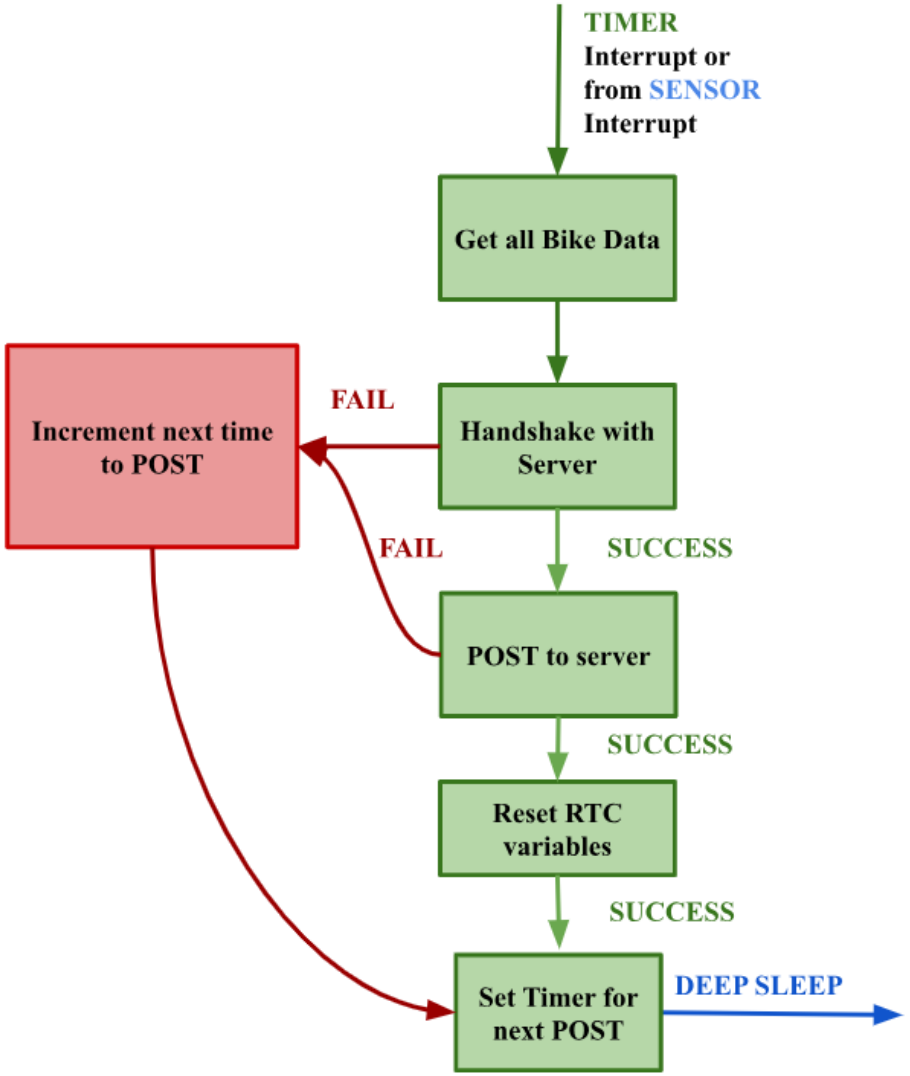
Bike Lane – FW – team 5

- Deep sleep
- Interrupt-driven architecture



Bike Lane – FW – team 5

- Deep sleep
- Interrupt-driven architecture

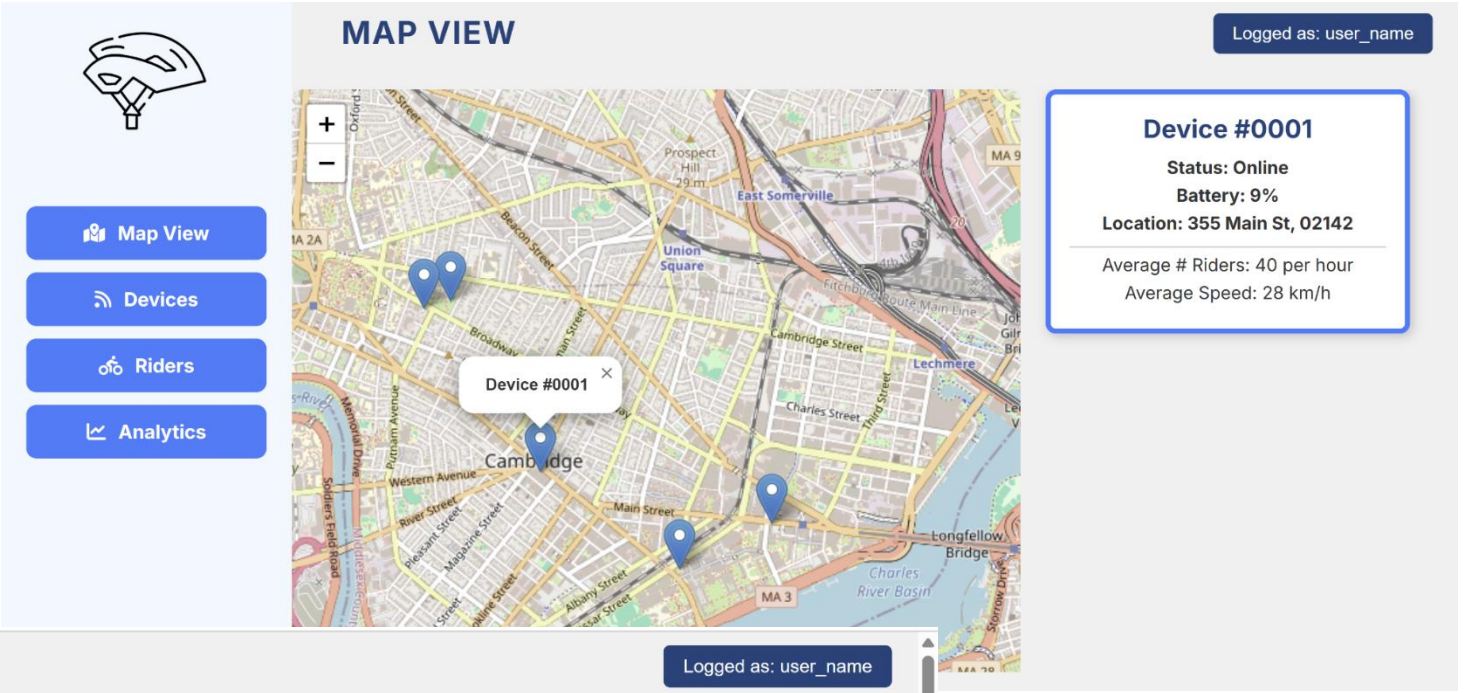


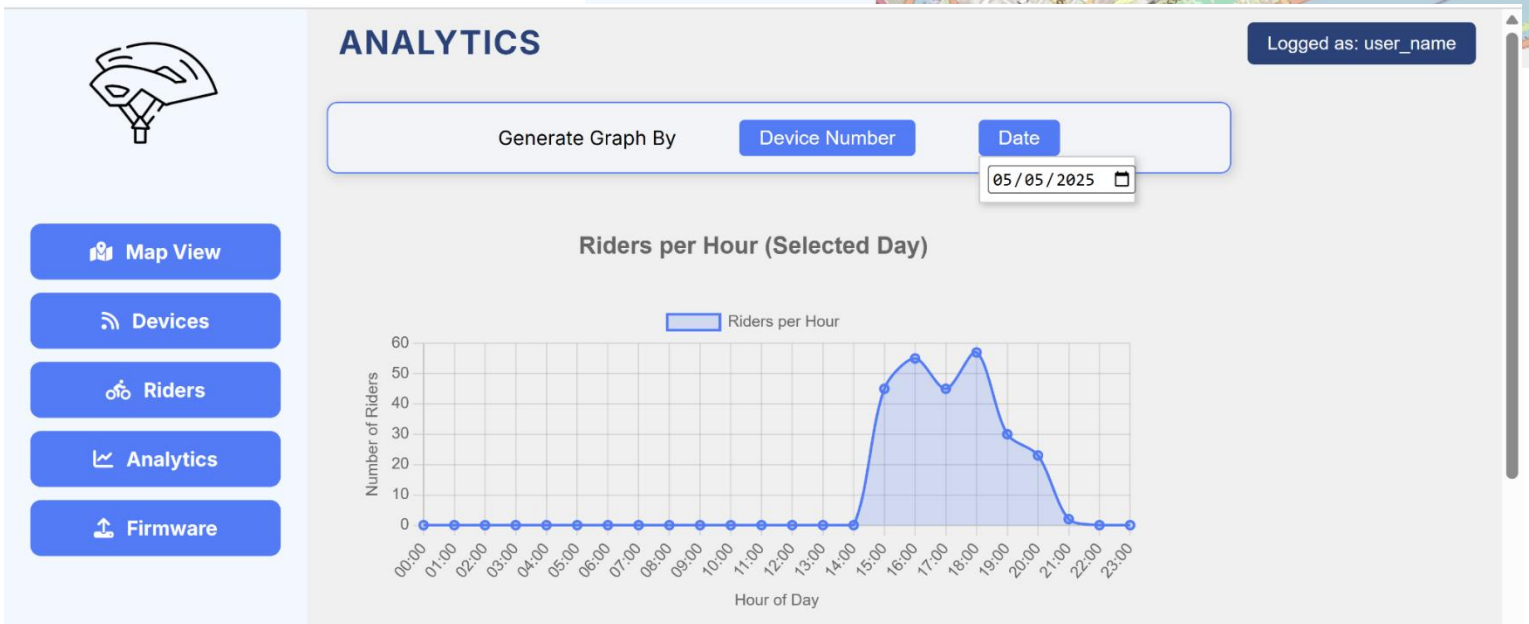
Bike Lane – FW – team 5

- FW supposedly had OTA working
- But Team left FW in debug state
  - Transmitting every 5 min instead of once an hour
  - Killed batteries in a few months
- Staff was unable to switch debug state
  - Because FW was left with several unmerged branches
  - FW had hardcoded debug state with MAC addresses (or something like that)
  - We didn’t want to merge and mess everything up

Bike Lane – front end – team 3

- What I like
  - A bit more intuitive front-end
  - Nicer plots
- What I don't like
  - Still unclear what is devices vs. riders vs. analytics
  - Cannot select date range
  - Cannot compare devices





Bike Lane – server – team 4

sensor_report POST endpoint:
•Receives from unit:
- Bike count array form the last hour
- Current battery percent

•Returns to unit:
- Current time as 64 bit unsigned integer
- Milliseconds until 6am
- Total number of bikes recorded from packet

setup_station POST endpoint:
•Receives from user:
- Station name
- Longitude
- Latitude

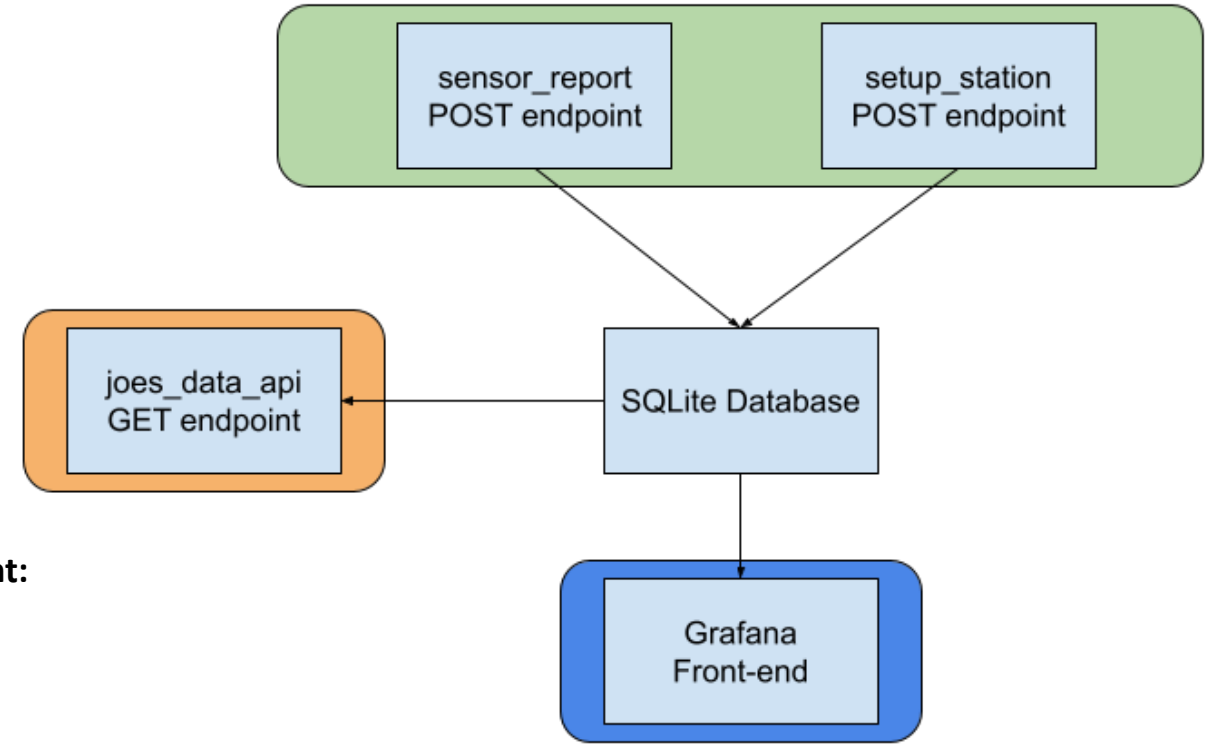
•Returns to user:
- Station ID

SQLite Database:
•Stores for each station ID:
- Name
- Longitude
- Latitude
- Reported bike bins
- Battery percent

joes_data_api GET endpoint:
•Request parameters:
- Station ID
- Start timestamp
- End timestamp

•Request response:
- Station name
- Station longitude
- Station latitude
- Timestamp bike count bins in 10-minute intervals

Grafana Front-end:
•Displays:
- Bike counts in 10-minute buckets
- Current battery percent
- Location of unit



Grafana was running on external server, so when semester ends…poof!
Now we require using our servers…

Bike Lane – server – team5

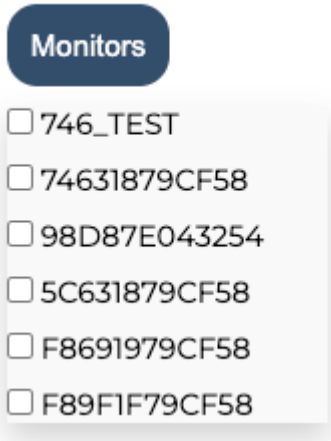
Finalized data sent to Server:

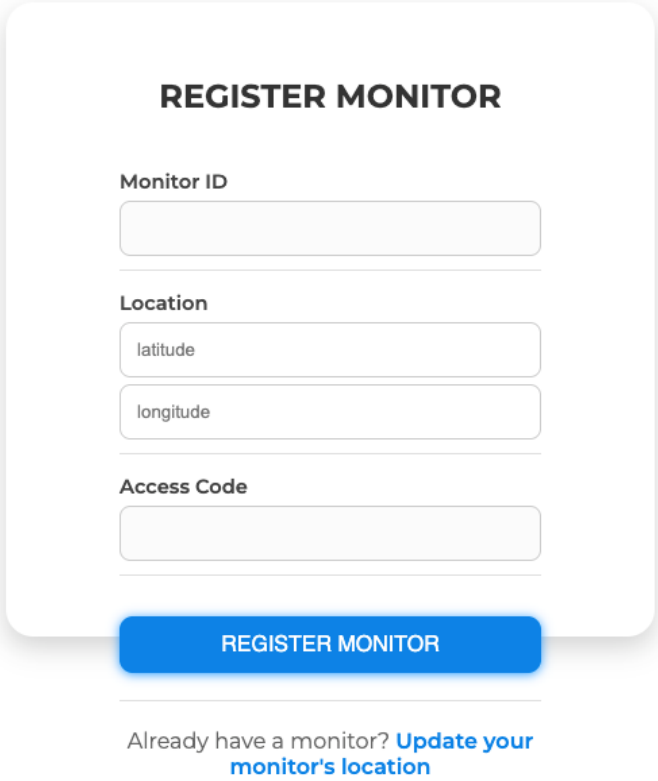
- Device’s Monitor ID (unique ID)
- Firmware Version
- Faults ID
- Battery Voltage
- List of timestamps where a bike was seen

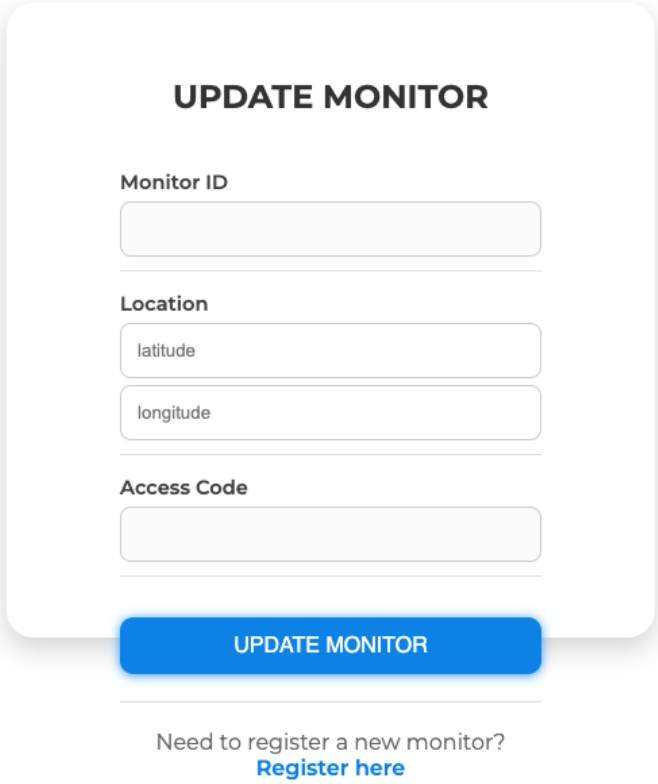
Data sent in 20-timestamp chunks every hour

Bike Lane – server – team5

- What I like
  - Can register & move systems
  - Can filter by date range
- What I don't like
  - Monitors are described by MAC address







Bike lane – accuracy – Team 3

- Claim 100% bike detection & 100% car rejection
  - Over 17-minute hand-classified test

This is certainly not true in long-term

Bike lane – accuracy – Team 5

- Did comparison to hand-counting
- Main issues were large trucks (FP) and back-to-back bikes (FN)
- Used some simple high-pass + peak detection to try to minimize

BIKES (non-motorized)	65
BIKES (motorized)	8
BIKES (runner/walker)	2
MISS BIKES (b2b)	0
MISS BIKES (other)	0
FP (Large Vehicle)	5
FP (other)	0

Industrial design &
Enclosure design

Form and function

- Your enclosure & front end communicate with the user
  - Enclosure: Color, shape, texture, user experience
  - UI/UX: Different users, including partners, staff, you, community, etc.
- Each should meet certain specifications
  - Enclosure: Ingress protection, easy of assembly, etc.
  - Front end: Data visualization, security, etc.

Think about how each will interact with the [you, partner, installer, debugger, etc.] and make sure to design for those use cases

Industrial design

- You have access to 3DP – don’t make a rectangular box unless you **choose** to make a rectangular box
- Form can convey information

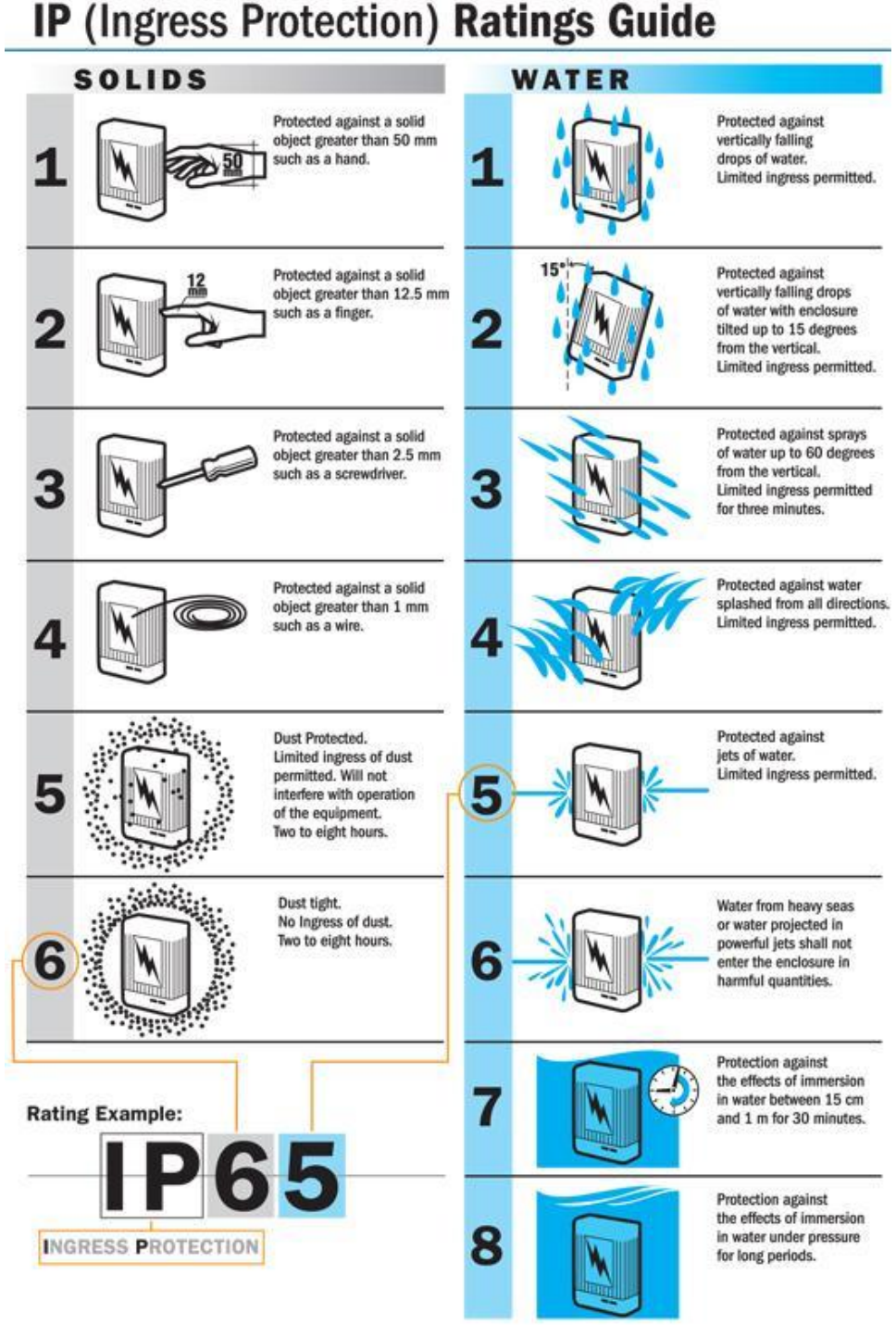
Form can convey information…

UI/UX for front-end

- We can arrange for partners to critique your dashboard, or your enclosure

Ingress protection

- What can your device handle?
- IP, NEMA ratings
- Typical outdoor use: IP44 – IP65
- We are not going to officially test for these ratings, but it is important to think about what you need to survive



Ingress protection

- What can your device handle?
- IP, NEMA ratings
- Typical outdoor use: IP44 – IP65

iPhone 17: IP68

Bose QuietComfort: IPX4

Ubiquiti G6 Pro Turret: IP66

Enclosure material

- In general you can choose plastic, metal, etc.
  - Differences in mechanical properties, ability to form/machine, cost
  - Electrical differences as well
    - Metal – faraday cage
    - Plastic – no shielding
- For 6.900, we are using 3DP
  - Plus laser cutting, milling, etc.
  - Wide latitude in geometry – it is not harder for the 3DP to print a cylinder vs. a rectangular solid

Enclosure material for outdoor use

- We care about
  - Sun: UV exposure & heat
  - Rain/water/moisture absorption & permeability
- ASA > PETg >>PLA
- We will use **PETg** for all prints

Enclosure material for outdoor use

- You can coat or paint your enclosure for added UV and water resistance
  - Acrylic spray paint
  - FlexSeal
- You may need to prime
- You may want to sand
- You may want multiple coats, top clear coat, etc.

Enclosure design for outdoor use

- Avoid depressions or horizontal flat surfaces that can collect water

Better

Worse

Enclosure design for outdoor use

- Avoid depressions or horizontal flat surfaces that can collect water

Better

Worse

Enclosure design for (any) use

- **Use asymmetry** to make it obvious how different pieces go together
- **Use lips** on your lid

Worse

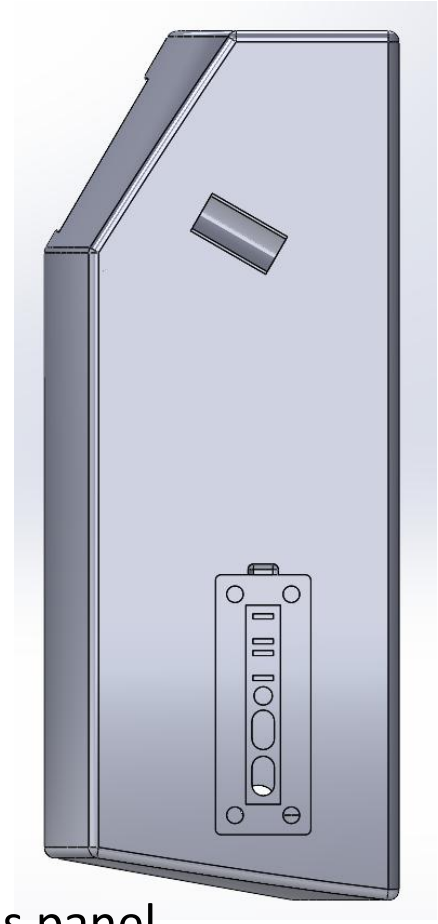
Better

Sealing your enclosure

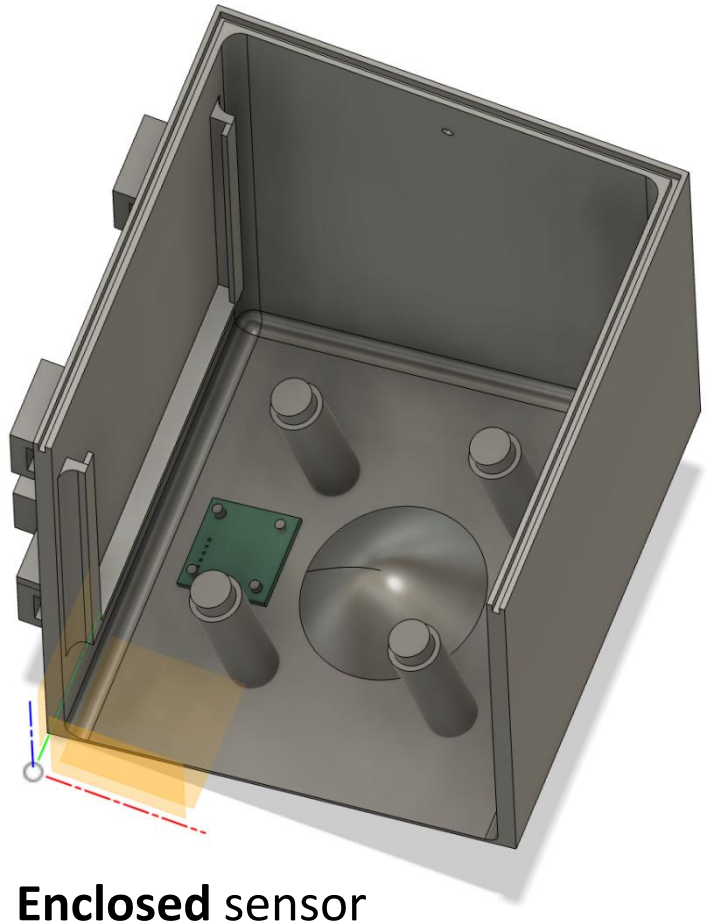
- You will have at least two parts to your enclosure
- You will also have openings (penetrations)
- **Water is the enemy**

Sealing your enclosure

- Strategy 1: minimize number and size of openings
- Strategy 2: place openings away from weather



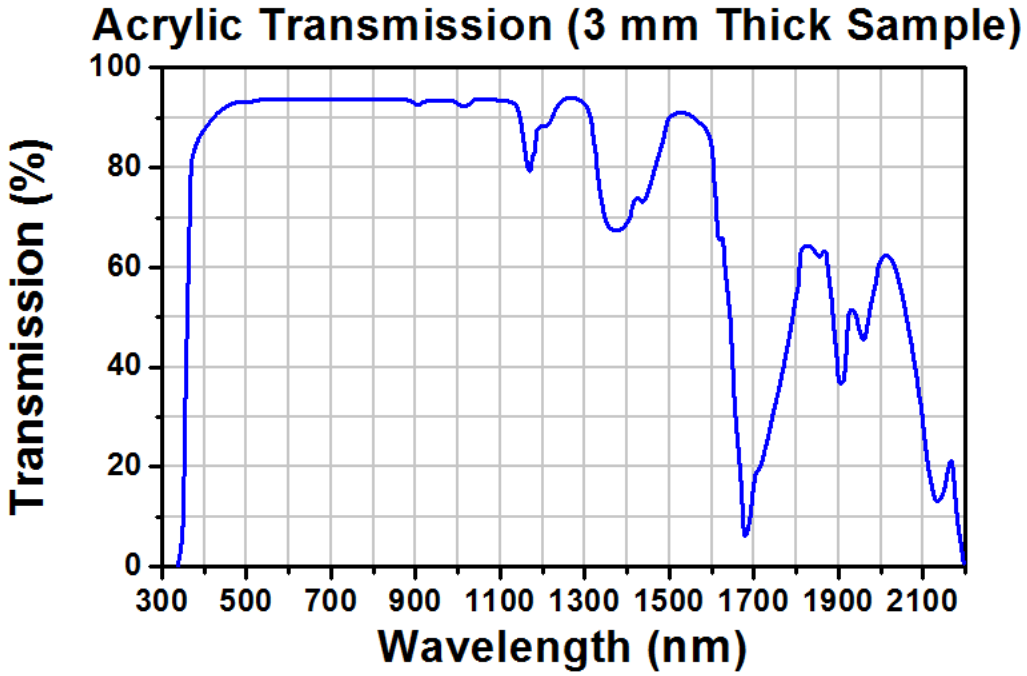
Side access panel



Enclosed sensor

Sealing your enclosure

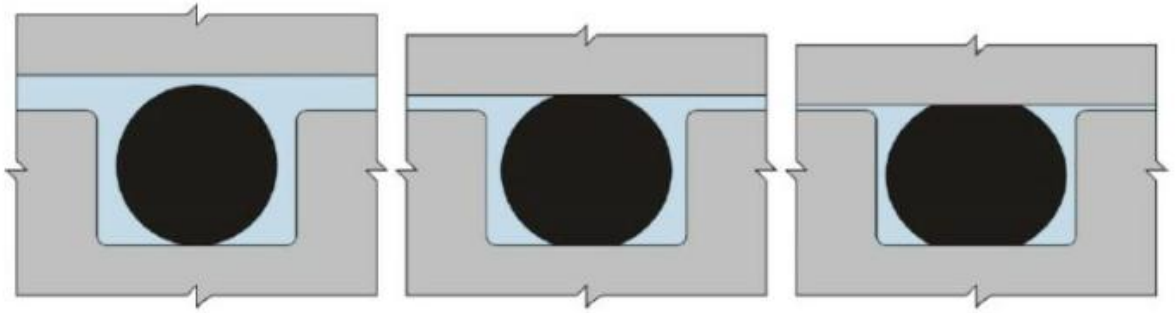
- Note: you may need more penetrations than you think
- Sensor access
  - Visible light: easy, use plexiglass (PMMA/acrylic) or equivalent
  - UV, IR may require different material
  - Radar, ultrasound, etc.: you need to check!
  - Humidity, temperature, air quality: need air access



Acrylic transmission
endurancelasers.com

Sealing your enclosure

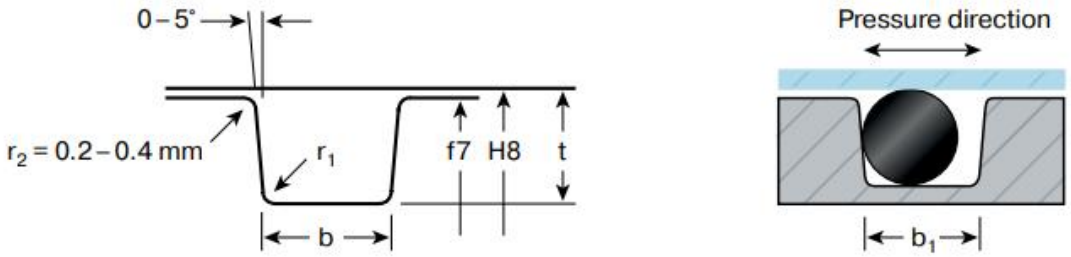
- Strategy 3: seal openings
  - Method 1: O-rings
    - Cylindrical soft material
    - Compress and deform to provide seal



Sealing your enclosure

- Strategy 3: seal opening
  - Method 1: O-rings
  - Must design O-ring “gland” or “groove”
    - Design can get elaborate
    - For us (low-pressure, static) ➔ simpler
      - 20-30% compression
      - Width ~40% wider than O-ring
  - Can purchase O-rings or O-ring cord stock
    - Choose soft O-ring material

Parker O-Ring Handbook



Cross-section d_2 [mm]	Gland depth t [mm]	Compression [mm]	Compression [%]	Groove width b_1 without anti-extrusion ring [mm]
1.78 ±0.08	1.40	0.26 - 0.58	15 - 31	2.40 - 2.60
2.62 ±0.09	2.20	0.26 - 0.64	10 - 23	3.60 - 3.80
3.53 ±0.10	2.90	0.40 - 0.85	11 - 23	4.80 - 5.00
5.33 ±0.13	4.50	0.57 - 1.08	11 - 20	7.20 - 7.40
6.99 ±0.15	5.90	0.80 - 1.35	11 - 19	9.60 - 9.80

Tab. 3.1 Design dimensions for O-Rings – static seal

Water-Resistant Soft Neoprene O-Ring Cord Stock

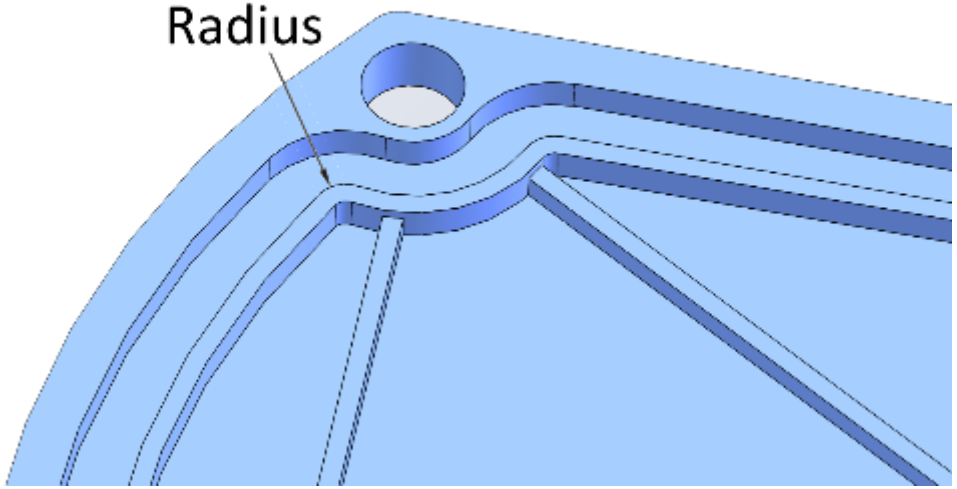
This soft neoprene cord stock creates a better seal than standard neoprene cord stock. It resists water and refrigerant R-12. Use it to make round-profile O-rings, which are suitable for a wide range of static and dynamic sealing applications.

Wd.

Fractional	Actual	Hardness	Specifications Met	Temperature Range, °F	Color	Lengths, ft.		Per Ft.
1/16	0.07"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K51	$0.90
3/32	0.103"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K53	1.06
1/8	0.139"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K55	1.40
3/16	0.21"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K57	1.87
1/4	0.275"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K59	2.56
5/16	0.313"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K61	3.02
3/8	0.375"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K63	3.20
7/16	0.437"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K65	3.97
1/2	0.5"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K67	4.83
5/8	0.625"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K69	7.22
3/4	0.75"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K71	8.75
1	1"	Durometer 50A (Soft)	ASTM D2000	-30° to 212°	Black	3, 10, 20, 50, 100	1430K73	10.54

Sealing your enclosure

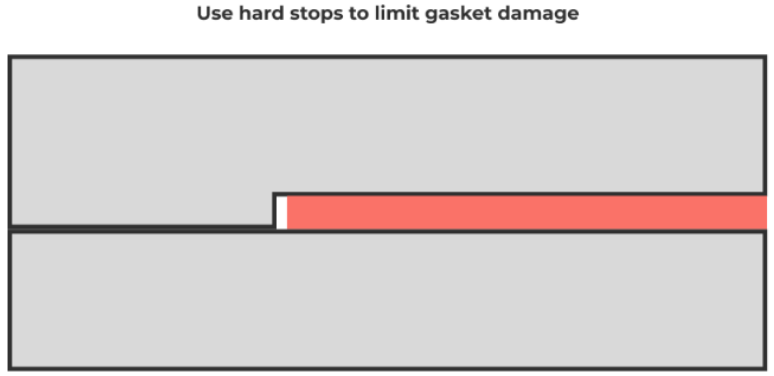
- Strategy 3: seal opening
  - Method 1: O-rings
  - Make sure to provide a radius for the O-ring to bend in the groove
    - Radius of bend > 3x diameter of O-ring



Apple Rubber

Sealing your enclosure

- Strategy 3: seal opening
  - Method 2: Gaskets
    - Flat soft material
    - Compress and deform to provide seal
      - ~30% deformation is plenty
    - Some available with adhesive backer
    - More work in assembly vs. O-ring
    - Need to apply more pressure more uniformly



fiveflute.com

Water- and Steam-Resistant EPDM Gasket Material

Damp vibration when sealing in moist environments with these EPDM gasket sheets. They resist water, steam, and salt water. Cut with scissors or a utility knife.

Sheets

Wd.	Lg.	Max. Pressure, psi	Temp. Range, ° F	Hardness	Hardness Rating	Color	Specs. Met	1/16" Thick		1/8" Thick	
									Each		Each
12"	12"	800	-20 to 220	Durometer 60A	Medium Hard	Black	ASTM D2000	8525T65	$6.24	8525T67	$8.02
24"	24"	800	-20 to 220	Durometer 60A	Medium Hard	Black	ASTM D2000	8525T66	19.78	8525T68	25.42
36"	36"	800	-20 to 220	Durometer 60A	Medium Hard	Black	ASTM D2000	8525T156	58.67	8525T157	114.27

sealanddesign.com

Sealing your enclosure

- Strategy 3: seal opening
  - For both gaskets & O-rings
  - Need to apply pressure to lid

    $$\text{Stiffness} \sim (\text{thickness})^3 / (\text{length})^4$$

  - Make it thick, and put fasteners every so often
- We could do elaborate FEA…but do a best-effort design and then test
  - Dummy enclosure with seal
  - Moisture test strips

Sealing your enclosure

- Strategy 3: seal opening
  - Method 3: Glue (adhesive)
    - Only if you **never ever** want to service the opening
    - Good option: Two-part epoxy

Sealing your enclosure

- Strategy 3: seal opening
  - Water-tight connectors
    - USBC, barrel jack, etc.
    - Function depends on seal of lip to enclosure ➔ proper placement is critical
  - Water-tight cable glands
    - One gland per cable
    - Bulky but will also work

IP68
$0.84 on digikey

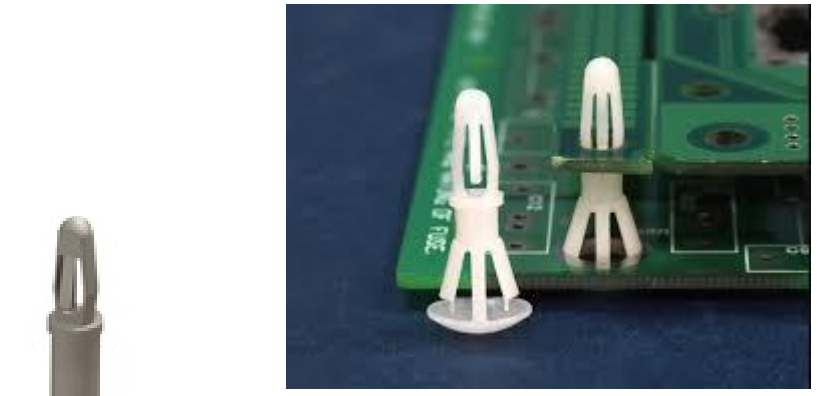
IP68
$0.64 on digikey

Enclosure internals

- **Don’t leave parts just dangling**
- Mount **everything** to the enclosure (or other parts)
  - PCBs, batteries, sensors, etc.
- Fastening approaches
  - Screws
    - Use M3, M4, M5 screws or bolts
      - Zinc-plated for intermittent outdoor use
      - Stainless steel for chronic outdoor use
    - Bosses with holes – if you want to attach once or a few times
    - Threaded inserts – repeated assembly, more work to install
  - Adhesive
    - Please don’t

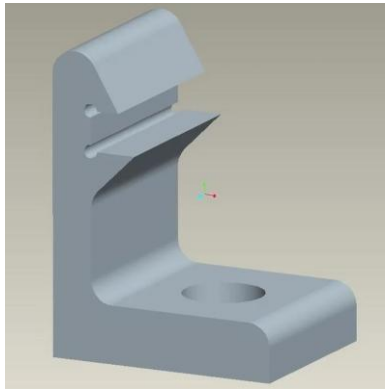
Enclosure internals

- **Don’t leave parts just dangling**
- Mount **everything** to the enclosure (or other parts)
  - PCBs, batteries, sensors, etc.
- Fastening approaches
  - Clips for PCBs
    - Can glue, screw or snap into enclosure
    - PCB snaps in
    - May or may not save assembly time
    - Harder to remove PCB
    - May be able to 3DP them?

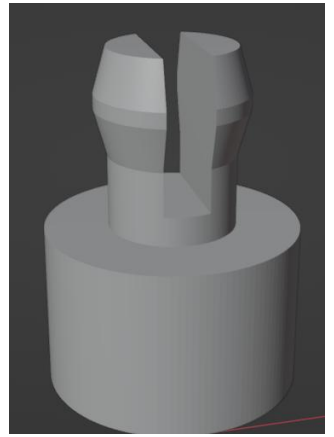


ALLPCB.com

Keystone Electronics



thingiverse.com/thing:47369



https://medium.com/@williamtech/3d-printing-snap-fit-mounting-plugs-for-pcbs-a2668a159a8c

Enclosure externals

- Conformal coating spray: provide moisture resistance to PCBs exposed to ambient
  - **Don’t coat your connectors! Or your sensors!**

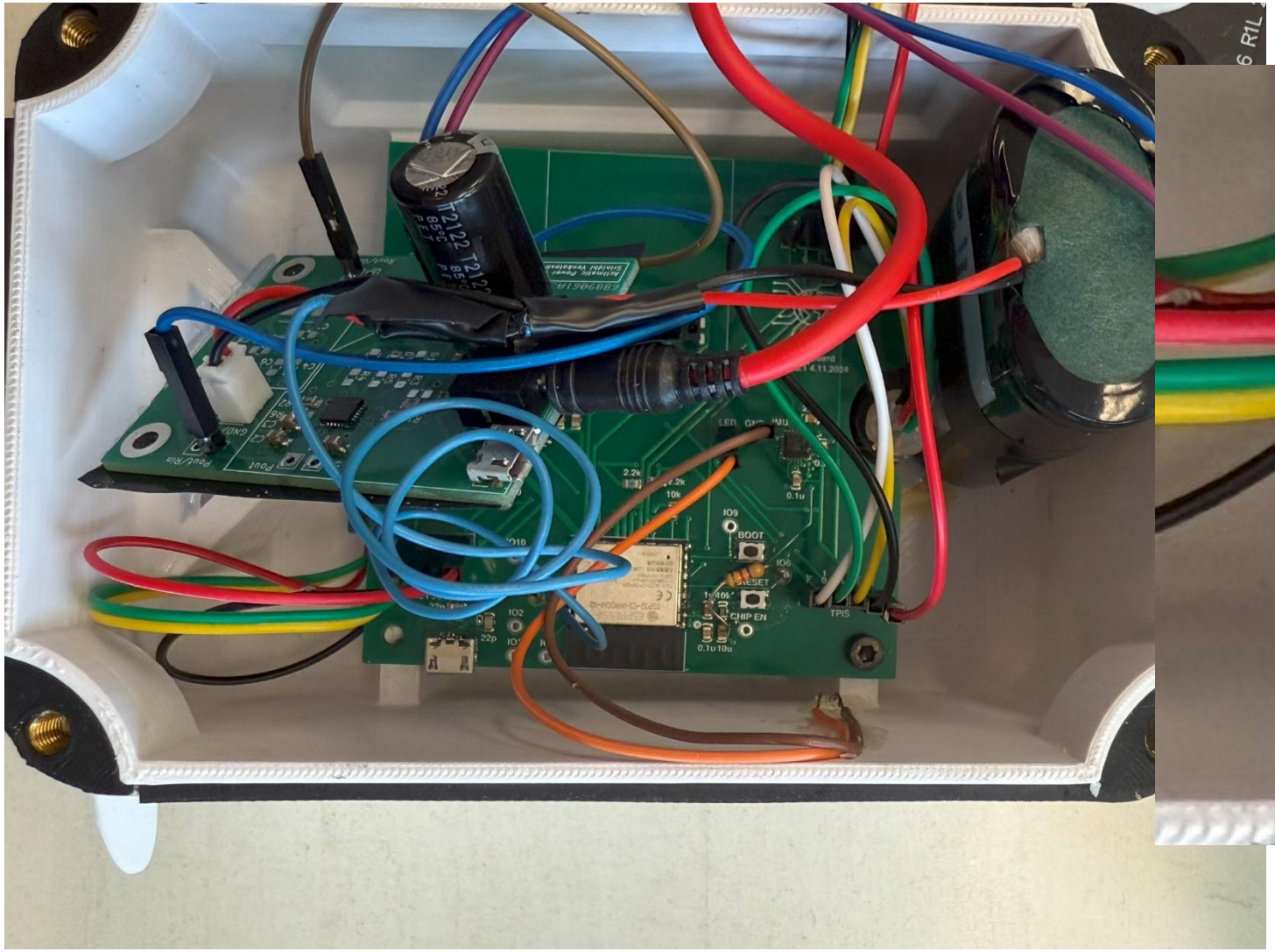
For this PCB!

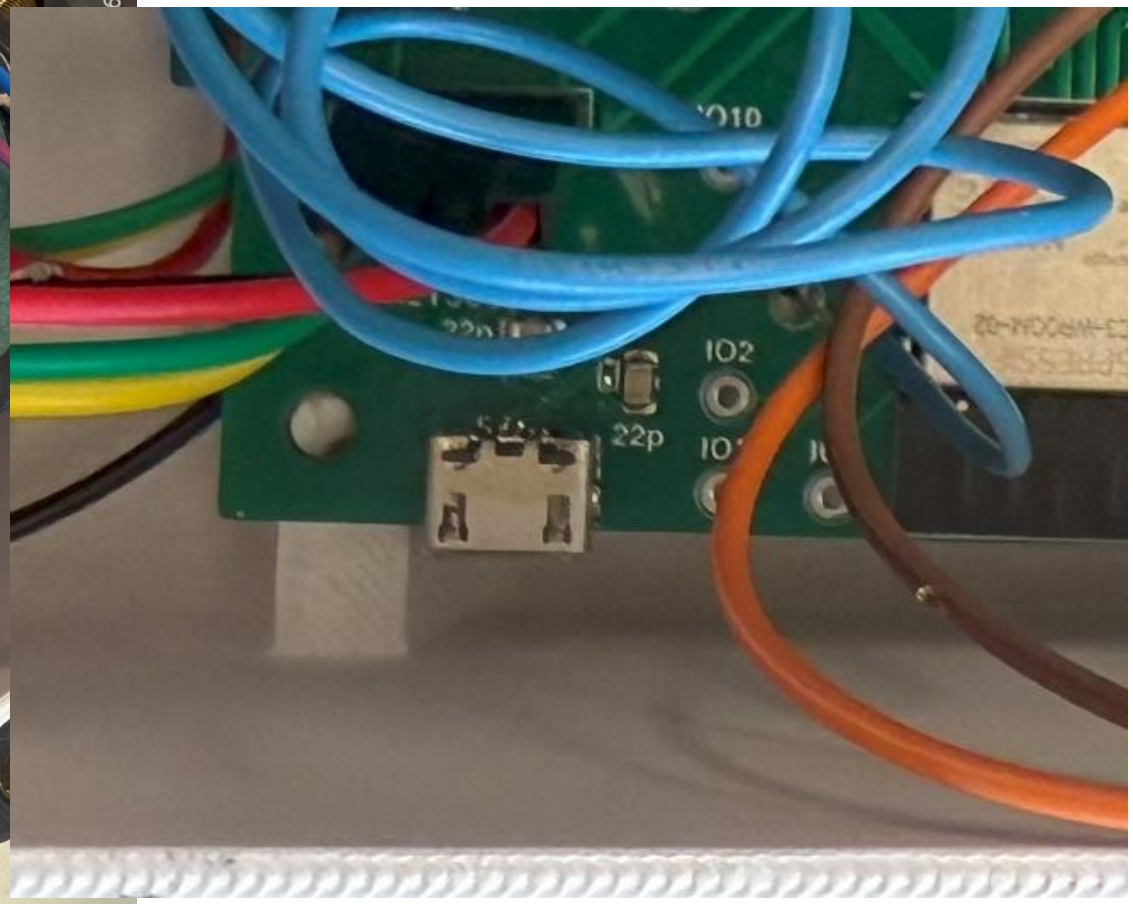
Enclosure fit-up

- Test entire assembly before the end of April
  - Ideally before end of March
  - Enclosure + PCB + components + cables
- Can you even assemble it?
- Do you have room for cables? For programming/debug cable?
- Can you redesign aspects to make it **easier to assemble**

Enclosure fit-up

2024 enclosure



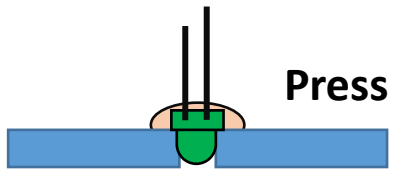


Incorporating displays & indicators

- E-ink displays can come with mounting holes
- Would be better to hide mounting holes
  - Screw in from behind
  - Or use adhesive tape
    - 3M VHB or similar

Incorporating displays & indicators

- LEDs have several options
  - Thru-hole LED
    - Relatively to integrate into enclosure
    - More work to connect to board
  - SMT LED
    - Right on board
    - Use light pipe to bring to surface



Press fit + adhesive

Incorporating buttons

- Pinhole reset button
  - Usually a SMT momentary button underneath
  - Might be ok for outdoors, if on bottom and small
    - Need to test!
- Put button in protected cavity
- Use waterproof momentary pushbutton switch
  - Bulky, $$, and may attract notice