# Product Specification: Stratosonde

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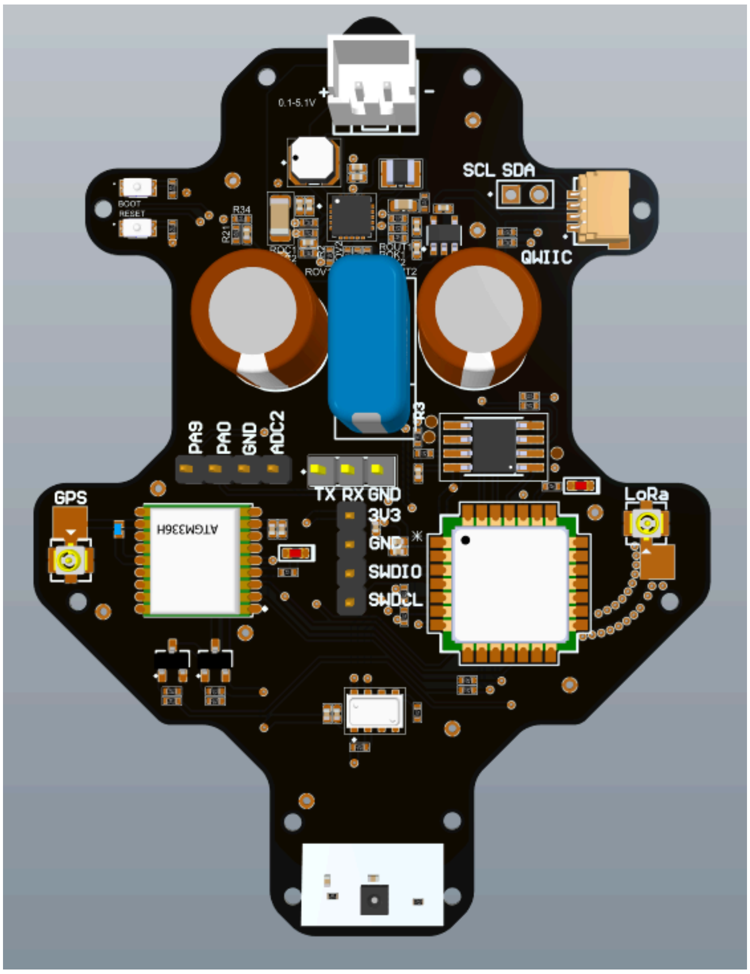



## 1. Introduction

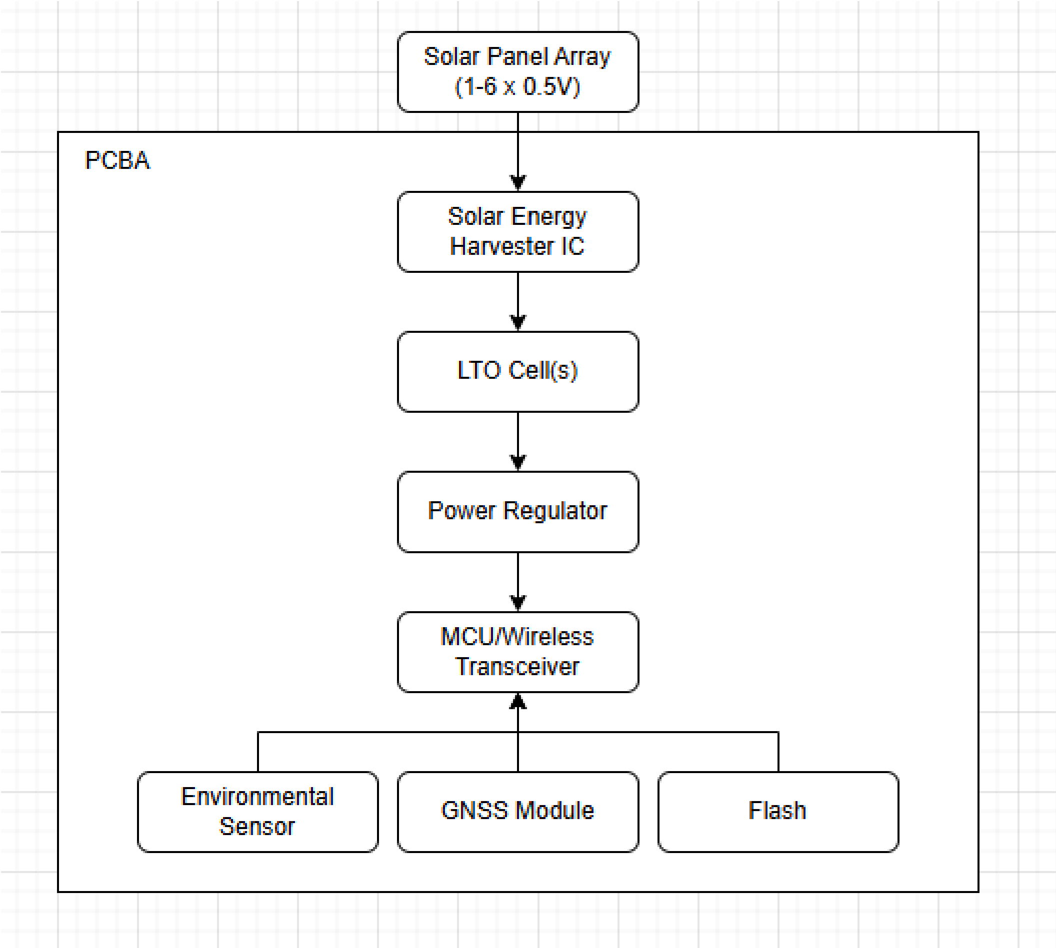
This document defines the hardware and firmware requirements for the development of an ultra-lightweight, solar-powered radiosonde designed for long-duration autonomous operation. The radiosonde will collect atmospheric and positional data using onboard environmental sensors and a GPS module, and transmit this data over LoRaWAN. In the absence of network coverage, the device must reliably cache data and opportunistically transmit it when connectivity is restored. The design prioritizes minimal size, weight, and power consumption, with components selected for compatibility with solar energy harvesting and extreme environmental conditions.

Recent advancements in component technology—such as ultra-low-temperature LTO battery cells, compact low-power GPS modules, and highly efficient LoRaWAN radios—now make it feasible to create a new class of radiosondes capable of continuous operation on low-cost, small-scale weather balloons. Unlike traditional high-cost, disposable sondes, this design aims to enable multi-day or even persistent atmospheric data collection using inexpensive party balloons and minimal hardware. These innovations reduce not only cost and weight, but also power requirements, opening the door to scalable, autonomous environmental sensing from the edge of the stratosphere.

### System Requirements

| | Must | Nice |
|---|---|---|
| Altitude | 40000 feet | 100000 feet |
| Temperature | -40°C | -60°C |
| Humidity | 5-95% RH | 0-100% condensing |
| Payload Weight | <15g | <12g |
| Power Consumption | <2mA @3.3V Avg | <1mA |
| | | |

## 2. System Overview




The radiosonde is specifically designed to be as lightweight as possible to enable flight with inexpensive party balloons rather than high-cost weather balloons. By minimizing system mass, the required volume of helium or hydrogen gas is significantly reduced, lowering both launch cost and logistical complexity. This opens the door to frequent, low-cost launches, even for hobbyists, educators, or distributed research efforts. Lightweight construction also improves balloon performance and altitude potential, making high-altitude, long-duration environmental sensing more accessible and scalable than traditional sondes.

Potential balloons: 32” Yokohama filled with 0.07 cubic meters will lift 8g payload. $15 each plus gas. SAG Orb balloons roughly the same price but shipping from Canada. Aliexpress balloons 32”-90” very low prices.

# 3. Hardware Requirements

## 3.1 Power System

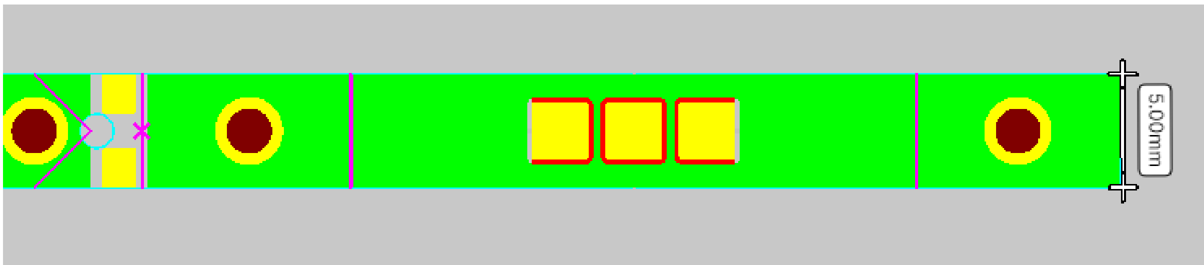
☀️Solar Input (Energy Harvester Input)

| Parameter | Value / Range | Notes |
|---|---|---|
| Input Voltage Range | 0.5 V – 3.0 V | Supports 1–6 0.5 V wafers in series |
| Cold Start Voltage | ≤ 0.6 V | Must start harvesting from weak early sunlight |
| Operating Voltage | 0.5 V – 3.0 V typical | Post start-up, under normal sunlight |
| Maximum Input Current | TBD (estimated ≤ 100 mA) | Based on panel area and lighting |

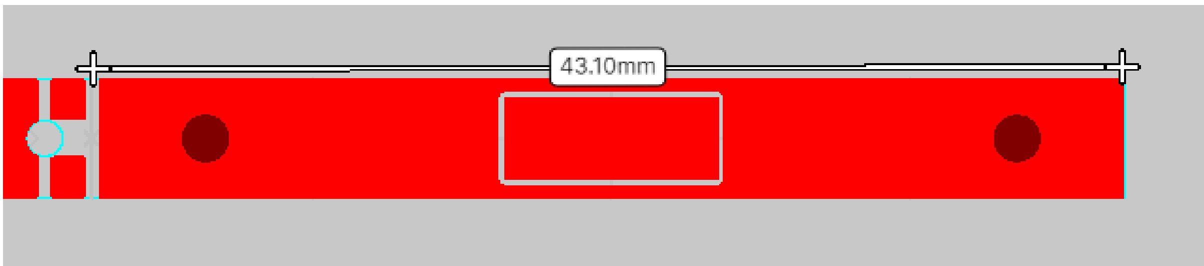
Potential solar panels: aoshike 52x19mm, 0.5v, 400mA weighing 0.9g each. ~25¢ each.

More robust but less efficient https://www.powerfilmsolar.com/

The solar panel array itself is not part of this project's scope, but the radiosonde will be designed to interface with it. We plan to use off-the-shelf or custom panels configured according to the methodology outlined in this open-source guide. The energy harvesting subsystem must accommodate input voltages ranging from 0.5 V to 3.0 V, depending on the number and configuration of 0.5 V panel wafers in series. The target maximum input current is **TBD**, but the design should support typical small-panel currents under varying lighting conditions. The boost converter must reliably start and operate at these levels, enabling cold-start behavior and continuous low-light harvesting.




*Traquito tracker solar system mating pcb top.2mm diameter holes.*




*Traquito tracker solar system mating pcb bottom.2mm diameter holes.*

### ⚡Energy Harvester IC

BQ25570 Datasheet

[BQ25570 Design Calculator]

The energy harvester IC is responsible for boosting the low-voltage input from the solar panel and managing safe, efficient charging of the LTO cell. It must support cold-start capability from voltages as low as 0.5 V, and operate continuously within an input range of 0.5 V to 3.0 V, aligning with expected solar panel configurations. The harvester should include Maximum Power Point Tracking (MPPT) or a similar technique to optimize energy extraction under varying light conditions. It must also safely limit the charge voltage to 2.8 V to prevent overcharging the LTO cell. The chosen IC must have ultra-low quiescent current, be capable of charging from low-power panels, and ideally offer a regulated output for system power, though regulation may be handled downstream.

### 🔋 Battery (LTO Cell)

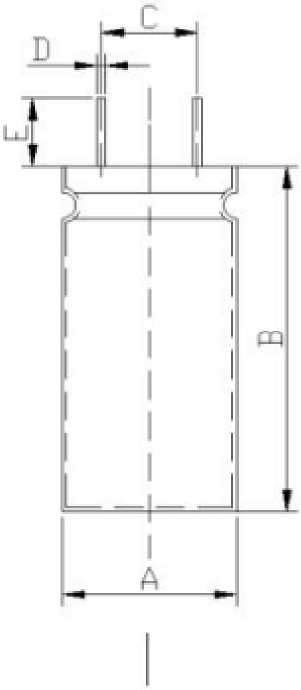
HTC1030 Datasheet
HTC1020 Datasheet
HTC1015 Datasheet

| Parameter | Value / Range | Notes |
|---|---|---|
| Chemistry | Lithium Titanate (LTO) | |
| Voltage Range | 1.5 V (min) – 2.8 V (max) | Charger must not exceed 2.8 V |
| Discharge Cutoff Voltage | ~1.5 V | To prevent deep discharge |
| Capacity | 100mAH | Based on size/weight tradeoff |

Potential cells: htc1030 with capacity of 100mAH weighing 4.7g. htc1020 with capacity of 50mAH weighs 3.0g.

*PCB Layout should accommodate 2S or 2P cells. Through-hole pads C(5.3mm) and cell diameter A(10.2mm) with a 'rotatable' population option.*

The radiosonde will use Lithium Titanate (LTO) cells for energy storage due to their excellent low-temperature performance, long cycle life, and fast charge capabilities. A single LTO cell operates in a voltage range of approximately 1.5 V (discharged) to 2.8 V (fully charged). This relatively low voltage range introduces a design challenge: it falls below the typical operating voltage of many microcontrollers and sensors, requiring a low-dropout or buck-boost regulator to provide a stable




| 项 目 | 参 数 |
| --- | --- |
| A(直径) | 10.2 |
| B(长度) | 30.5±0.5 |
| C(封口皮头导针孔中心距) | 5.3（胶塞孔中心距） |
| D(引脚直径) | ¢0.8 |
| E(引脚长度) | 6±1 |

3.3 V system rail.

## 3.2 Microcontroller & Radio

🧠 Microcontroller

Possibilities: ESP32, Wio LORA-E5, Heltec HT-CT62

[STM32WLE5 Datasheet]

The system's processing is handled by the Wio STM32WLE5JC, a compact module built around the ARM Cortex-M4 core. This microcontroller is responsible for managing sensor interfaces, timekeeping, flash memory logging, and power state transitions. It supports deep sleep modes, low-power peripheral gating, and wake-on-RTC, enabling efficient duty cycling critical to ultra-low-power radiosonde operation. Its integrated design reduces component count, saves PCB space, and simplifies routing compared to separate MCU + RF configurations.

📡 Wireless Communication

Consider: sx1262, stm32wle5, Wio-sx1262 with esp32

[Wio LoRa-E5 Datasheet]

| Parameter | Value / Description |
|---|---|
| Protocol Support | LoRa, LoRaWAN |
| Frequency Bands | ISM (EU868, US915) |
| Output Power | Up to +22 dBm (configurable) |
| Communication Range | 100km |
| Spreading Factor | SF7 – SF12 |
| Bandwidth Options | 125 / 250 / 500 kHz |
| Duty Cycle Compliance | Yes (regional limits enforced by firmware) |
| Network Join Method | ABP |
| Uplink Mode | Unconfirmed (default), Confirmed (optional) |
| Downlink Support | Yes (Class A only) |
| Antenna Interface | 50 ohm RF output (external wire) |
| Licensing Requirement | None (license-free ISM bands) |
| Infrastructure Required | Public/private LoRaWAN gateway (optional cache) |

The radiosonde uses a Semtech SX126x LoRa transceiver, integrated within the Wio STM32WLE5JC module, to provide long-range wireless data transmission. This transceiver supports several transmission protocols, with LoRaWAN being the primary mode used due to its efficiency, license-free operation, and growing global infrastructure.

Other systems like APRS (Automatic Packet Reporting System) and WSPR (Weak Signal Propagation Reporter) have historically been used for balloon telemetry. APRS operates on amateur radio VHF/UHF frequencies and provides wide coverage through digipeaters and gateways, but it requires an amateur radio license and is limited to certain regions and user communities. LoRa APRS, a variation using LoRa modulation for APRS-style packets, offers unlicensed short- to medium-range communication but typically relies on a sparse, hobbyist-operated infrastructure.

In contrast, LoRaWAN operates in unlicensed ISM bands (e.g., EU868, US915) and supports unconfirmed uplinks, adaptive data rate, and global operation without a license. It allows the radiosonde to opportunistically transmit data wherever public or private LoRaWAN gateways (e.g., The Things Network, Helium Network) are in range, making it an ideal choice for low-cost, long-duration, and infrastructure-free deployments. The global support and license-free nature of LoRaWAN make it more scalable and cost-effective than amateur radio-based alternatives for unattended and commercial use cases.

### 3.3 Sensors

🛰️GNSS Module

Consider ATGM336H-5N31, ATGM336H-5NR32

[ATGM336H-5NR31 Datasheet](#)

| Parameter | Value / Description |
|---|---|
| Interface | UART |
| Position Accuracy | < 2.5 m CEP |
| Hot Start Time | 1 s |
| Cold Start Time | ~29 s typical |
| Supply Voltage | 3.3V |
| Active Current | ~25–30 mA |
| Sleep Mode Support | Yes (power-down via enable pin) |
| Operating Temperature | -40 °C to +85 °C |
| Antenna Type | Passive or Active (external, optional) |

The radiosonde integrates a compact GNSS receiver, such as the Ublox Max M8, to acquire accurate position (latitude, longitude, altitude) and UTC time. The GNSS module communicates with the microcontroller over UART and is configured to operate in a duty-cycled mode to reduce power consumption. It is activated only during scheduled acquisition windows to obtain a fresh fix, then powered down. The chosen module should support cold-start operation at altitude, and maintain a fast fix time and stable signal lock during balloon flight. Position data is logged with environmental data and used to configure regional LoRaWAN frequency plans dynamically.

Some gnss modules do not work above a certain elevation and speed due to security reasons.

## 🌡️ Environmental Sensors

Atmospheric sensing is provided by a combination of high-precision digital environmental sensors.

### Pressure Sensor – MS5607-02BA03, MS5637-02BA03

[MS5607-02BA03 Datasheet]

| Parameter | Value / Description |
| --- | --- |
| Interface | I²C or SPI |
| Temperature Range | -40 °C to +85 °C |
| Pressure Range | 10 – 2000 hPa |
| Pressure Accuracy | ±1.5 hPa (typical) |
| Supply Voltage | 1.8 V – 3.6 V |
| Current (active) | ~1.4 µA (average) |
| Sleep Current | <0.1 µA |

The **MS5607-02BA03** barometric pressure sensor, capable of measuring at extremely low pressures down to 10 hPa versus bosch sensors which can only measure down to 300hPa. This is important as we expect our working altitude to be around 35000’ or 200hPa.

### Temperature & Humidity Sensor – SHT31

[SHT3x Datasheet]

| Parameter | Value / Description |
| --- | --- |
| Interface | I²C |
| Temperature Range | -40 °C to +125 °C |
| Temperature Accuracy | ±0.3 °C (typical) |
| Humidity Range | 0 – 100% RH |

| | |
|---|---|
| Humidity Accuracy | ±2% RH (typical) |
| Supply Voltage | 2.15 V – 5.5 V |
| Current (active) | ~0.5 mA (measuring) |
| Sleep Current | <0.2 μA |

The **SHT31** is used for temperature and relative humidity measurements, offering high accuracy and low power consumption.

Both sensors communicate with the MCU via I²C or SPI and are sampled periodically during the measurement cycle. This separation allows optimal performance at extreme altitudes and cold temperatures. Their small footprint and low power requirements make them ideal for ultralight, solar-powered platforms.

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### 🔌Aux Port

If there are free peripherals to support future extensions or mission-specific payloads, the design should reserve one or more general-purpose digital or analog interfaces. These may include an unused ADC channel, I2C, SPI, or GPIO lines routed to test points or a small connector. This expansion capability allows for the optional integration of additional low-power sensors or peripherals, such as light sensors, ozone detectors, or external analog probes, without significantly impacting the weight or power envelope of the core system.

## 💾Memory

[W25Q80DVSNIG Datasheet]

| Parameter | Value / Description |
|---|---|
| Interface | SPI |
| Capacity | 1 MB (8 Mbit) |
| Write Endurance | ≥100,000 program/erase cycles |

| | |
|---|---|
| Data Retention | ≥20 years |
| Supply Voltage | 2.7 V – 3.6 V |
| Write Current | ~5 mA (typical) |
| Standby Current | ~1 µA or less |
| Operating Temperature | -40 °C to +85 °C |

The radiosonde includes serial SPI flash memory to enable onboard data logging in environments where LoRaWAN coverage is unavailable. A chip such as the W25Q16JV (2 MB) provides ample space for storing timestamped sensor and GPS records using a circular buffer structure. Data is written to flash at each measurement interval and marked for transmission. When connectivity is restored, the device transmits stored entries and frees space accordingly. The flash must support low standby current, fast page writes, and sufficient endurance to handle frequent erase/write cycles during long-duration flights. This subsystem ensures that no data is lost due to network unavailability and enables reliable, opportunistic telemetry.

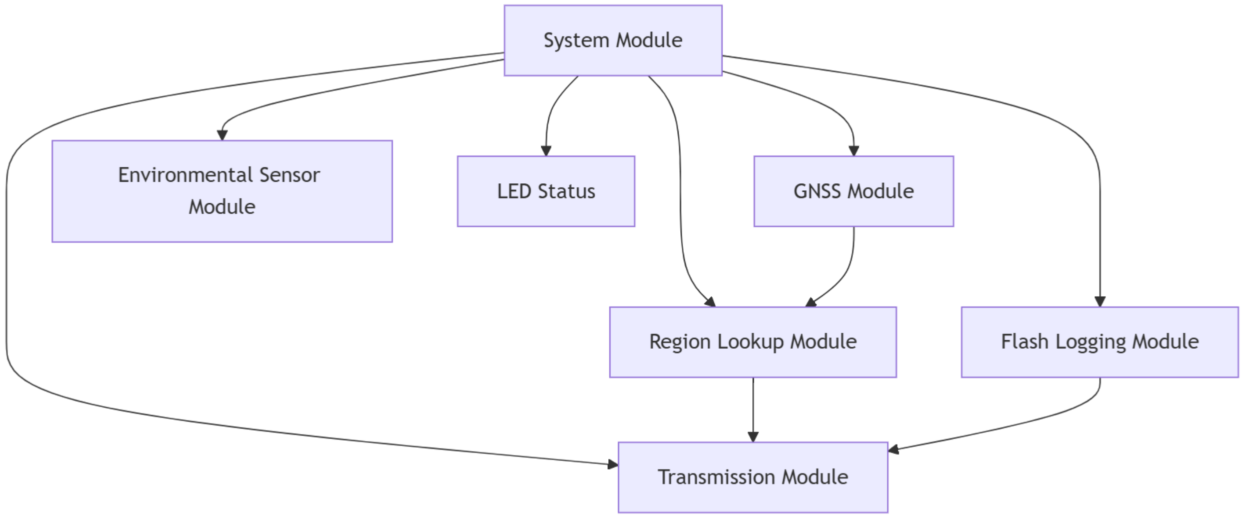
## 3.5 PCB & Mechanical

The PCB must be as compact and lightweight as possible, targeting a total system weight (including battery, pcb and sensors) of under 20 grams, with lower being strongly preferred. The board should be designed with minimal dimensions, using high-density component placement and surface-mount packages (0402 preferred) to reduce area and weight. The total Bill of Materials (BOM) cost should remain low, ideally under $20 USD per unit in moderate volume, using components readily available from suppliers like LCSC or Digikey and suitable for JLCPCB or PCBWay assembly. Environmental conditions may include cold temperatures (-50 °C), condensation, and rapid pressure changes at high altitude. While the radiosonde is designed to be disposable, basic environmental protection measures such as conformal coating or lightweight hydrophobic barriers may be used if necessary to prevent failure due to moisture ingress during ascent. The board should avoid heavy connectors or enclosures unless essential, and all components must be selected for low-temperature operation and reliability.

Schematics
[Stratosonde Version 1 Schematics pdf]

# 4. Firmware Requirements

The firmware is tailored for the STM32WLE5JC module, leveraging its integrated microcontroller and LoRa transceiver to minimize part count and power consumption. Firmware modules are tightly coupled to the hardware subsystems described earlier and operate in coordination via a simple state machine with deterministic wake-sleep behavior. The design prioritizes modularity, verifiability, and ultra-low power usage.

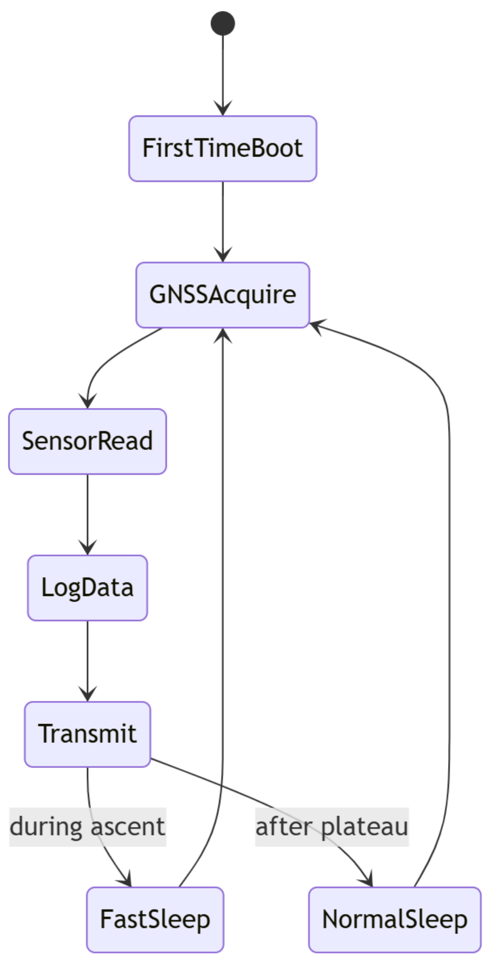


## System Module

The System Module serves as the central orchestrator for all firmware operations. On first-time boot, it initializes the system, then enters a repeatable telemetry cycle: acquiring GNSS position, sampling environmental sensors, logging high-resolution data to flash, and transmitting a compact telemetry packet. This cycle is repeated indefinitely for the duration of the mission.

The only dynamic element in this loop is the sleep duration between cycles. During the initial ascent phase, the system uses a shortened sleep interval to capture higher-resolution data while pressure and altitude are changing rapidly. After a predefined time or upon detection of a plateau in altitude, it transitions to a longer, steady-state sleep interval to conserve power. This design allows the same logic path to serve both high-resolution and long-duration needs without introducing complex mode switching.

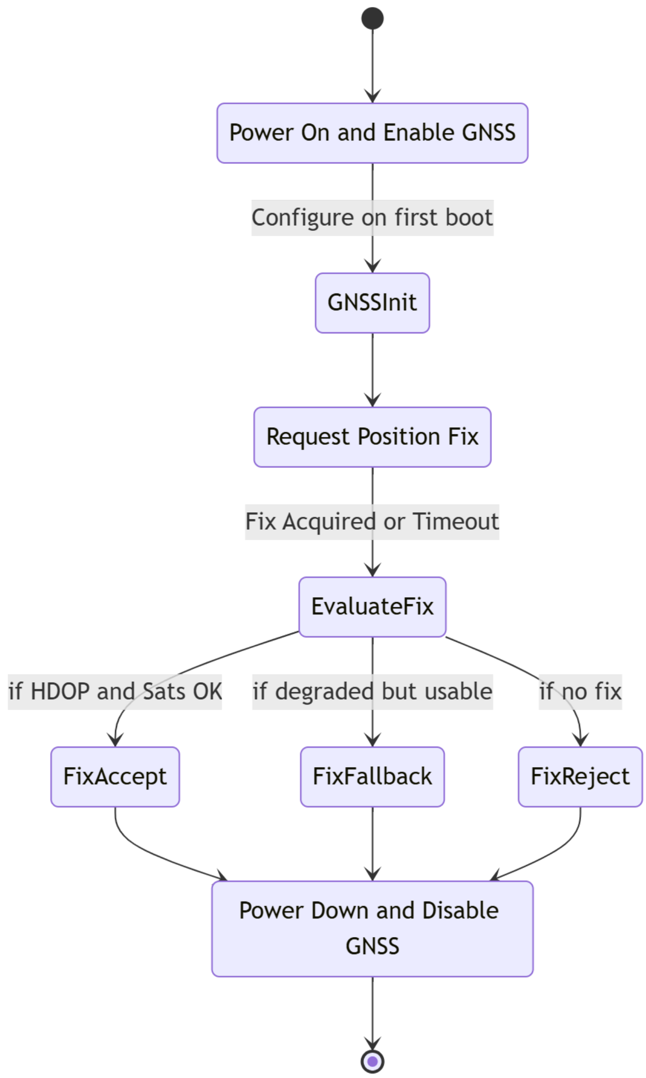
The System Module manages the RTC-driven sleep and wake schedule, coordinates all other modules, and ensures fault conditions are handled gracefully. It also controls LED behavior to indicate operational state, such as blink patterns during provisioning, solid on during ascent, and fast blink during transmission.



## GNSS Module (ATGM336H-5NR31 or equivalent)

The GNSS Module is responsible for obtaining accurate position and time information with minimal power usage. Upon first-time boot, the module is fully initialized, including any configuration commands required to unlock high-altitude operation above 18000 feet. Communication is handled over UART, while both the main power line and an independent enable line are controlled by firmware. A dedicated VBAT backup line allows the GNSS module to retain ephemeris data between fixes, enabling hot-start performance on each cycle.

During each telemetry cycle, the system briefly powers and enables the GNSS module, requests a fix, and evaluates its quality using two configurable thresholds: the number of satellites and horizontal dilution of precision (HDOP). If the fix meets or exceeds the required quality, the module is shut down immediately to conserve energy. If not, the firmware continues waiting within a bounded timeout before either accepting a degraded fix or falling back to RTC-based timing. This process typically completes in 1–2 seconds, taking advantage of hot-start conditions from prior sessions. All valid fixes are passed to both the logger and the Region Lookup module for use in frequency plan selection.

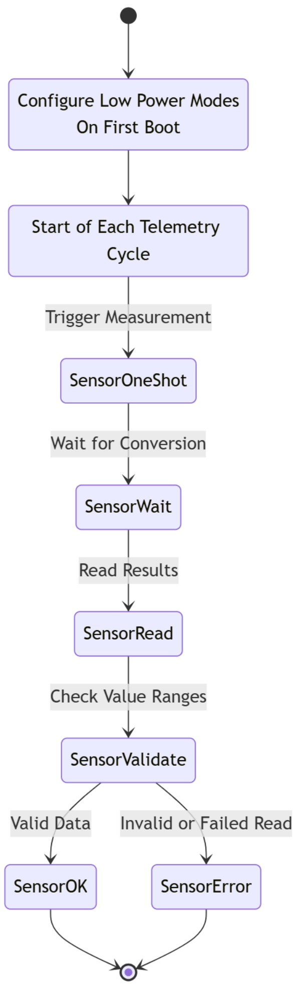


## Environmental Sensor Module

The Environmental Sensor Module handles measurement from the onboard atmospheric sensors: the MS5607-02BA03 pressure sensor and the SHT31 temperature and humidity sensor. These devices are continuously powered without external hardware control, making their internal low-power configuration modes essential to minimizing energy usage.

On first-time boot, the firmware performs a one-time configuration of both sensors to enter their lowest-power operational modes — typically by disabling internal heaters, enabling standby or idle modes, and preparing them for one-shot polling. During each telemetry cycle, the microcontroller wakes the sensors via I²C or SPI, initiates a single measurement, and retrieves the result after a brief settling delay. This mode ensures sensors remain in a quiescent state between measurements, drawing only microamps of idle current.

Each sample is validated against predefined acceptable ranges to detect outliers or potential sensor failure. The readings are then packaged into the telemetry log alongside GNSS position and timing data. Since sensors are always powered, strict adherence to low-duty-cycle polling and ultra-low standby current is required to meet the system's power budget.



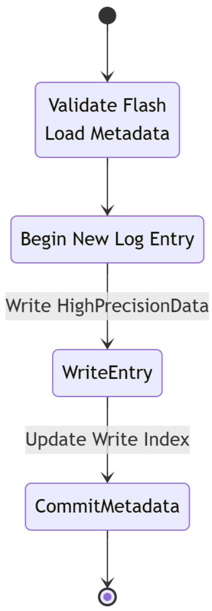

### Flash Logging Module (W25Q80DVSNIG or equivalent)

The Flash Logging Module is responsible for persistent, high-resolution data storage across the radiosonde's mission. It interfaces with an SPI NOR flash chip such as the W25Q80DVSNIG and implements a simple, robust circular buffer system for logging each telemetry cycle.

At boot, the module validates flash accessibility and reserves a small metadata region at the start of memory to store the current write index and a provisioning-complete flag. All telemetry records are appended sequentially to flash in a binary structure, wrapping around when capacity is reached. Each record includes GNSS data, environmental measurements, DOP, satellite count, and timestamps, written in a fixed-length format to simplify indexing.

Data integrity is prioritized over compression. The flash memory is treated as append-only during flight, and transmission routines always read from the latest entries backward. The design ensures that even if no network connectivity is available, all telemetry is safely cached for later recovery or bulk transmission.

Flash is always powered, and writes occur only once per cycle. Read operations are typically limited to the most recent entries for transmission. A configurable maximum number of records may be transmitted before triggering the next confirmed packet check.




```c
typedef struct {
    uint8_t version;
    uint32_t timestamp;
    float latitude;
    float longitude;
    float altitude;
    float temperature;
    float humidity;
    float pressure;
    uint8_t satellite_count;
    float hdop;
} HighPrecisionData;
```

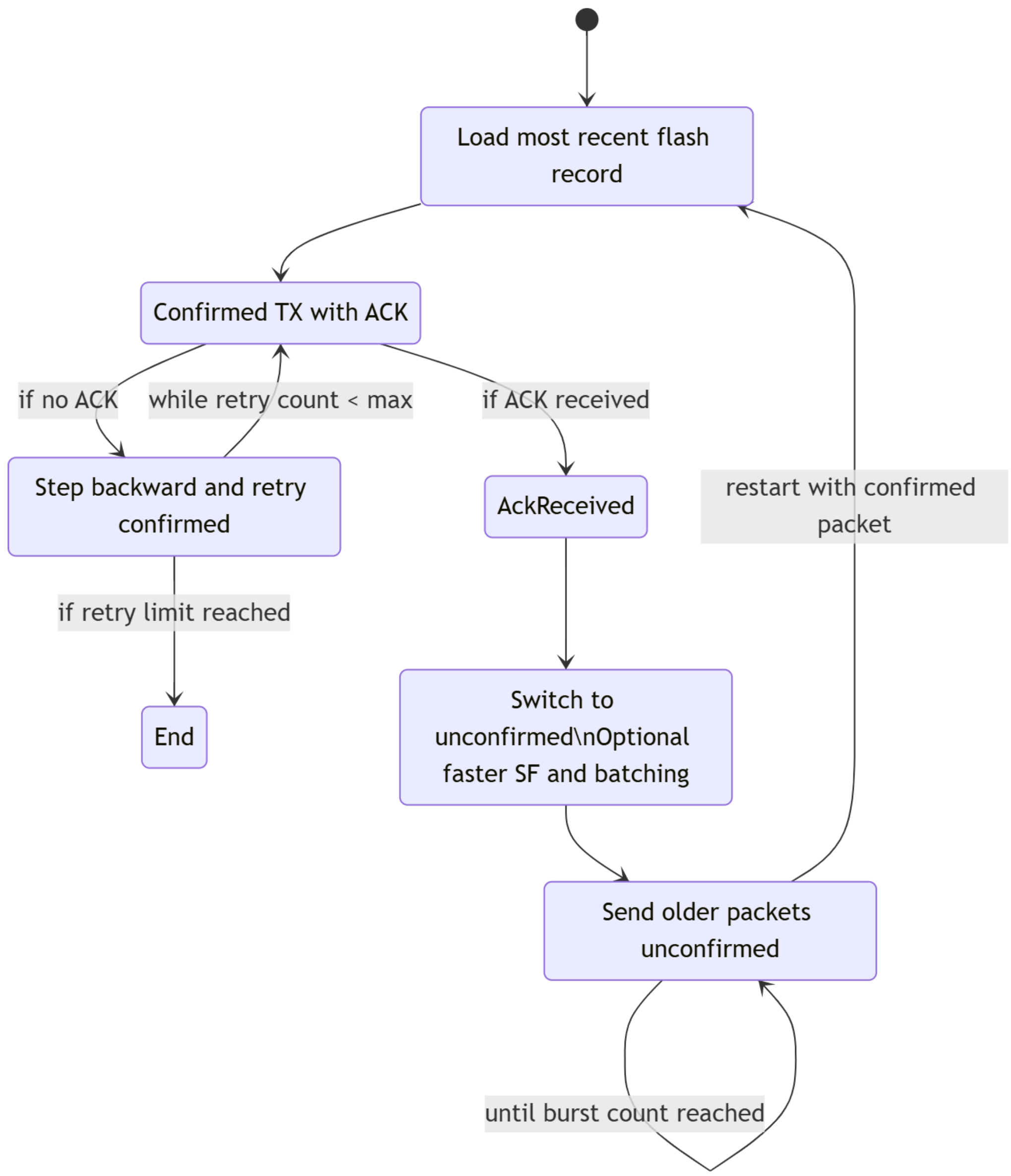
## Transmission Module (LoRaWAN via SX1262 inside STM32WLE5JC)

The Transmission Module handles efficient, adaptive LoRaWAN telemetry using the STM32Cube LoRaWAN stack with ABP provisioning. The module begins each cycle by reading the **most recent flash entry**, converting it into the compact 11-byte packet format. It transmits this packet as a **confirmed uplink** to probe for gateway availability and link quality.

If an **ACK is received**, the system switches to **unconfirmed uplinks** for a configurable number of subsequent packets, working **backwards through earlier flash records**. In this mode, the device may also raise its data rate (i.e. reduce spreading factor) and send **batched payloads**, combining multiple 11-byte packets into one LoRaWAN frame if allowed by MAC layer limits and duty cycle constraints.

If no ACK is received for a confirmed packet, the system moves one record backward in time and tries a new confirmed packet. This continues up to a configurable limit. This progressive retry strategy avoids sending the same packet multiple times, reduces wasted airtime, and favors fresh data.

All parameters — including the **maximum number of unconfirmed packets per burst**, the **number of confirmed retries allowed**, and the **thresholds for rate/batch size adaptation** — are configurable at compile time.



## LoRaWAN Region Lookup(H3-lite)

This code will be provided.

The Region Lookup Module is responsible for determining the appropriate **LoRaWAN regional frequency plan** based on the radiosonde's current latitude and longitude. It uses a compact, preprocessed lookup table derived from official LoRaWAN regional coverage areas, such as US915, EU868, AU915, AS923-1 through AS923-4, RU864, and CN470. These regions are compiled offline from **GeoJSON polygon outlines** and converted into a dense, static H3 hex grid at an appropriate resolution (e.g. res 5–7), resulting in a fast and memory-efficient embedded map.

The module provides one main function — `get_region()` — which is called immediately after GNSS position acquisition. It accepts a latitude and longitude as input and returns one of the known LoRaWAN regions. In some special cases, it returns:

- `NO_TX`: the device is in a restricted area where transmission is not permitted (e.g. North Korea, Syria).
- `NONE`: no region match found; typically means the device is **over the ocean** or in a region with no defined terrestrial LoRaWAN coverage.

If `NONE` is returned, the module can also provide a **sorted list of the nearest valid regions**, along with their distance in kilometers. This allows the firmware to optionally direct transmissions toward edge-of-range gateways (e.g. coastal) or switch to satellite fallback if available.

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### Core Functions

```
RegionCode get_region(float lat, float lon);
```

Returns:

- One of: `US915`, `EU868`, `AU915`, `AS923_1`, `AS923_2`, `AS923_3`, `AS923_4`, `CN470`, `RU864`, `NO_TX`, or `NONE`

```
int get_nearest_regions(float lat, float lon, RegionDistance out_regions[], int max_regions);
```

Returns:

- A sorted list of the `max_regions` closest valid regions with their distance in km.

```c
typedef enum {
    REGION_NONE,
    REGION_NO_TX,
    REGION_US915,
    REGION_EU868,
    REGION_AU915,
    REGION_AS923_1,
    REGION_AS923_2,
    REGION_AS923_3,
    REGION_AS923_4,
    REGION_CN470,
    REGION_RU864,
    // etc.
} RegionCode;

typedef struct {
    RegionCode region;
    float distance_km;
} RegionDistance;
```

---

### Usage in Firmware

After GNSS fix is acquired:

1. Call `get_region(lat, lon)` to select the transmission region.

2. If the result is `NONE` or `NO_TX`, optionally call `get_nearest_regions()` to obtain a list of backup targets or assess viability for edge-region transmission or satellite fallback.

## LED Status Module

The LED Status Module provides visual feedback during initial boot and launch, using a single onboard LED to indicate system state. The LED is active only during the early phases of operation when user interaction or observation is expected — specifically during commissioning and initial ascent. Once the radiosonde reaches float altitude and transitions into low-power, long-duration operation, the LED is disabled entirely to conserve energy and eliminate unnecessary emissions.

This minimal UI allows ground operators to verify system readiness at launch without the need for external tools or interfaces. It provides distinct, time-encoded patterns that correspond to firmware activity.

**Operational States and LED Patterns:**

| State | LED Behavior |
|---|---|
| Cold boot / Commissioning | 1 Hz blink |
| GNSS fix in progress | 2 Hz blink |
| Initial ascent transmission | Solid ON |
| Standard telemetry cycle | Fast blink (TX) |
| Sleep / Float mode | OFF |
| Error / Fault detected | Triple short blink |

**Behavioral Summary:**

- During **commissioning**, the LED blinks at 1 Hz to indicate system initialization and validation of flash, sensors, and region.
- When **GNSS acquisition** is active, the LED blinks at 2 Hz, providing visible confirmation that satellite lock is being attempted.
- Once a valid fix is obtained and data logging begins, the LED turns **solid ON** during the fast update cycle (ascent phase), ensuring that launch staff can visually confirm that transmissions are underway.
- After the radiosonde reaches float (determined by timer or stable pressure/altitude), the LED is **turned off entirely** to conserve power.

- During normal transmission cycles, a **brief fast blink** may optionally be used to indicate packet send events, if enabled.

- Any system fault during commissioning will trigger a repeating **triple-blink pattern**, alerting to a blocking error condition.

This strategy ensures clarity during setup and launch while maintaining power efficiency and stealth during flight. The LED behavior can be entirely disabled at compile time for minimal builds.

The LED driver uses low-power timers and GPIO control with optional compile-time disable.

# 5. Deliverables

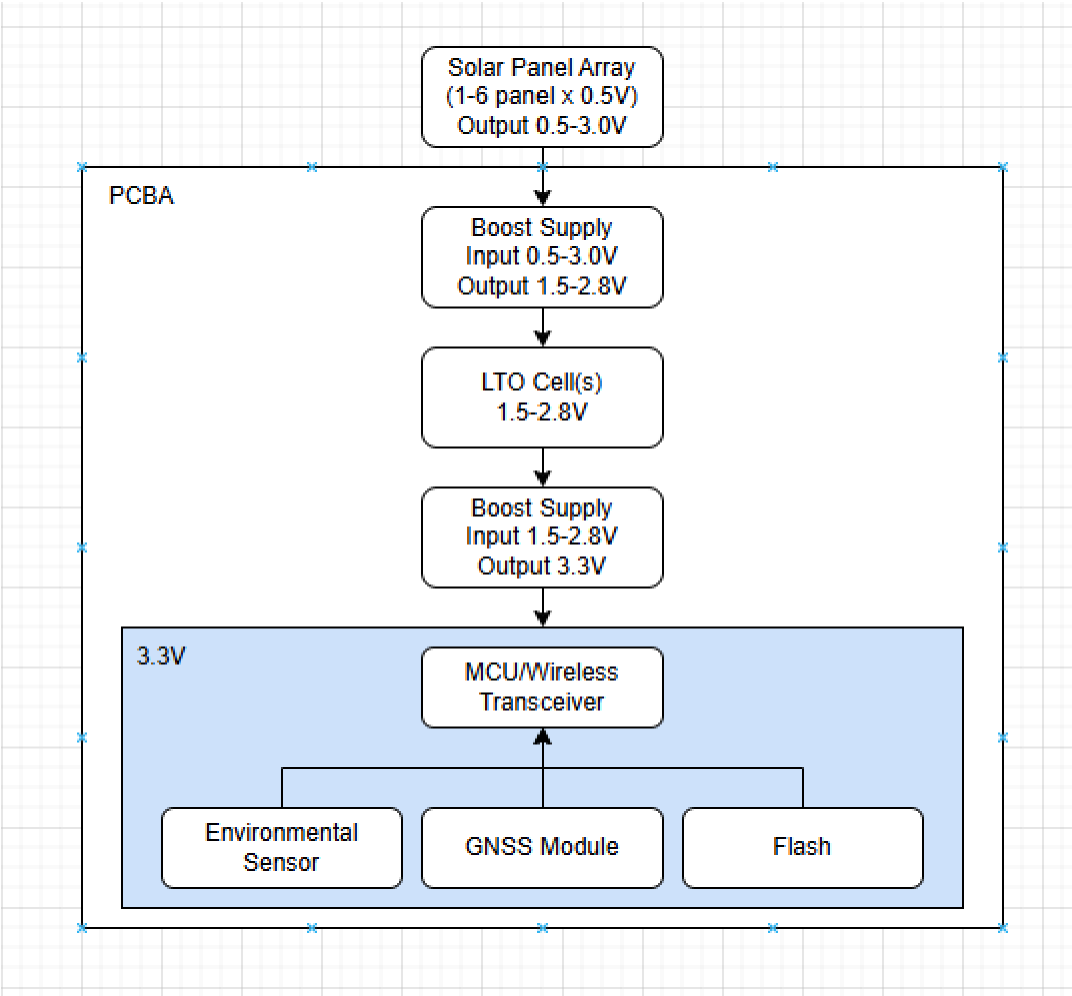
- Firmware source code

- Compiling and flashing instructions

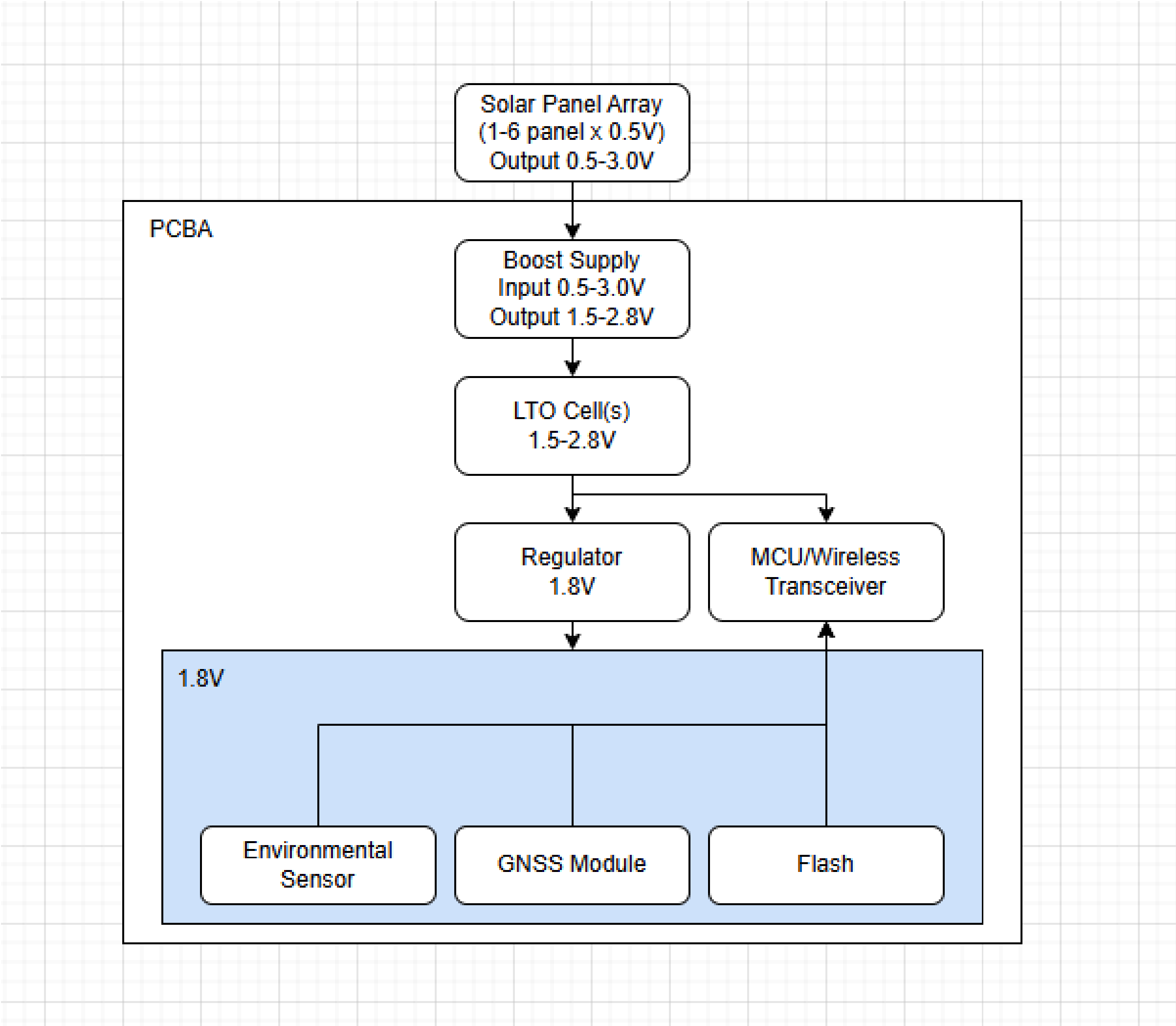
# 6. Open Design Items / TBD

- Battery capacity and size
- Final antenna design
- Optimal logging and transmission interval and data batch size. Depending on sector size and indexing scheme

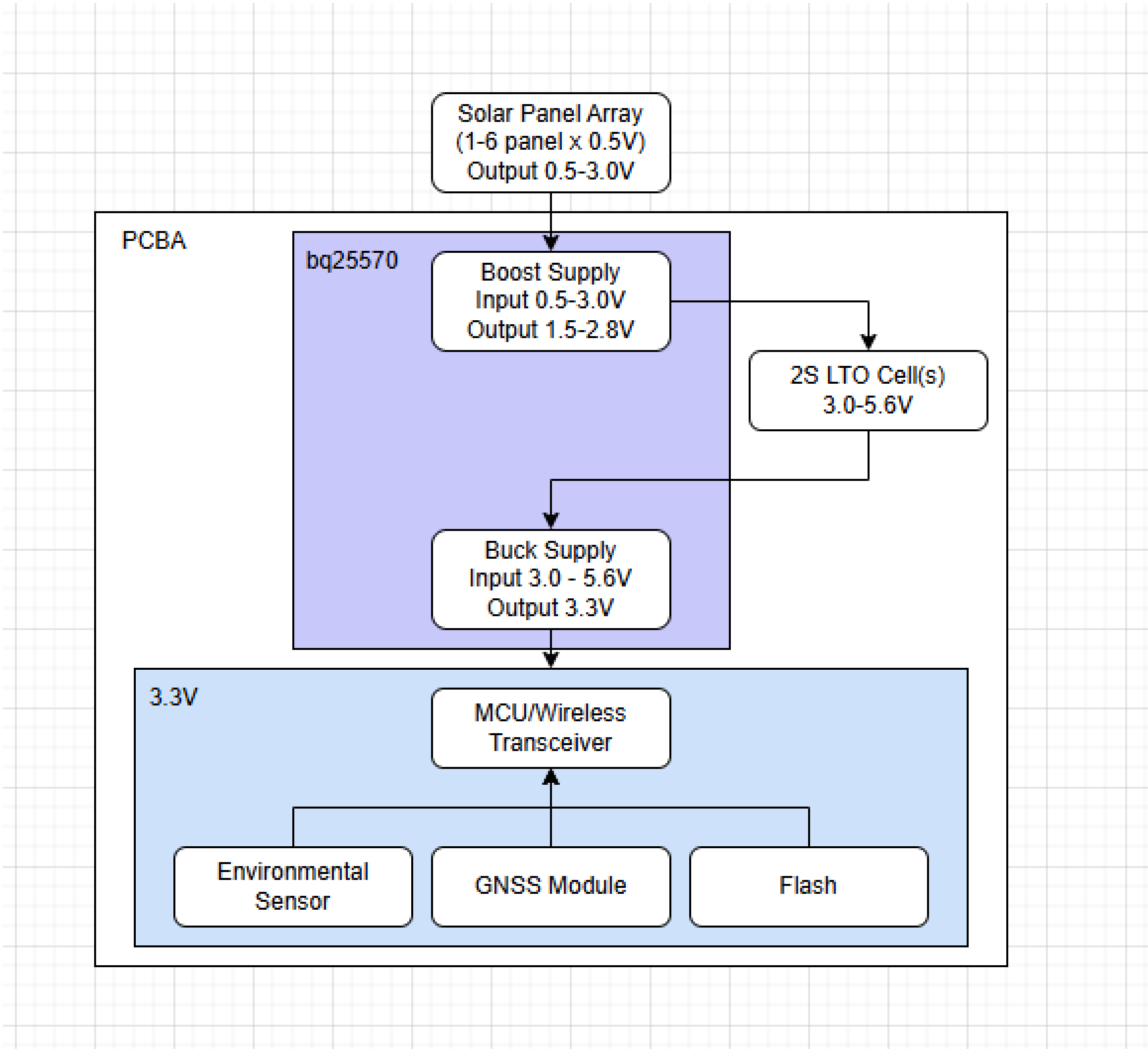
# 7. Alternative Architectures




*Boost supply*




*Low-voltage Version*




*Buck Supply*

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*Note: This is a working specification and may evolve during development. Suggestions for improved integration, power savings, or reduced cost/weight are encouraged. All part numbers are examples and suitable alternatives should be considered.*