

ALPINE RESCUE SYSTEM

GPS + LoRa mountain safety monitoring platform

An experimental engineering MVP combining trip registration, live telemetry, rescue-state logic and an operator dashboard.

868

MHz · LoRa band

5 s

SOS hold

3

system states



Final 3D-printed enclosure · OLED window · external 868 MHz antenna · serviceable split housing.

Alisher Balbayev · Alina Akylova

Haileybury Almaty · August 2026
READY FOR ENGINEERING REVIEW · FIELD TEST COMPLETE

Engineering Portfolio

Evidence-led systems engineering · field validation · rescue-awareness design

AUTHORS, SCOPE, REVISION STATUS AND EVIDENCE BOUNDARIES

PROJECT IDENTITY

Project: Alpine Rescue System
Document: Engineering Portfolio
Status: MVP development
Location: Almaty, Kazakhstan
Edition: July 2026

AUTHORS

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Student-led engineering team

PURPOSE

To document the engineering rationale, architecture, development, testing plan, limitations and evidence behind the Alpine Rescue System prototype.

REVISION CONTROL

V0.1 — concept and research
V0.2 — backend and dashboard integration
V0.3 — T-Beam hardware integration
V0.4 — field-testing edition
V1.0 — final engineering portfolio after mountain testing

PROJECT ACCESS



Scan to open the ARS trip-registration page.

Device-specific QR access links the tourist form to the selected beacon ID.

EVIDENCE STANDARD

Field testing has been completed. Range, packet-loss, GPS and battery claims remain unpublished until raw logs, station records and timestamps are reconciled.

56-PAGE ENGINEERING NARRATIVE

01–05	INTRODUCTION	Cover · control · contents · overview · objectives
06–12	RESEARCH & REQUIREMENTS	Problem · users · existing solutions · requirements · concept
13–22	SYSTEM DESIGN	Architecture · electronics · firmware · backend · safety logic
23–34	ENGINEERING DEVELOPMENT	CAD · assembly · manufacturing · software integration
35–42	TESTING	Methodology · GPS · LoRa · battery · altitude · reliability
43–56	RESULTS & CLOSING	Evaluation · limitations · deployment · reflection · references

READING PRINCIPLE

Each section closes with a verification method, decision or limitation rather than presentation-only content.

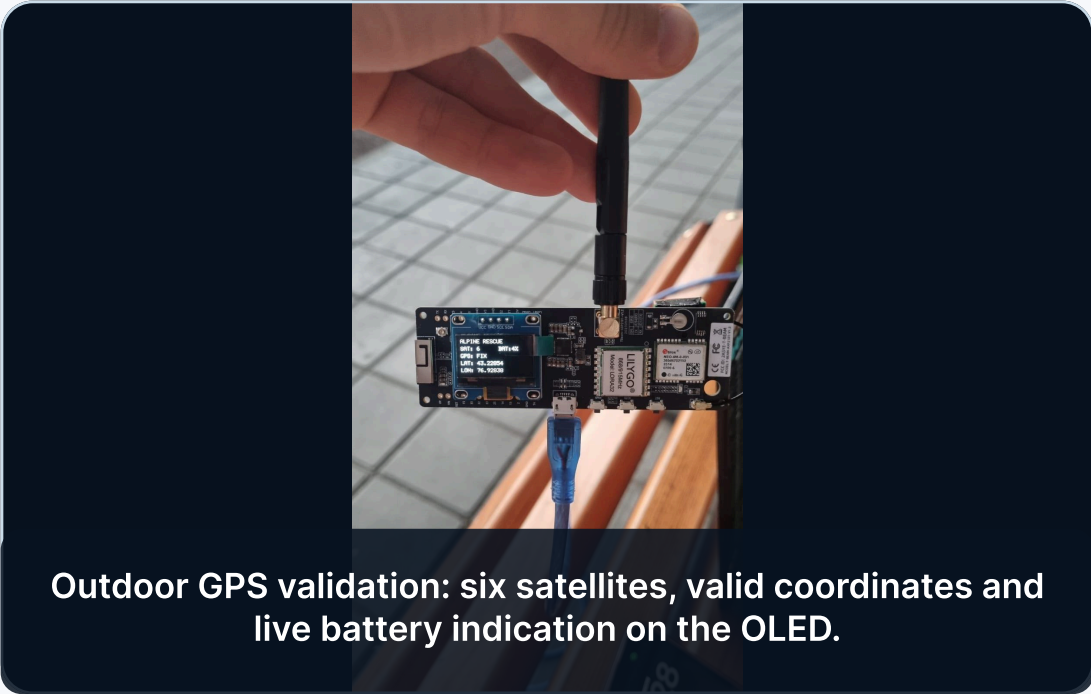
GPS- AND LORA-BASED MOUNTAIN SAFETY MONITORING MVP

PROBLEM

In mountain areas, mobile coverage can be weak or absent. When a tourist is delayed or missing, rescuers may lack a reliable route, expected return time and last known location.

SOLUTION

ARS combines a portable GPS/LoRa beacon, QR trip registration, a receiver, backend storage and a monitoring dashboard.



Outdoor GPS validation: six satellites, valid coordinates and live battery indication on the OLED.

CORE FUNCTIONS

- QR trip registration
- GPS coordinates
- LoRa telemetry
- 5-second SOS
- Green–Yellow–Red logic
- Dashboard monitoring

CURRENT STATUS

QR workflow, backend, dashboard, telemetry architecture and status logic are developed. Hardware integration is substantially complete; field validation remains the decisive final phase.

MVP BOUNDARY

ARS is an experimental engineering system and does not replace certified rescue equipment, satellite communicators or official rescue infrastructure.

OBJECTIVES ARE LINKED TO VERIFIABLE EVIDENCE

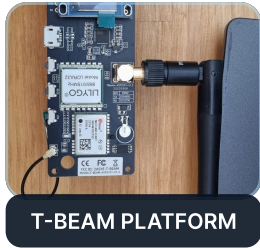
LOCATION VISIBILITY

Provide a reliable last-known GPS position and preserve its timestamp.



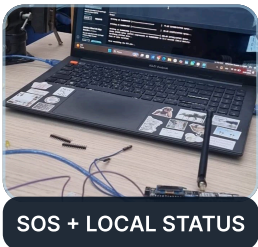
LOW-DEPENDENCY COMMUNICATIONS

Transmit essential telemetry without continuous mobile connectivity.



CLEAR EMERGENCY LOGIC

Use explicit Green, Yellow, Red and SOS states with a deliberate long press.



FIELD ENDURANCE

Operate through a full hiking window with usable battery reserve.



RESCUER USABILITY

Present concise, readable data through one operator dashboard.



TESTABLE MVP

Generate evidence for range, GPS, battery and altitude performance.



48–60 h

Target operating window

2 devices

Beacon + receiver

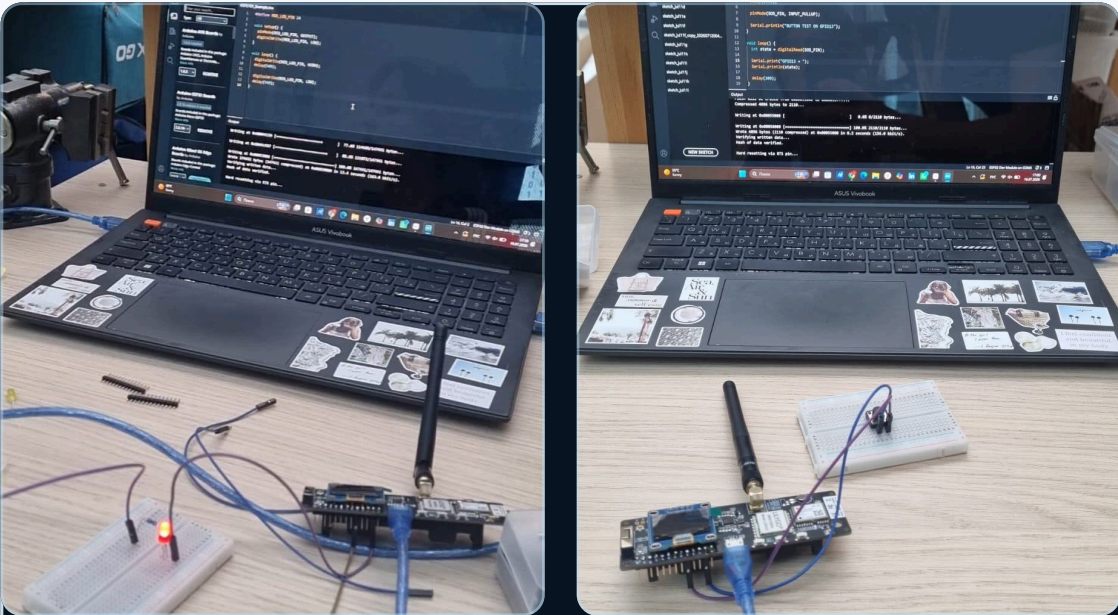
5 s

SOS confirmation threshold

6+ tests

GPS · LoRa · battery · altitude

FROM RESCUE UNCERTAINTY TO ENGINEERING REQUIREMENTS



Bench integration evidence: firmware upload, T-Beam wiring and subsystem checks before enclosure assembly.

OPERATIONAL GAP

Delayed reporting, incomplete route information, limited phone signal and uncertain last known position can expand the rescue search area.

INFORMATION GAP

Rescue coordination benefits from device ID, route, leader, group size, expected return, emergency contact and timestamped telemetry.

HUMAN FACTORS

A safety device must be simple enough for tourists, but structured enough for rescuers to interpret quickly under pressure.

38 km

Project-origin journey

26 h

Continuous effort

4,147 m

Molodezhny Peak

1 data chain

Registration → telemetry → dashboard

ENGINEERING RESPONSE

The project does not attempt to replace certified rescue equipment. It investigates whether a low-cost GPS/LoRa MVP can provide additional situational information and support earlier, better-informed decisions.

13 RESPONDENTS · TOURISTS, CLIMBERS AND CLUB MEMBERS · JUL–AUG 2026

TOURIST / GROUP LEADER

- SOS button
- GPS coordinates
- Works without mobile coverage
- Long battery life
- Water / impact protection
- Low weight
- Simple trip registration

MONITORING OPERATOR

- One view of active trips
- Freshness and overdue timer
- Battery and signal context
- Readable alert reason
- Breadcrumb history
- Filters and debug tools

RESCUER / MCHS

- Identity and contact context
- Route intention
- Last known position
- Time sequence
- Evidence quality
- Transparent limitations



DESIGN IMPLICATION

Across 13 responses, device usefulness averaged 8.8/10 (median 10). Respondents repeatedly prioritised SOS, GPS coordinates, operation without mobile coverage, long battery life and protection. Feedback also requested attachment clips, protected SOS access, group communication and geofence-style warnings.

OPERATING PRINCIPLE

Research converted recurring user needs into testable engineering requirements rather than adding features without evidence.

BENCHMARKING WITHOUT CLAIMING EQUIVALENCE

GARMIN INREACH / ZOLEO / SPOT

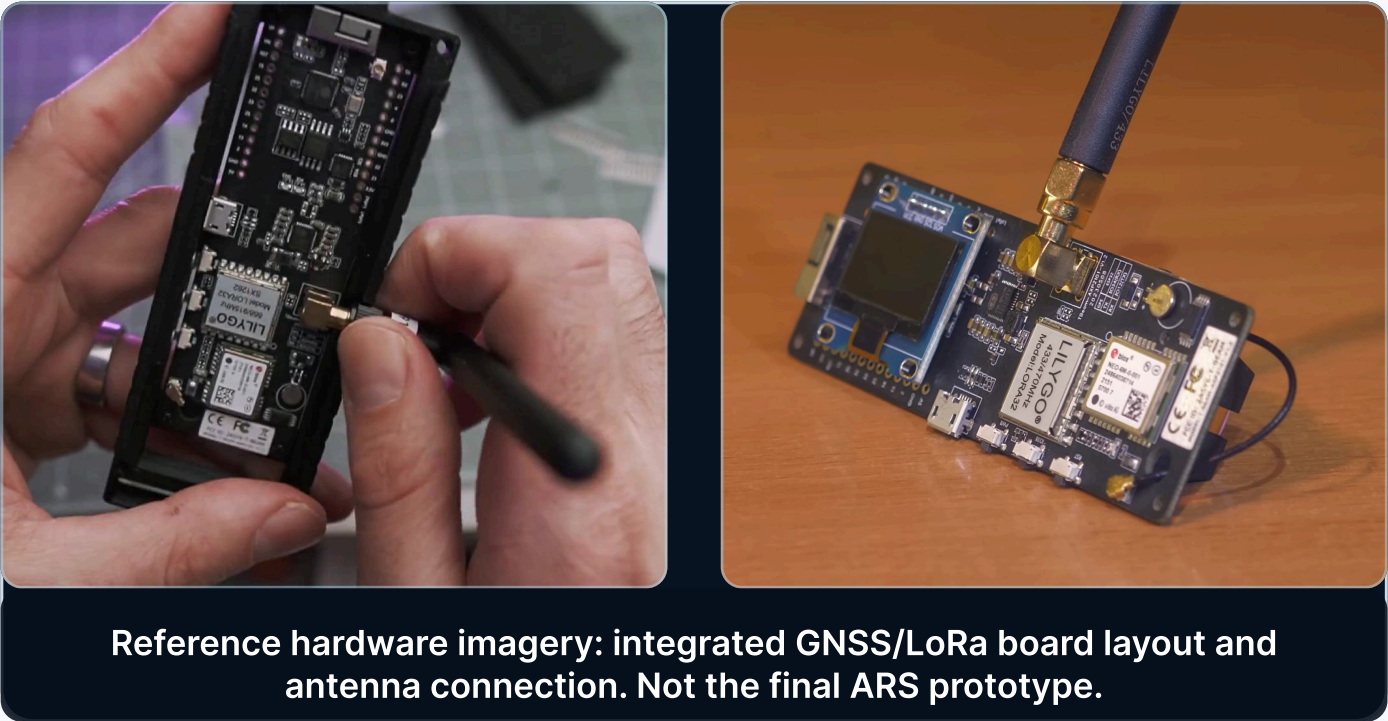
Wide-area emergency reach, independent communication, mature industrial design and proven ecosystems. Trade-off: higher hardware and service costs.

MOBILE-ONLY TRACKING

Accessible and familiar, but dependent on coverage, permissions and phone battery.

LOCAL LORA SYSTEMS

Low power and low cost, but require receiver infrastructure and careful terrain-aware testing.



COMPARISON MATRIX			
Coverage	Satellite	Cellular	Local LoRa
Recurring cost	High	Low / variable	None for MVP
Infrastructure	Satellite network	Mobile network	Receiver station
Best use	Wide-area emergency	Routine tracking	Local prototype validation

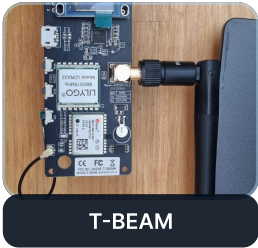
ARS POSITION

A lower-cost experimental architecture focused on local LoRa telemetry, structured trip data and a custom dashboard—not feature parity with certified satellite devices.

REQUIREMENTS CONNECT HARDWARE, SOFTWARE AND FIELD VALIDATION

COMMUNICATION

868 MHz LoRa telemetry between beacon and receiver.



POSITIONING

GPS coordinates, altitude, time and satellite-fix information.



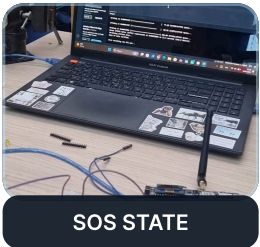
POWER

Protected 18650 supply. Dedicated endurance test: indicated battery 34% → 0% over 7 h of continuous operation. This does not validate the original 24–48 h target.



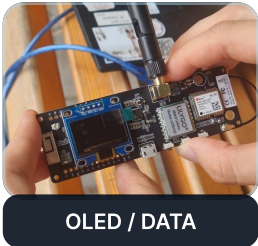
SAFETY LOGIC

Green / Yellow / Red plus 5-second SOS confirmation.



DATA

Device, trip, position, battery, RSSI, emergency and timestamp fields.



ENCLOSURE

Portable, serviceable 3D-printed housing. Protective pouch carry was field-tested; clip / attachment ideas remain future user-research input.



WEB SYSTEM

Node.js / Express backend, JSON storage and monitoring dashboard.



TESTING

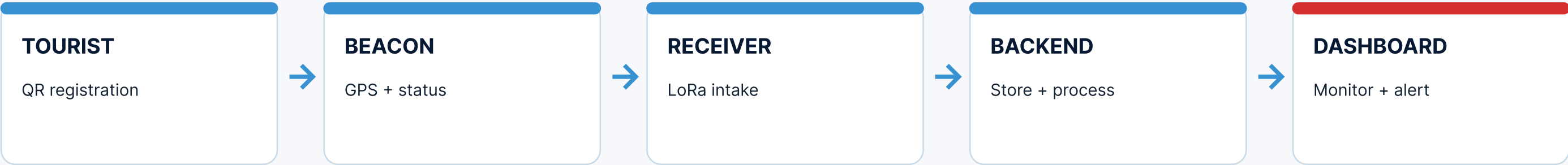
Six documented mountain stations from 2,264 m to 3,604 m with GPS, LoRa, battery and packet-delivery evidence.



VERIFICATION RULE

Published numerical results are linked to evidence records and controlled by RESULTS_FREEZE_v1.

ONE END-TO-END FLOW FROM REGISTRATION TO OPERATOR ACTION



Prototype path: electronics integration → additive manufacturing → enclosed field-ready form.

PRIMARY TELEMETRY PACKET

deviceId
tripId
latitude / longitude
altitude
battery
signalStrength
emergency
timestamp

STATE TRANSITION CONCEPT

GREEN — normal monitoring
YELLOW — overdue / stale-telemetry warning
RED — manual SOS / highest-priority dashboard state
SOS — deliberate 5-second onboard-button hold

ARCHITECTURE PRINCIPLE

Trip context is created before departure. During the hike, the beacon transmits small repeated packets. The receiver forwards them to the backend, which links telemetry to the active trip and updates the dashboard.

FROM PRODUCT RESEARCH AND EARLY CAD TO A SERVICEABLE FIELD-TEST PROTOTYPE

01 · PRODUCT & USER RESEARCH



Commercial beacons informed compactness, clear SOS access, antenna clearance and backpack mounting.

CAD & DESIGN RESEARCH

02 · PRELIMINARY ENCLOSURE



Early orthographic concepts used a large external SOS button and three separate status indicators.

EARLY CONCEPT · NOT FINAL



03 · IMPLEMENTED MVP

Split 3D-printed housing, OLED window, external antenna, service access and mounting features.

REMOVED FROM FINAL BUILD

An external LED was tested on the bench prototype but removed after the assembly assessment. It duplicated OLED/dashboard information while adding solder joints, wiring and another enclosure vulnerability.

IMPLEMENTED USER INTERFACE

The final local interface uses the onboard T-Beam button for a deliberate 5-second SOS hold and the OLED for GPS status, battery condition, device state and SOS confirmation.

DEFERRED UNTIL TESTING

A custom PCB, certified waterproofing and production mounting system remain future work. Field evidence must identify the real weaknesses before redesign.

DESIGN EVOLUTION RULE

Each revision preserves the same end-to-end workflow: register a trip, acquire a valid GPS position, transmit a compact LoRa packet, link it to the active journey and present interpretable evidence to an operator.

THE MVP WAS SELECTED FOR INTEGRATION SPEED, DEBUG ACCESS AND END-TO-END TESTABILITY



DOCUMENTED SELECTION RATIONALE

DECISION AREA	SELECTED APPROACH	STATUS / LIMIT
Core electronics	LilyGO T-Beam AXP2101 V1.2	Implemented
Device roles	Two boards: carried beacon + receiver	Implemented
Communication	Point-to-point LoRa at 868 MHz	Field range pending
Trip context	QR webpage writes directly to backend	Implemented
Monitoring	Node/Express + JSON + dashboard	Implemented / evolving

MVP BOUNDARY — INCLUDED

GPS telemetry · 868 MHz LoRa sender/receiver · QR trip registration · onboard-button SOS · OLED local status · backend · dashboard · 3D-printed enclosure.

MVP BOUNDARY — EXCLUDED

Satellite communication · AI route prediction · automatic rescue dispatch · custom PCB · certified waterproofing · smartphone ecosystem.

2 boards

Beacon + receiver

5 s

SOS confirmation

868 MHz

LoRa band

TEST PENDING

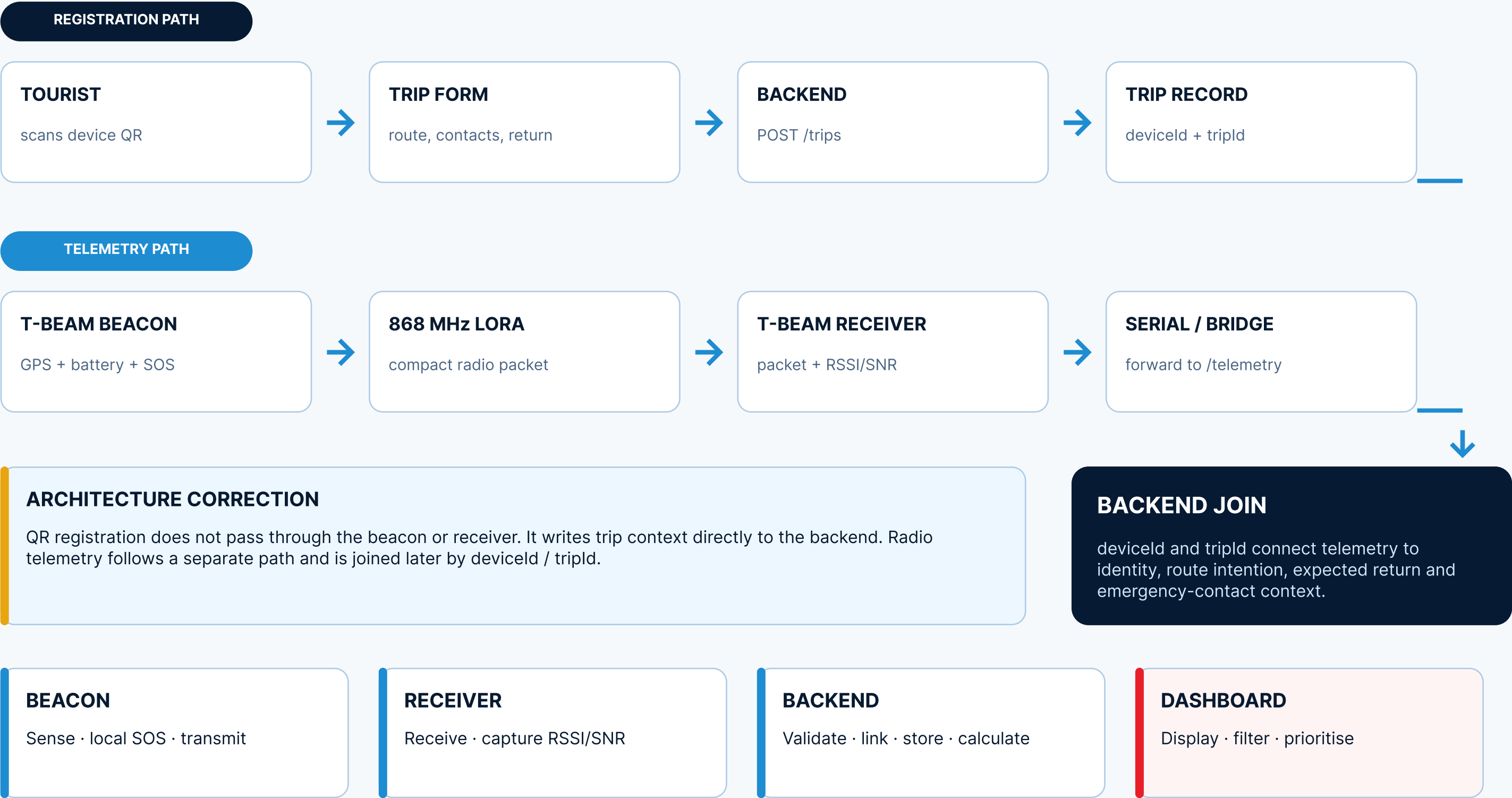
Battery endurance

EVIDENCE RULE

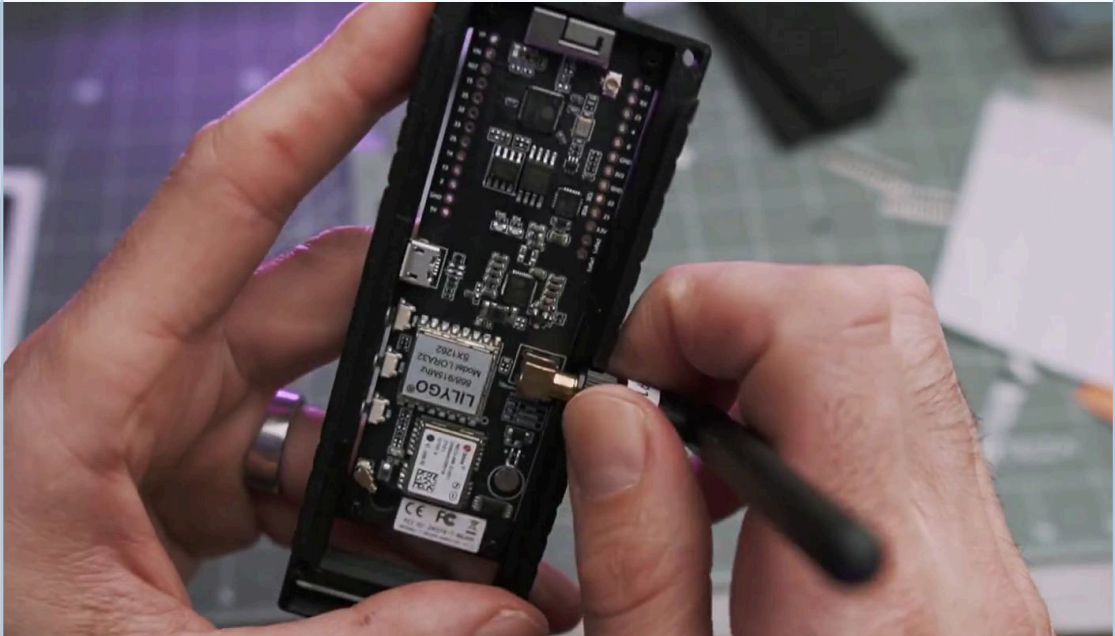
Targets are not results. Range, runtime, packet loss and altitude performance remain testing outputs until measured.

SOURCE BASIS · Master Engineering Document · Architecture · Software & Firmware

TWO INPUT PATHS CONVERGE IN THE BACKEND AND BECOME ONE OPERATOR VIEW



THE FINAL PROTOTYPE USES INTEGRATED T-BEAM SUBSYSTEMS WITH OLED-BASED LOCAL STATUS



LILYGO T-BEAM AXP2101 V1.2 · ACTUAL DEVELOPMENT PLATFORM

ESP32 CONTROLLER

Firmware scheduling, GPS parsing, SOS timing, packet construction and OLED control.

U-BLOX GNSS

Latitude, longitude, altitude, timestamp, satellite count and fix validity.

868 MHz LORA

Point-to-point telemetry to a second matched T-Beam receiver.

AXP2101 PMU

Power rails, charging and battery monitoring; ALDO3 must be enabled at 3.3 V.

ONBOARD SOS BUTTON

GPIO 38; deliberate press held for approximately 5 seconds.

OLED LOCAL INTERFACE

Displays GPS status, battery condition, device state and SOS confirmation without additional external wiring.

INTEGRATION ADVANTAGE

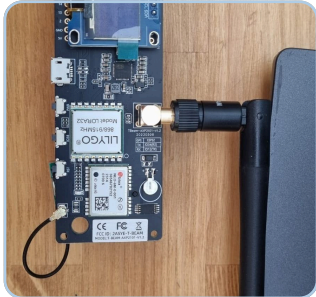
GPS, LoRa, OLED, charging and 18650 support are already on the development board. The final prototype does not add separate external GPS or LoRa modules.

REVISION CONTROL

Some research PDFs contain older T-Beam / AXP192 diagrams and early three-LED concepts. These are retained as planning references only. The final implementation record is the AXP2101 V1.2 pin map on page 16.

SOURCE BASIS · Hardware · Research · actual assembled prototype

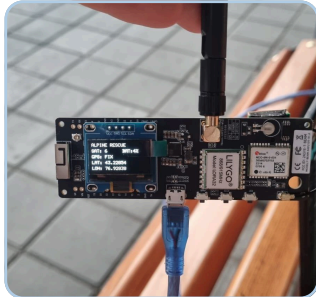
COMPONENTS WERE CHOSEN FOR A TESTABLE MVP — NOT YET FOR PRODUCTION OPTIMISATION



LILYGO T-BEAM AXP2101 V1.2

Integrated ESP32, GNSS, LoRa, OLED and battery support.
Trade-off: fixed PCB and board-specific power setup.

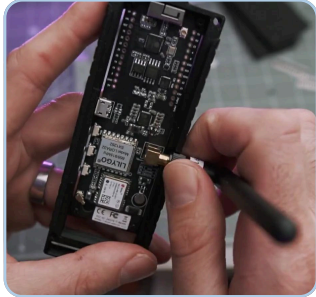
PLATFORM



INTEGRATED U-BLOX GNSS

No external wiring and direct time/location data. Trade-off: terrain and sky visibility affect fix quality.

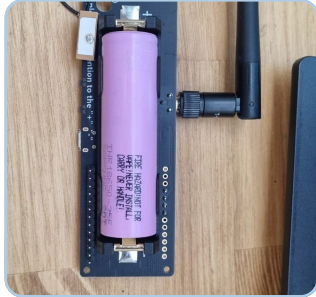
POSITION



868 MHz LORA TRANSCEIVER

Low-power compact packets without mobile coverage.
Trade-off: terrain, body shielding and antenna orientation dominate range.

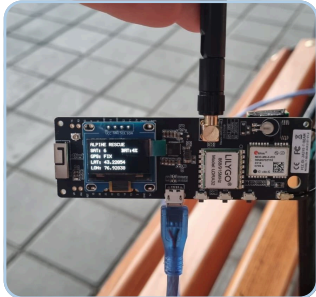
RADIO



SINGLE 18650 LI-ION CELL

Rechargeable and supported by the onboard holder.
Trade-off: cold-weather endurance and runtime require measurement.

POWER



OLED LOCAL INTERFACE

Displays GPS status, battery condition, device state and SOS confirmation without introducing additional external wiring.

INTERFACE



3D-PRINTED SPLIT ENCLOSURE

Rapid iteration, access to electronics and practical carry/service features. Trade-off: not certified waterproof or impact-rated.

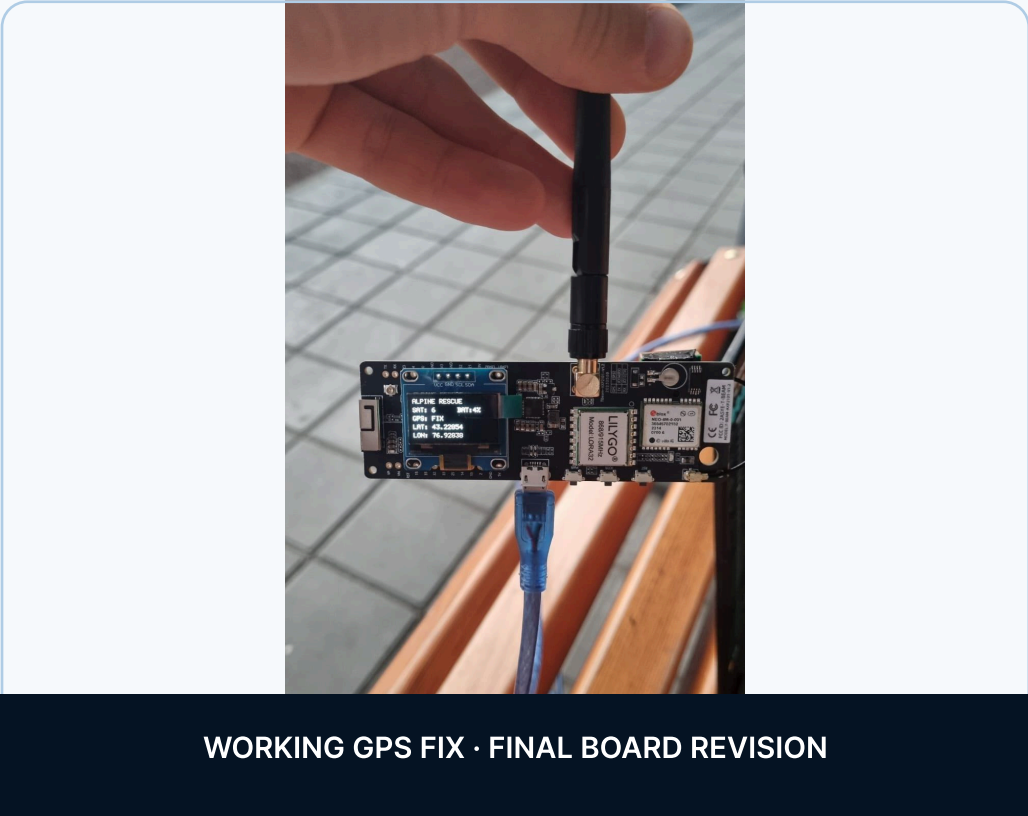
MECHANICAL

DECISION RULE

Use integrated, inspectable and replaceable components until field testing justifies custom electronics or a production enclosure.

SOURCE BASIS · Hardware · Software & Firmware · CAD & Design

FINAL AXP2101 V1.2 MAPPING — OLDER PDF PINOUTS ARE REFERENCE MATERIAL ONLY



POWER-UP REQUIREMENT

The AXP2101 configuration must enable ALDO3 at 3.3 V before normal GPS / OLED operation. This is specific to the final board revision.

PIN / BUS ALLOCATION

FUNCTION	GPIO / BUS	IMPLEMENTATION
GPS UART	RX34 / TX12	Integrated u-blox GNSS
I ² C	SDA 21 / SCL 22	OLED + AXP2101 PMU
LoRa SPI	NSS 5 · MISO 19 · MOSI 27 · SCK 18	Board radio bus
Radio control	DIO0 26 · RST 23 · DIO1 33	Interrupt + reset
DIO2 / BUSY	GPIO 32	Board-specific radio line
PMU IRQ	GPIO 35	Input-only power status
Onboard button	GPIO 38	5-second SOS hold

INTEGRATION SEQUENCE

- 1

Attach LoRa + GPS antennas
- 2

Enable PMU / ALDO3
- 3

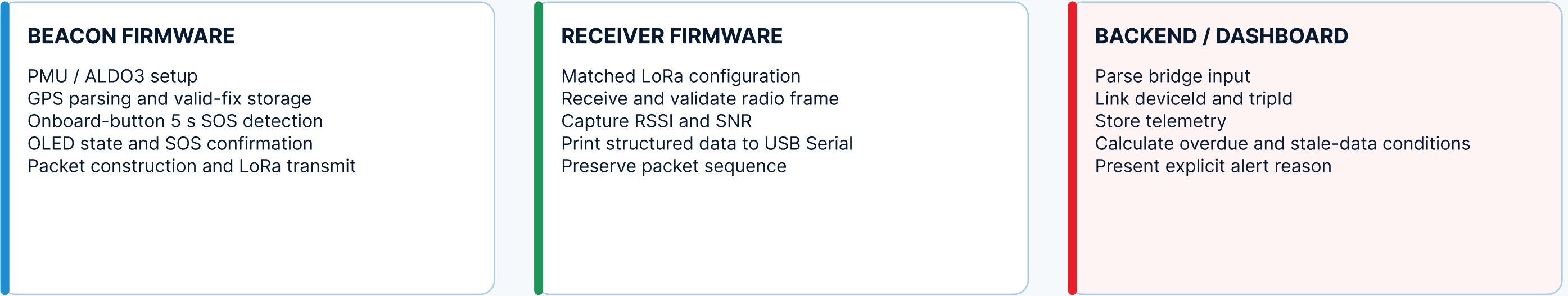
Verify OLED + valid GPS
- 4

Match sender/receiver radio settings
- 5

Install enclosure and strain relief

SOURCE BASIS · Hardware · Software & Firmware · actual AXP2101 V1.2 board

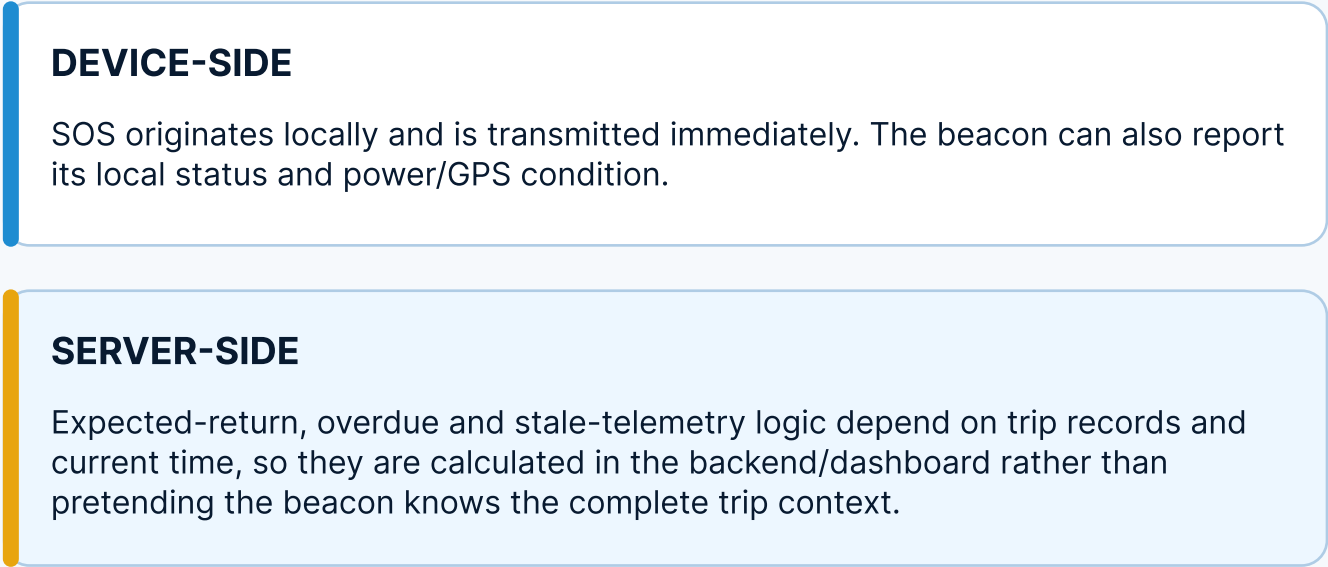
BEACON, RECEIVER AND BACKEND LOGIC ARE SEPARATED TO PREVENT FALSE CLAIMS



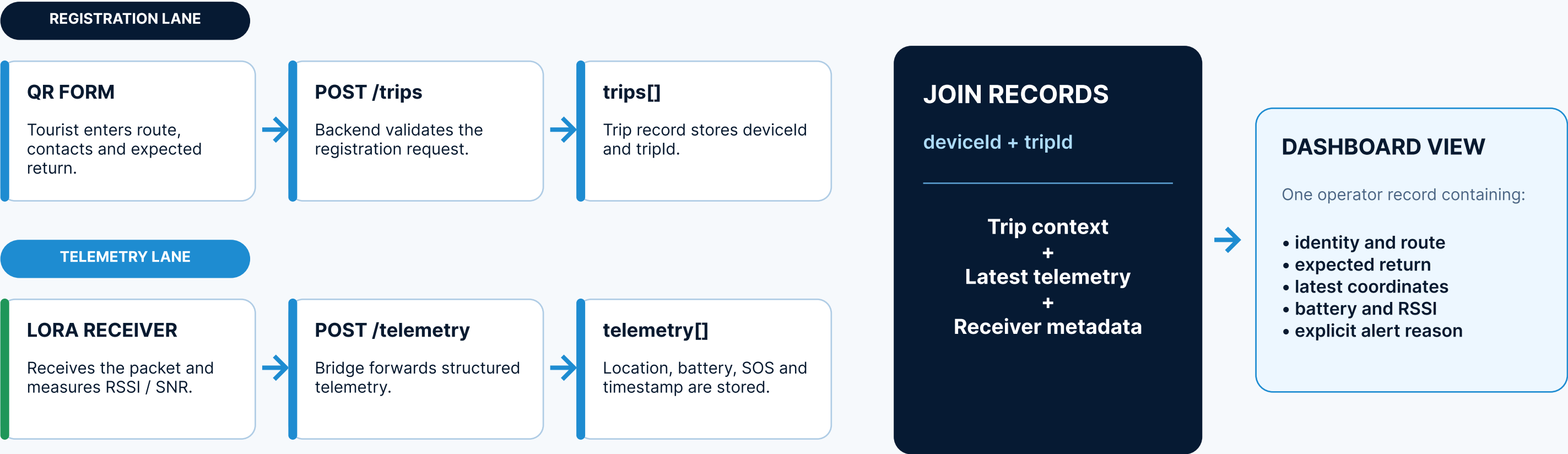
NON-BLOCKING BEACON CONTROL FLOW

```
setup()  
  enableAXP2101andALDO3();  
  startSerialOLEDandGPS();  
  configureOnboardButton();  
  initialiseLoRa();  
  
loop()  
  parseAvailableGPSBytes();  
  detectFiveSecondSOS();  
  updateOLEDState();  
  if (telemetryDue) buildAndTransmit();
```

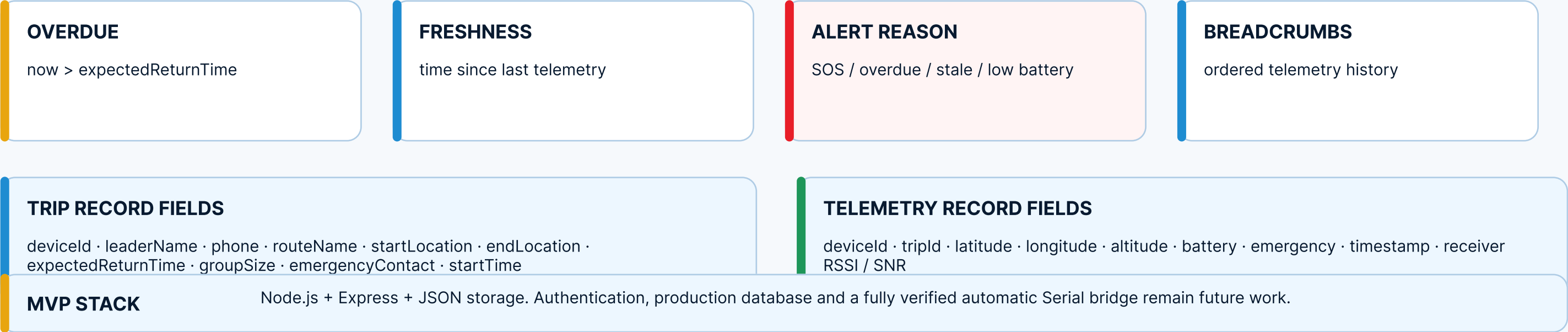
STATE OWNERSHIP



TWO INPUT STREAMS ARE STORED SEPARATELY, THEN JOINED BY `deviceId` + `tripId`

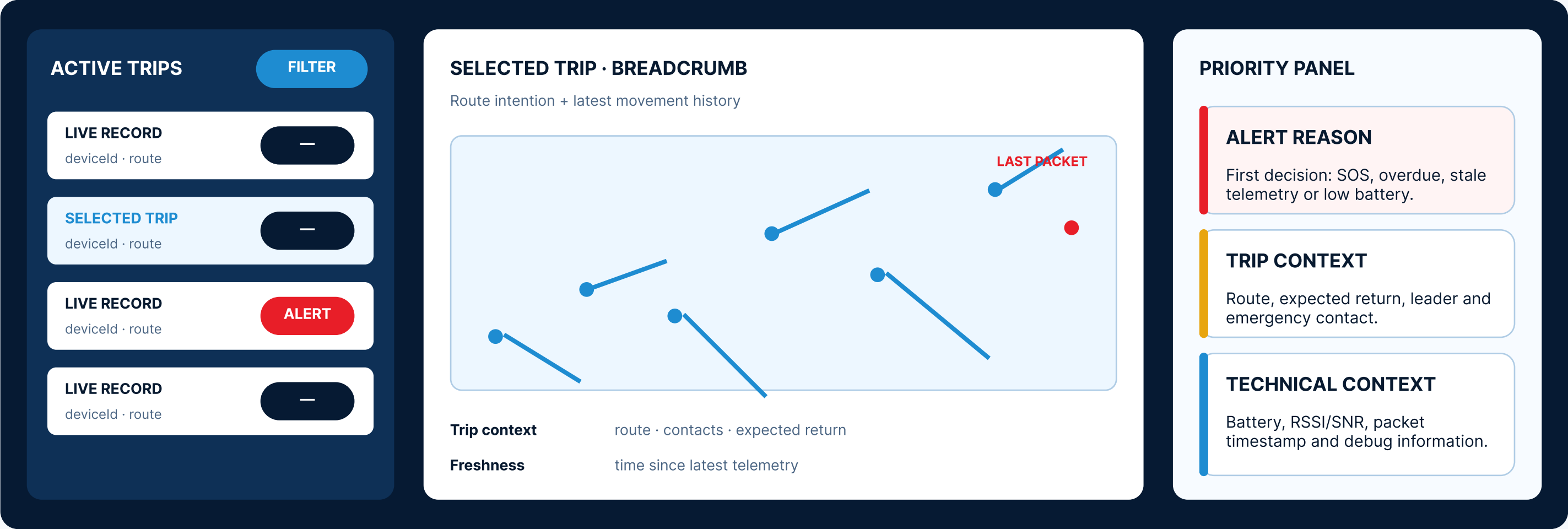
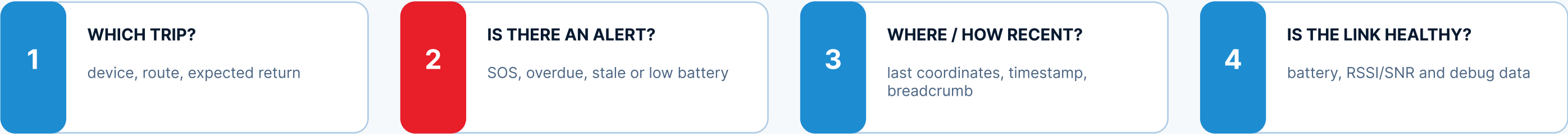


WHAT THE BACKEND CALCULATES

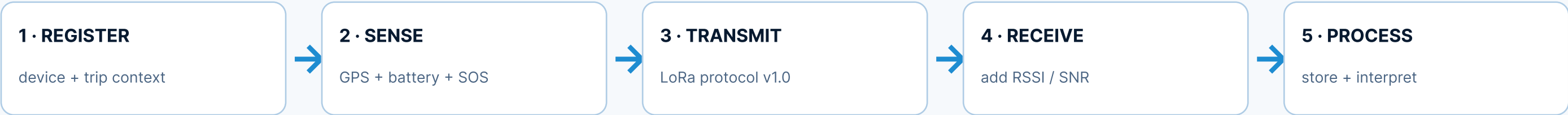


SOURCE BASIS · Software & Firmware · Architecture · backend implementation notes

THE DASHBOARD ANSWERS FOUR QUESTIONS IN A FIXED ORDER



PROTOCOL V1.0 SEPARATES TRANSMITTED FIELDS FROM RECEIVER-DERIVED RADIO METADATA



TRANSMITTED PACKET · PROTOCOL V1.0

packet_version	device_id
trip_id	packet_type
timestamp	latitude
longitude	altitude
battery	state
sos	packet_seq
checksum	

STATE AND EVENT OWNERSHIP

SOS is confirmed locally after the 5-second hold. Overdue and stale-telemetry conditions use backend trip/time context. A routine packet must not silently clear a confirmed emergency.

EVIDENCE RULE

Intervals are protocol design settings, not measured range, runtime or reliability results.

SOURCE BASIS · Software & Firmware protocol v1.0 · Architecture

RECEIVER-DERIVED METADATA

RSSI and SNR are measured by the receiving radio after reception. They are attached to storage/debug records and are not presented as fields measured by the beacon.

PACKET TYPES

TELEMETRY	WARNING
EMERGENCY	TEST

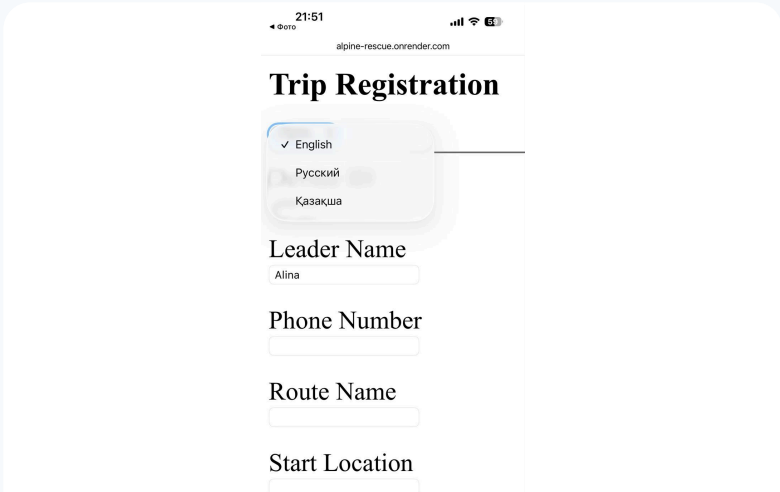
CONCEPTUAL TRANSMISSION INTERVALS

GREEN	3–5 min
YELLOW	30–60 s
RED	10–30 s
SOS	immediate burst, then repeat

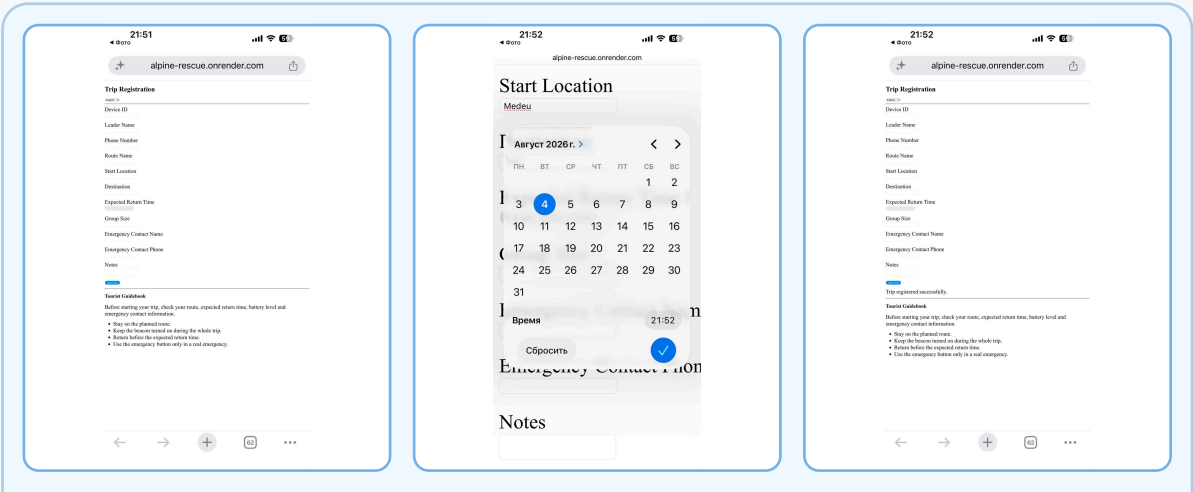
THE QR LABEL LINKS A PHYSICAL BEACON TO ONE ACTIVE TRIP RECORD



Final beacon enclosure with Device ID / QR label zone



Mobile registration opened from the device QR



Registration sequence: form, expected return and confirmation

1 • IDENTIFY

QR contains or resolves the selected deviceId.

2 • REGISTER

Tourist submits leader, route, return time, group size and emergency contact.

3 • CREATE TRIP

POST /trips creates an active trip record in backend storage.

4 • LINK DATA

Future telemetry is joined to the trip through deviceId and tripId.

TRIP RECORD — CORE FIELDS

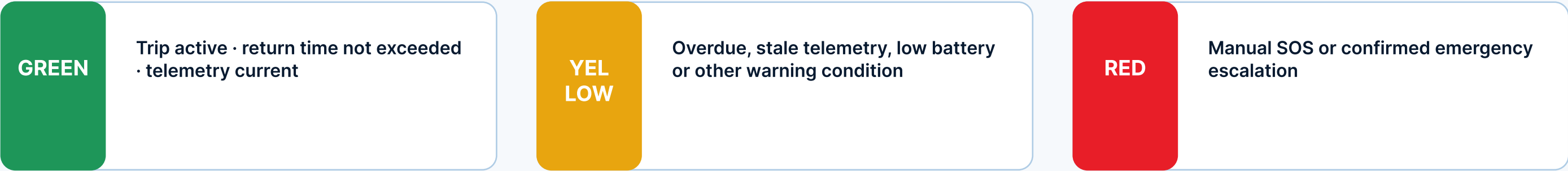
deviceId · leaderName · phone · routeName · startLocation · endLocation · expectedReturnTime · groupSize · emergencyContact · startTime

DESIGN BOUNDARY

QR registration writes directly to the backend. It does not pass through the beacon or LoRa receiver. The beacon carries the device identity; the backend stores the journey context.

SOURCE BASIS · Architecture · QR registration workflow · backend trip manager

OPERATOR STATES ARE CALCULATED FROM TRIP TIME, TELEMETRY FRESHNESS AND SOS



DECISION FLOW



BEACON-SIDE STATUS

The local OLED reports GPS status, battery condition, device state and SOS confirmation. The beacon does not independently know the complete trip schedule unless that context is explicitly transmitted to it.

DASHBOARD-SIDE STATUS

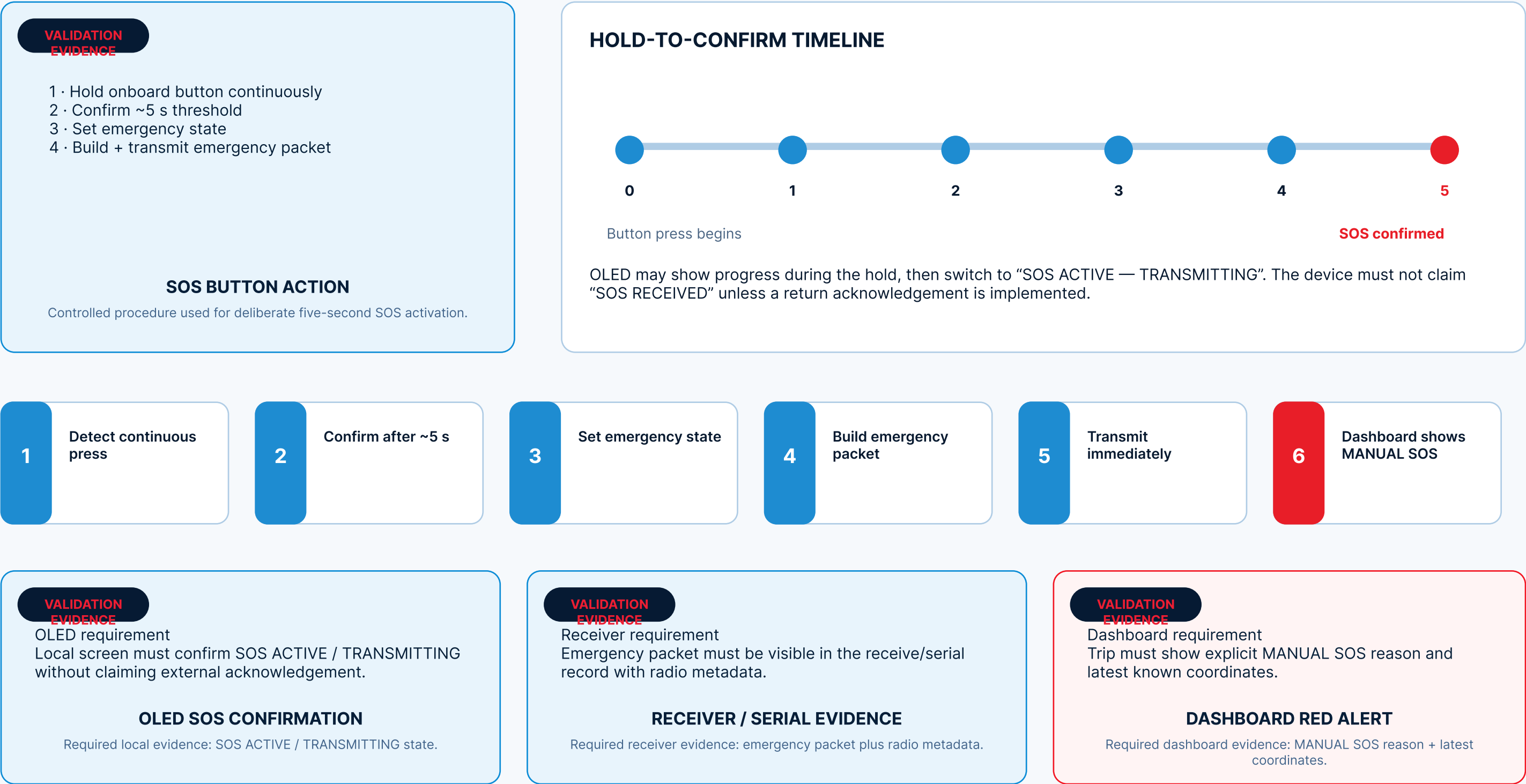
The backend compares current time with expectedReturnTime and checks telemetry age. The dashboard must display the explicit alert reason rather than only a colour.

SAFETY RULE

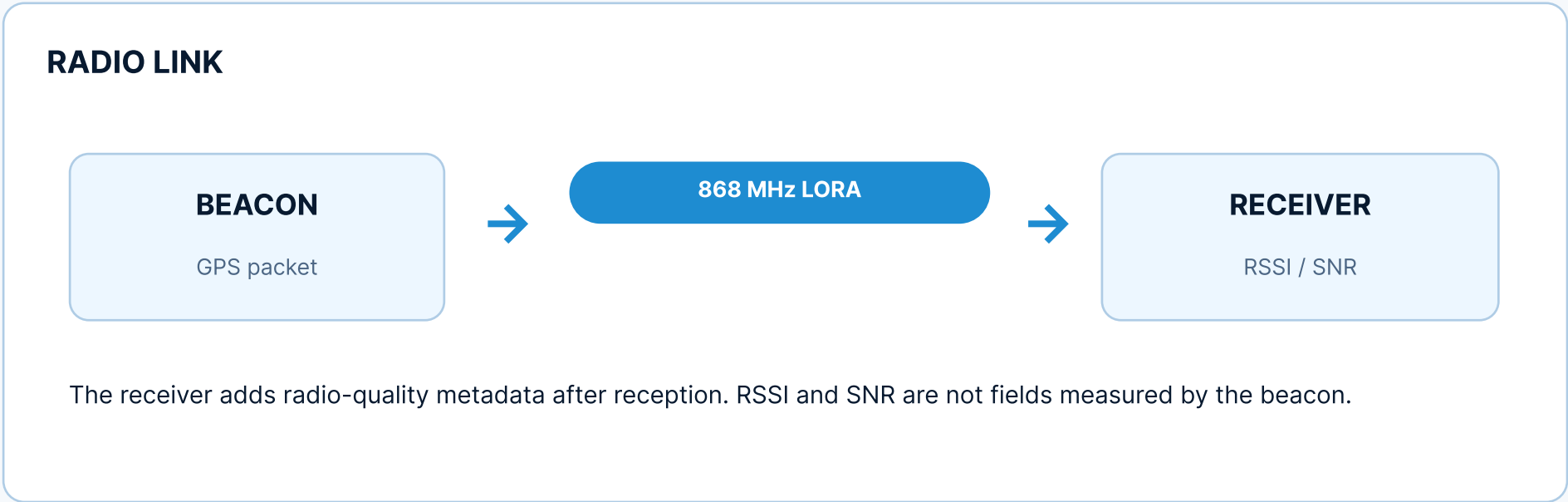
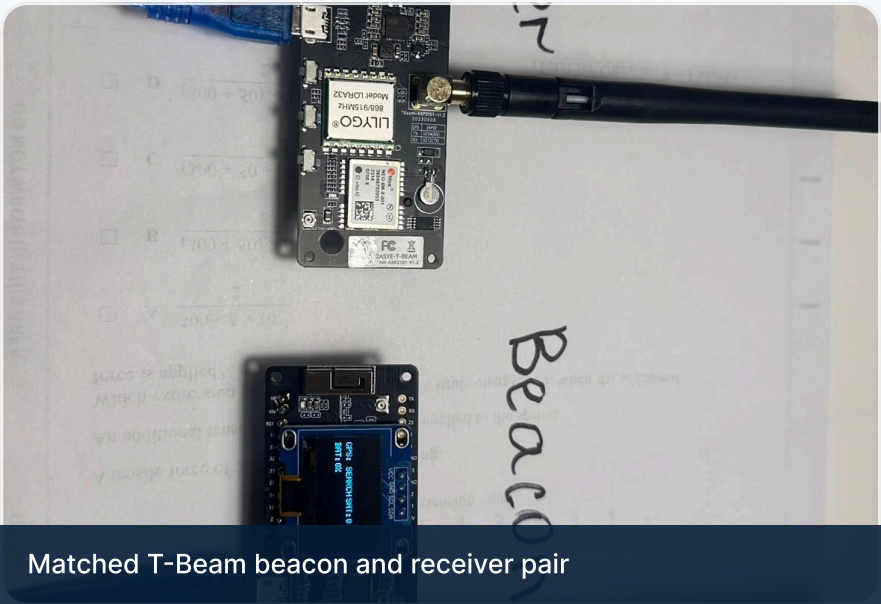
A routine packet must not silently clear a confirmed SOS. State transitions require explicit logic and must be visible in the event history.

SOURCE BASIS · Architecture · state transition logic · delayed-return workflow

A DELIBERATE FIVE-SECOND HOLD REDUCES ACCIDENTAL ACTIVATION



POINT-TO-POINT 868 MHz LORA CARRIES COMPACT TELEMETRY WITHOUT MOBILE COVERAGE



LINE OF SIGHT

Mountain ridges and buildings may block the direct radio path.

ANTENNA ORIENTATION

Vertical alignment and clear placement affect the link.

BODY SHIELDING

A person or backpack can absorb or shadow the signal.

PACKET SETTINGS

Spreading factor, bandwidth, coding rate and payload length affect robustness.

DISTANCE

Only measured test distance may be reported as a project result.

RECOVERY

Receiver and backend should recover after temporary communication loss.

FIELD LINK PHOTO

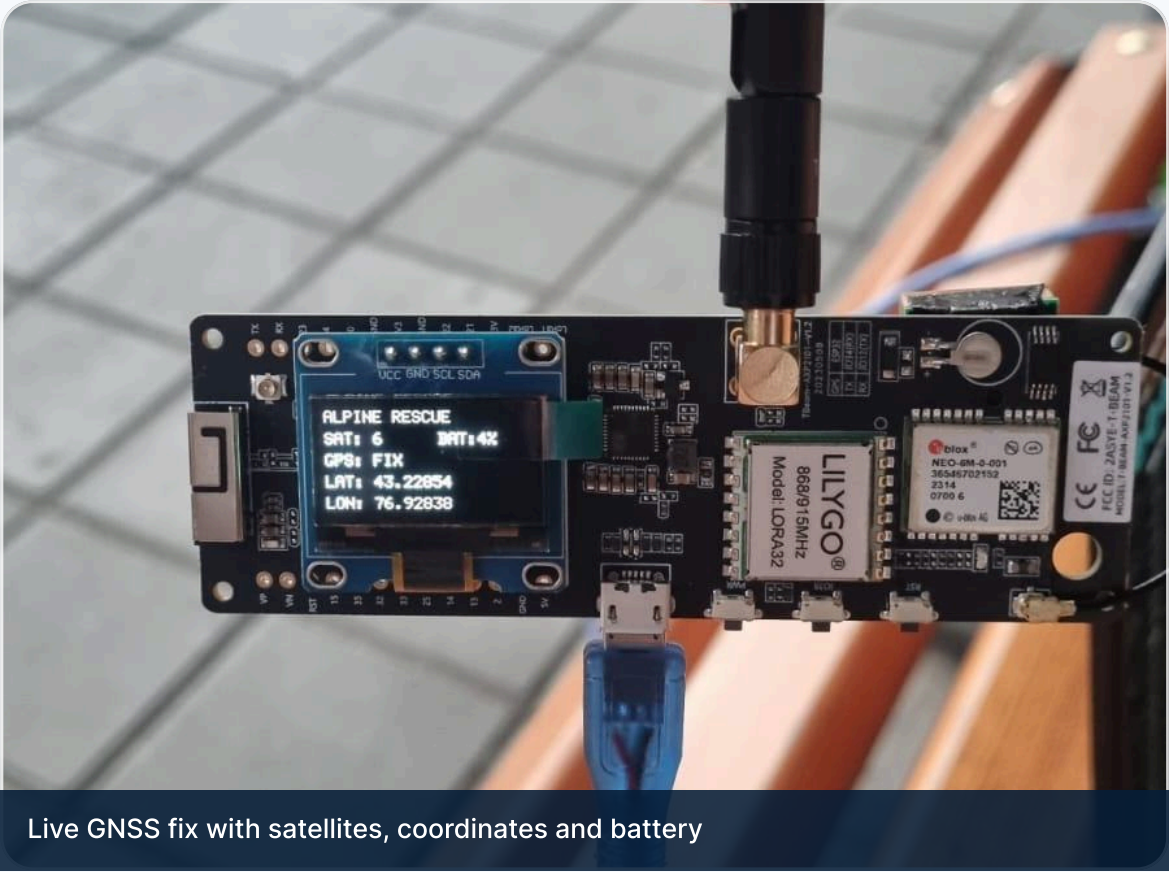
Beacon and receiver at a documented separation; include distance and terrain.

ANTENNA ORIENTATION PHOTO

Correct external mounting with the antenna upright and unobstructed.

SOURCE BASIS · LoRa research · protocol v1.0 · testing plan

THE BEACON REPORTS POSITION EVIDENCE — IT DOES NOT PERFORM NAVIGATION OR HAZARD PREDICTION



GNSS DATA PIPELINE



VALID FIX

Store and transmit the newest valid coordinates with timestamp and satellite evidence.

NO CURRENT FIX

Retain the last valid position and show its age. Do not replace it with zero or fabricated coordinates.

EVIDENCE TO CAPTURE

INITIAL FIX

time to first valid position

SATELLITES

count at each station

RECOVERY

time after signal loss

POSITION AGE

last valid timestamp



SOURCE BASIS · Hardware · GPS research · Software & Firmware

BATTERY ENDURANCE IS NOW MEASURED: 34% → 0% OVER 7 HOURS OF CONTINUOUS OPERATION



18650 cell installed on the T-Beam power side

POWER DESIGN PRIORITIES

- SAFE CELL**

Inspect damage and insulation.
- SERVICE ACCESS**

Charge and update without disassembly risk.
- MEASURED RUNTIME**

Measured endurance: 7 h from 34% indicated charge to 0%.

POWER PATH



AXP2101 SETUP

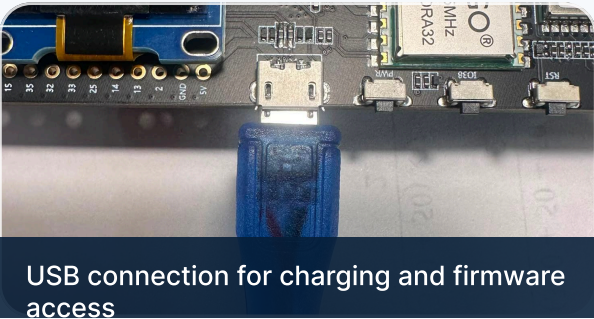
ALDO3 must be enabled at 3.3 V on the final AXP2101 board revision before normal GPS and OLED operation.

DUTY CYCLE

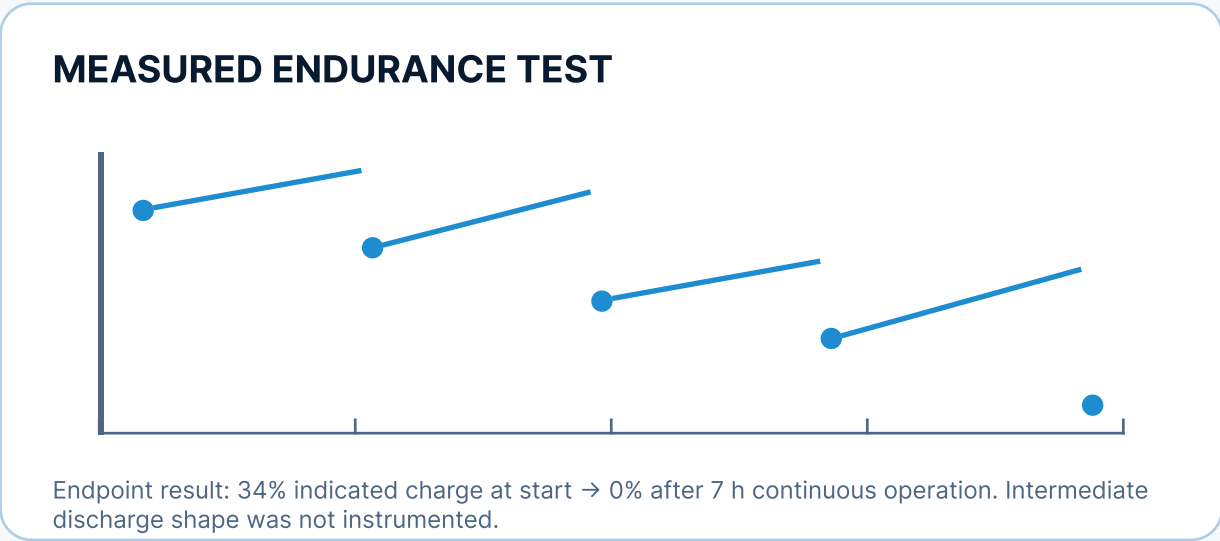
GNSS activity, OLED use and LoRa transmission frequency control the electrical load.

COLD WEATHER

Li-ion capacity and voltage behaviour can degrade at low mountain temperatures.



USB connection for charging and firmware access



SOURCE BASIS · Hardware · AXP2101 integration · battery testing plan

THE FINAL MVP USES OLED + ONBOARD BUTTON + QR — NO EXTERNAL LED

OLED STATES

NORMAL

GPS fix · satellites · battery

WARNING

stale / no-fix information

SOS

active and transmitting



Final handheld prototype — OLED, antenna and enclosure geometry

INTERACTION POINTS

ONBOARD BUTTON

~5 s deliberate SOS hold

QR LABEL

opens selected device registration

DASHBOARD

remote alert and technical context

VALIDATED
WORKFLOW

FIELD METHOD
Use the onboard T-Beam button; hold continuously for approximately five seconds; verify local OLED state, transmitted emergency packet and dashboard alert reason.

BUTTON-HOLD EVIDENCE

Finger holding the onboard control through the five-second confirmation

WHY THE EXTERNAL LED WAS REMOVED

Bench testing showed that the LED duplicated OLED/dashboard information while adding solder joints, wiring and an additional enclosure vulnerability. Removing it improved assembly quality, serviceability and product appearance.

OLED CONFIRMS LOCAL STATE

DO NOT CLAIM “RECEIVED” WITHOUT ACK

SOURCE BASIS · Hardware revision · firmware UI · QR workflow

MECHANICAL TARGETS SUPPORT FIELD TESTING — THEY ARE NOT CERTIFICATION CLAIMS



REQUIREMENT MAP

1

PROTECTION
shield PCB, battery and OLED

2

RF CLEARANCE
avoid antenna obstruction

3

GPS VIEW
retain sky visibility

4

SERVICE
open without wire damage

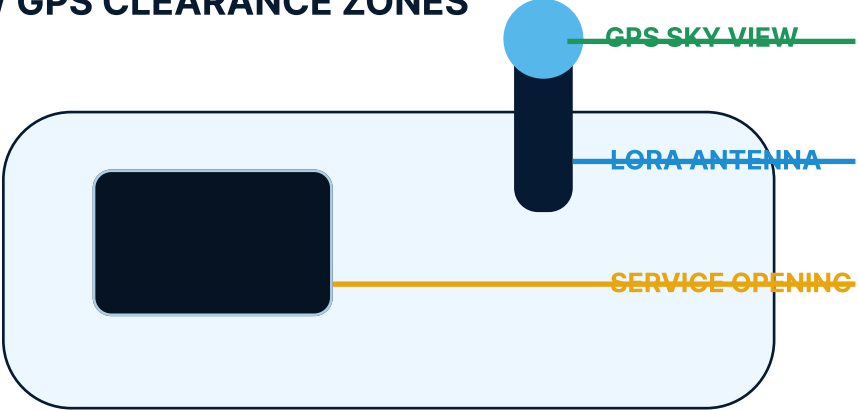
5

MOUNTING
support protected carry or optional lanyard

6

COMFORT
soft edges and low snag risk

RF / GPS CLEARANCE ZONES



The diagram shows a top-down view of the enclosure. A blue circle at the top is labeled 'GPS SKY VIEW' with a green line. A blue rectangle below it is labeled 'LORA ANTENNA' with a blue line. A yellow rectangle at the bottom is labeled 'SERVICE OPENING' with a yellow line.

Do not block the antenna with the body or dense equipment. Keep cable bends and enclosure penetrations to a minimum.



SOURCE BASIS · CAD & Design · enclosure requirements · hardware integration

COMMERCIAL PRODUCTS INFORMED MECHANICAL AND HUMAN-FACTOR LESSONS — NOT FUNCTIONAL EQUIVALENCE

REFERENCE BENCHMARK

DESIGN CUES

- compact body with softened edges
- protected, readable display
- deliberate emergency access
- external antenna clearance
- minimal enclosure penetrations

GARMIN INREACH MINI 2

Reference product studied for compact packaging, protected display and deliberate emergency access.

REFERENCE BENCHMARK

ZOLEO

Reference product studied for portable outdoor form, antenna clearance and simple user interaction.

REFERENCE BENCHMARK

SPOT X

Reference product studied for physical controls, rugged packaging and communication-device ergonomics.

WHAT ARS ADOPTED

rounded compact body

recessed readable display

deliberate emergency access

carry / attachment provisions

external antenna clearance

minimal enclosure penetrations

BENCHMARK RESPONSE MATRIX

DESIGN FEATURE	OBSERVATION	ARS RESPONSE
Rounded body	Reduces snagging and improves hand comfort.	Use softened edges and restrained external features.
Emergency access	Commercial devices prioritise deliberate activation.	Use onboard-button hold plus explicit OLED confirmation.
Antenna clearance	The antenna remains external and unobstructed.	Maintain upright placement and mechanical strain relief.
Screen integration	The display is protected but readable.	Recess the OLED window without blocking visibility.
Mounting / ports	Outdoor products minimise loose openings.	Retain simple attachment provisions, protective-pouch carry method and no external LED opening.
BOUNDARY	ARS is a LoRa/GPS prototype, not a satellite messenger and not a certified commercial rescue device.	

SOURCE BASIS · Commercial-device research · CAD & Design

EACH REVISION CHANGED A SPECIFIC FIT, ACCESS OR DURABILITY RISK



1



2



REVISION DECISIONS

OLED OPENING
visibility + protection

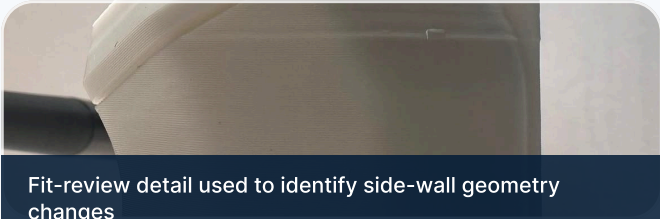
BATTERY DEPTH
match 18650 holder

ANTENNA / SMA
avoid bending loads

FASTENING
reduce movement

BUTTON ACCESS
retain onboard SOS

MOUNTING
carry / attachment geometry



The lower-right V7 image is intentionally the visual endpoint of the page. Replace it with the cleanest final enclosure photograph.

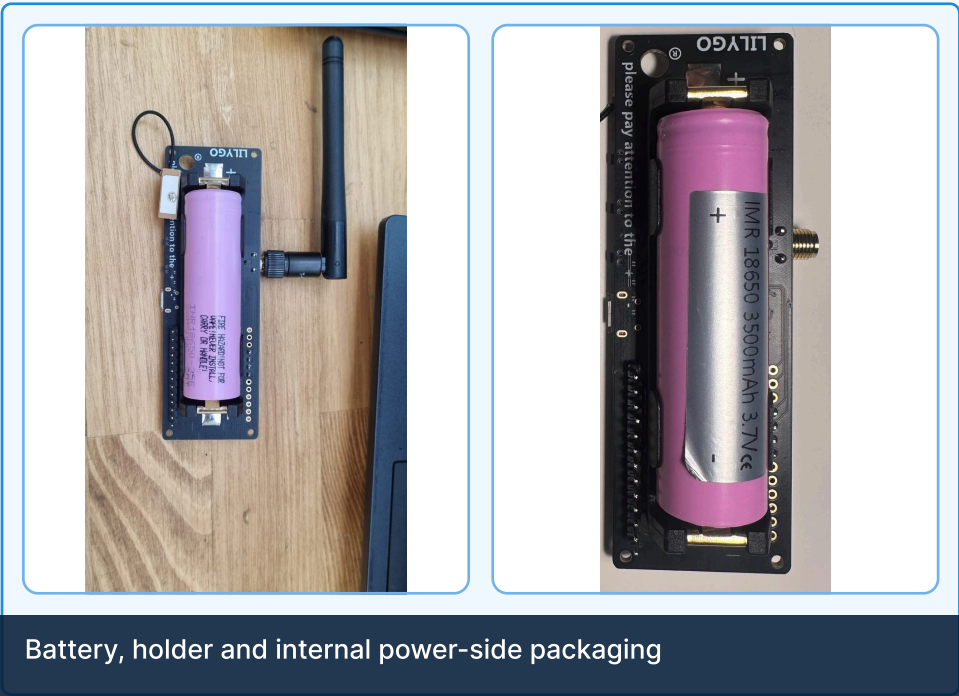


3



SOURCE BASIS · CAD & Design · enclosure files · manufacturing evidence

THE ENCLOSURE MUST HOLD THE ELECTRONICS WITHOUT LOADING THE PCB, BENDING THE SMA CONNECTOR OR BLOCKING SERVICE ACCESS.



PACKAGING STACK

OLED WINDOW

Visible from front; no pressure on display

T-BEAM PCB

Centred and supported at mounting points

18650 CELL

Retained against movement; polarity visible

BACK COVER

Opens without pulling cables or antenna lead



BATTERY MOVEMENT

Cell must not slide during walking or impact.

PCB PRESSURE

Cover must not press directly on components or OLED.

SMA BENDING

Antenna load must be transferred into the enclosure, not the PCB.

USB ACCESS

Programming and charging remain accessible without full disassembly.

BUTTON ACCESS

Onboard SOS control remains reachable through the enclosure.

NO EXTERNAL LED

Removed to reduce wiring, openings and assembly risk.

INTEGRATION GATE

Close the case only after OLED, GPS, LoRa, USB access and the 5-second onboard-button SOS remain functional.



SOURCE BASIS · Hardware Integration · CAD and Manufacturing · current no-LED revision

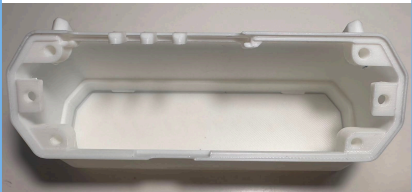
FDM PROTOTYPING ON THE BAMBU LAB X1-CARBON TURNS CAD REVISIONS INTO TESTABLE HARDWARE WITH A CONTROLLED QUALITY GATE.

01	EXPORT CAD	Confirm correct V7 frame, back, inserts and covers.
02	SLICE	Orient parts, define supports and inspect wall thickness.
03	PRINT	Record material, machine, duration and observed defects.
04	POST-PROCESS	Remove supports; clean openings and mating surfaces.
05	FIT CHECK	Verify OLED, battery, button, SMA and back-cover retention.
06	INTEGRATE	Install electronics, antenna, battery and labels.
07	FUNCTION TEST	Power → OLED → GPS → button → LoRa → backend.

MANUFACTURING RECORD

Part version, material, print settings, assembly time and acceptance decision should be logged for every revision.

SOURCE BASIS · CAD and Manufacturing · Bambu Lab X1-Carbon evidence · assembly workflow



Bambu X1-Carbon and printed enclosure evidence

QUALITY GATE — DIMENSIONAL

Board fit · OLED opening · battery depth · button access · SMA clearance · back-cover retention.

QUALITY GATE — SURFACE

Warping · support scars · cracked walls · blocked ports · loose inserts · sharp edges.



POST-PROCESSING CONTROL

After printing, inspect fit, port clearance, insert retention, enclosure closure and surface defects before electronics are installed.

DEVICE POSITION CONTROLS RF PERFORMANCE, GPS SKY VIEW, USER ACCESS AND PHYSICAL COMFORT.

VERIFIED FIELD METHOD

01 · TRANSPORT

Dedicated protective pouch

02 · DEPLOY

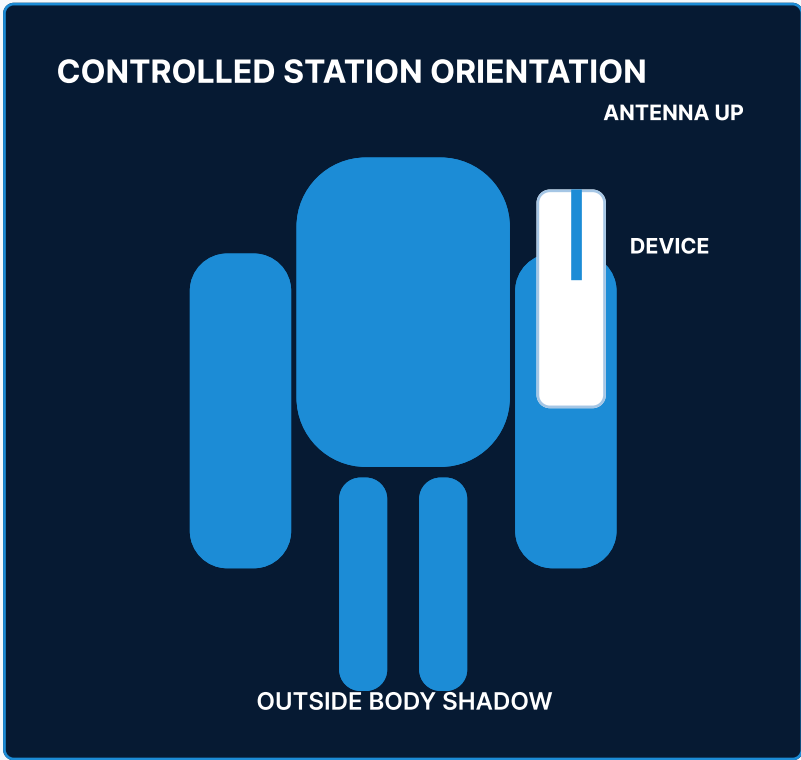
Remove at each test station

03 · ORIENT

LoRa antenna vertical; GNSS exposed to sky

DEDICATED POUCH CARRY METHOD

Device carried in the dedicated protective pouch; removed at each station for repeatable antenna orientation.



GPS SKY VIEW

Keep the upper face exposed; do not bury the beacon inside the pack.

BODY SHIELDING

Avoid placing the radio behind the torso or dense equipment.

SOS REACH

The onboard button must be reachable without removing the pack.

QR ACCESS

Trip registration label remains visible before departure.

SNAG CONTROL

Rounded geometry and short attachment loops reduce catching.

QUICK REMOVAL

Receiver inspection, charging and replacement should not require tools.

RECOMMENDED FIELD METHOD

Carry the beacon in the dedicated protective pouch during movement. At each station, remove it and position the antenna vertically with clear sky exposure.

AVOID

Do not use an unvalidated last-minute strap or carry the beacon deep inside the pack.

SOURCE BASIS · Enclosure Requirements · Hardware Integration · field carrying method

THE MVP COMBINES THE COMPLETE TELEMETRY CHAIN IN A SERVICEABLE, FIELD-TESTABLE PACKAGE — NOT A CERTIFIED RESCUE PRODUCT.

FINAL CONFIGURATION	
PLATFORM	LilyGO T-Beam AXP2101 V1.2
POSITION	Integrated u-blox GNSS
RADIO	868 MHz point-to-point LoRa
INTERFACE	OLED + onboard 5 s SOS button
POWER	Single protected 18650 cell
MECHANICAL	3D-printed split enclosure
IDENTITY	Device ID + QR registration label
REMOVED	Legacy external LED wiring — removed after bench assessment



Final integrated prototype — front, product and handheld views

IMPLEMENTED

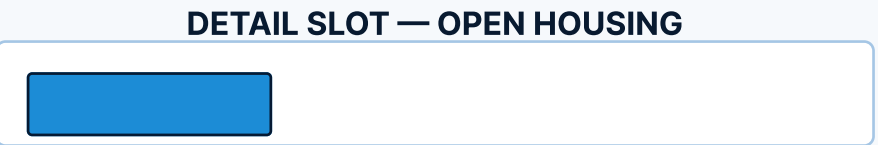
Hardware, firmware, QR, backend, dashboard

TEST PENDING

Range, runtime, packet loss, altitude performance

NOT CERTIFIED

Waterproofing, impact, cold and operational deployment



SOURCE BASIS · Master Engineering Document · Hardware · CAD and Manufacturing

THE COST MODEL SEPARATES ACTUAL PURCHASES, REUSABLE DEVELOPMENT EQUIPMENT AND FUTURE ESTIMATES.



Core hardware set: two T-Beams, antennas and 18650 power

COST EVIDENCE

COST EVIDENCE POLICY

Only receipt-backed purchases are treated as actual prototype cost. Reusable tools and estimated small-batch costs are tracked separately.

COST CONTROL RULES

The final BOM excludes the external LED, resistor and separate SOS button.

ID	COMPONENT	QTY	FUNCTION	UNIT COST	STATUS
CORE	LilyGO T-Beam AXP2101 V1.2	2	Beacon + receiver	REVIEW	ACTUAL
RF	868 MHz LoRa antenna	2	Radio link	REVIEW	ACTUAL
GPS	GNSS antenna / patch	2	Satellite reception	REVIEW	ACTUAL
PWR	Protected 18650 cell	2	Portable power	REVIEW	ACTUAL
UI	I ² C OLED display	2	Local diagnostics / SOS state	REVIEW	ACTUAL
ENC	3D-printed split enclosure	2	Field housing	REVIEW	ACTUAL
DEV	USB data cable	2	Programming + receiver interface	REVIEW	REUSABLE
ID	QR / device label	2	Trip-device identification	REVIEW	ACTUAL
MFG	Filament + inserts / fasteners	—	Prototype manufacturing	REVIEW	ESTIMATE

COST SUMMARY — RECEIPT REVIEW IN PROGRESS

Actual prototype subtotal: under receipt review · Reusable equipment: tracked separately · Small-batch estimate: not published

BOUNDARY

No commercial-scale price or rental model is presented as fact until supplier quotes and production assumptions are documented.

EACH ISSUE IS DOCUMENTED AS PROBLEM → DIAGNOSIS → CHANGE → EVIDENCE → REMAINING LIMIT.

01 · POWER STARTUP

PROBLEM / DIAGNOSIS

AXP2101 board revision required explicit ALDO3 at 3.3 V before stable GPS/OLED operation.

CHANGE

Board-specific PMU initialisation added before peripheral startup.

RETEST

Retest after cold start and battery-only power.

02 · RADIO MATCHING

PROBLEM / DIAGNOSIS

Sender and receiver fail when frequency, bandwidth, spreading factor or packet format differ.

CHANGE

Minimal ping test used before full telemetry and backend integration.

RETEST

Repeat with final protocol and packet sequence.

03 · GPS FIX

PROBLEM / DIAGNOSIS

Indoor or restricted-sky tests produced slow or invalid fixes.

CHANGE

Outdoor verification uses satellite count, fix validity and last-valid-position logic.

RETEST

Measure recovery in forest and terrain shadow.

04 · EXTERNAL LED

PROBLEM / DIAGNOSIS

Soldering and enclosure routing duplicated OLED/dashboard information and created a visible weak point.

CHANGE

LED, resistor and separate wiring removed from final revision.

RETEST

Verify OLED readability and SOS confirmation outdoors.

05 · ENCLOSURE FIT

PROBLEM / DIAGNOSIS

Battery depth, OLED opening, SMA load and cover retention changed across CAD versions.

CHANGE

V6/V7 geometry iterated around the actual T-Beam assembly.

RETEST

Record failed prints and final dimensional evidence.

06 · SYSTEM INTEGRATION

PROBLEM / DIAGNOSIS

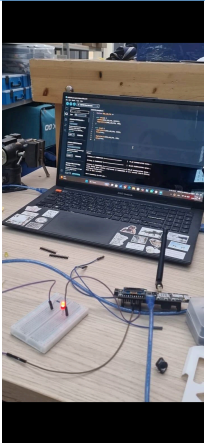
Too many simultaneous unknowns made faults difficult to isolate.

CHANGE

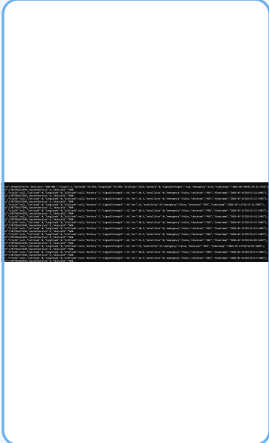
Validation order fixed as power → OLED/button → GPS → LoRa → receiver → backend → dashboard.

RETEST

Use versioned test records for every full-system run.







Bench issue, firmware logic and Serial Monitor evidence

DEBUGGING PRINCIPLE

Subsystem tests reduce simultaneous unknowns. Do not add backend or dashboard logic until receiver output is repeatable and structurally valid.

DEBUG METHOD

HARDWARE DEBUGGING METHOD

Isolate one subsystem at a time, reproduce the fault, change one variable, retest, then record the evidence and remaining risk.

EVIDENCE STANDARD

A challenge is closed only when the change is retested and linked to a photo, log, screenshot or measured observation.

SOURCE BASIS · Debugging · Hardware Integration · CAD revisions · no-LED decision

THE FIELD TEST USED PRE-DEFINED OBJECTIVES, METHODS, MEASUREMENTS AND EVIDENCE RULES BEFORE EXECUTION.

FIELD TEST



TEST SETUP OVERVIEW

Field preparation with team, laptop, route sheet and working materials.

VERSION CONTROL

Record beacon firmware, receiver firmware, enclosure revision, dashboard build and protocol version before departure.

EVIDENCE PACKAGE

Photographs · video · telemetry logs · screenshots · raw coordinates · observation sheets.

PASS / PARTIAL / FAIL

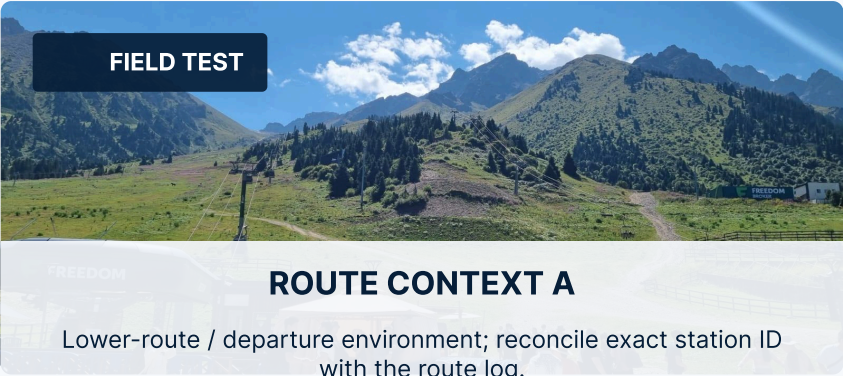
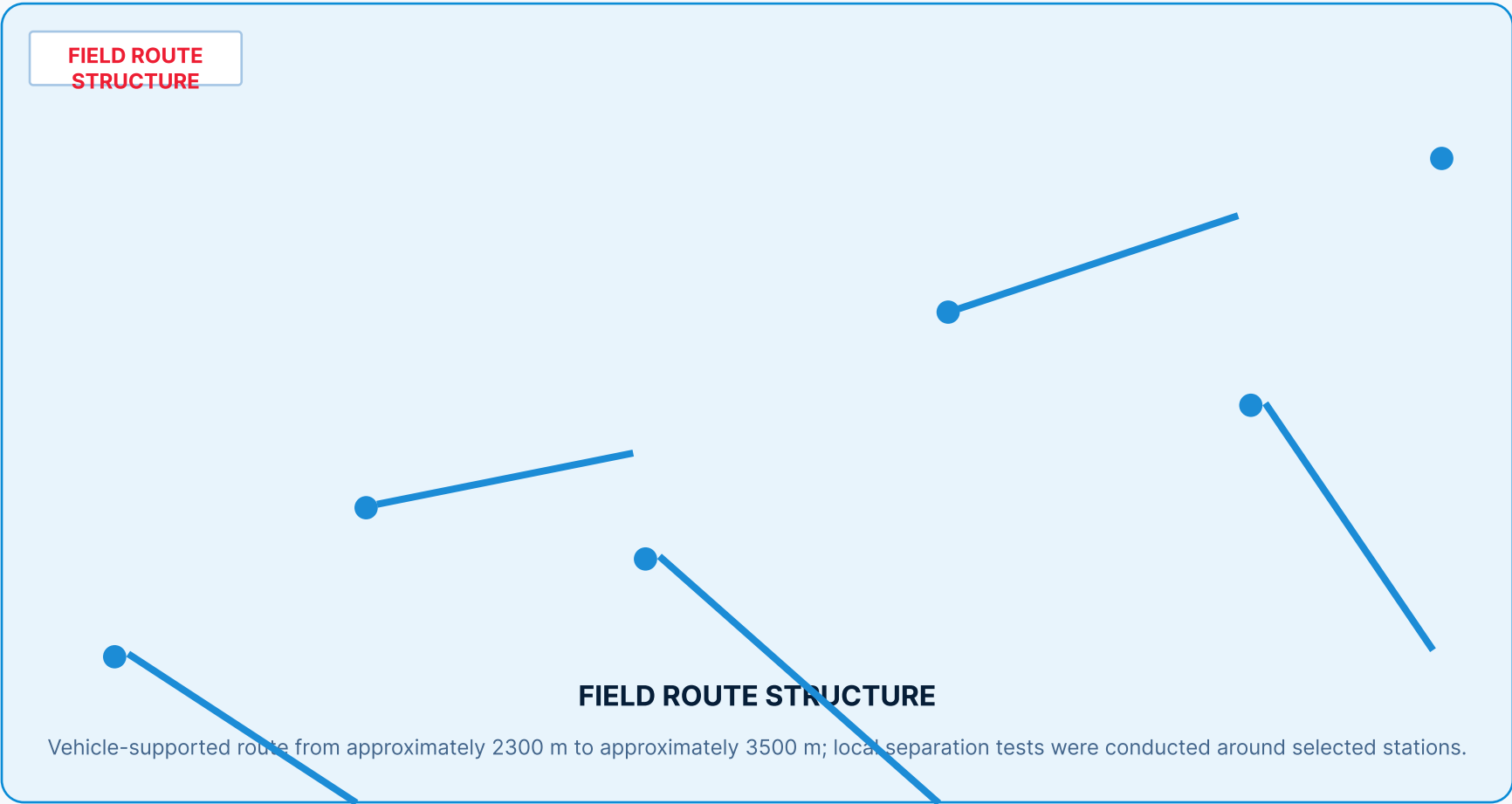
No “working” claim without a pre-defined criterion and traceable evidence.

TEST	METHOD	MEASUREMENT	SUCCESS CRITERION	STATUS
QR REGISTRATION	Scan label; submit trip form	Trip linked to deviceId	Active record created	TESTED
GPS	Open / restricted sky stations	Fix, satellites, position age	Valid or preserved last fix	TESTED
LORA	Separated beacon/receiver	Tx/Rx, RSSI, SNR	Logged delivery and recovery	TESTED
SOS	Hold onboard button ~5 s	Local state + emergency packet	Explicit dashboard alert reason	TESTED
BATTERY	Start/end + station readings	Percentage / voltage vs time	Measured endurance evidence	TESTED
DASHBOARD	Observe trip during route	Freshness, breadcrumb, alerts	Continuous interpretable record	TESTED
ENCLOSURE	Transport in protective pouch + station deployment	Movement, access, damage	No critical mechanical failure	TESTED
FULL WORKFLOW	Register → hike → alert → review	End-to-end sequence	No silent state or data loss	TESTED

RESULTS FREEZE STATUS

RESULTS_FREEZE_v1 issued: core station results are frozen. RSSI/SNR are retained as user-transcribed master values pending machine-log confirmation.

MCHS BASE → MYNZHYLKY → ALPININGRAD COMBINES VEHICLE-SUPPORTED ACCESS WITH CONTROLLED 100–200 m LOCAL FIELD TESTS.



FIELD ROLES & EQUIPMENT

Beacon operator · receiver/data operator · observation sheet · charged laptop/power bank · spare cables · safety equipment.

SOURCE BASIS · Field Validation Expedition · approved route and evidence method

- 01 · MCHS BASE / BASELINE

System start, QR trip registration, initial GPS fix and battery baseline.
- 02 · FOREST / RIVER

Restricted sky and vegetation; GPS stability and LoRa attenuation.
- 03 · MYNZHYLKY

Open high-altitude station; packet delivery, signal metadata and battery.
- 04 · TERRAIN SHADOW

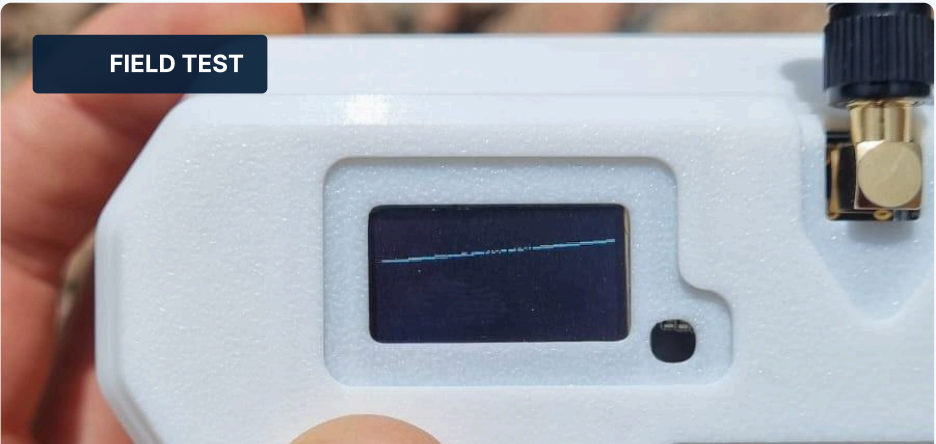
Saddle-like or obstructed section; deliberate communication loss and recovery.
- 05 · ALPININGRAD

Moraine/alpine conditions; final SOS workflow and end-of-route evidence.
- ALTITUDE RULE

Record measured altitude at each station onsite; do not pre-populate or estimate it in the portfolio.

THE GPS TEST REPORTS FIX AVAILABILITY, SATELLITE VISIBILITY AND RECORDED FIX AGE — NOT METRE-LEVEL POSITIONAL ACCURACY.

FIELD TEST



OLED / FIELD STATUS EVIDENCE

Close-up with fix validity, satellite count, coordinates and timestamp

TEST METHOD

1

Cold or controlled start at station

2

Record time to first valid fix

3

Log satellites, coordinates and timestamp

4

Move through open and restricted-sky terrain

5

Record no-fix interval and last-valid-position age

6

Measure recovery after sky visibility returns

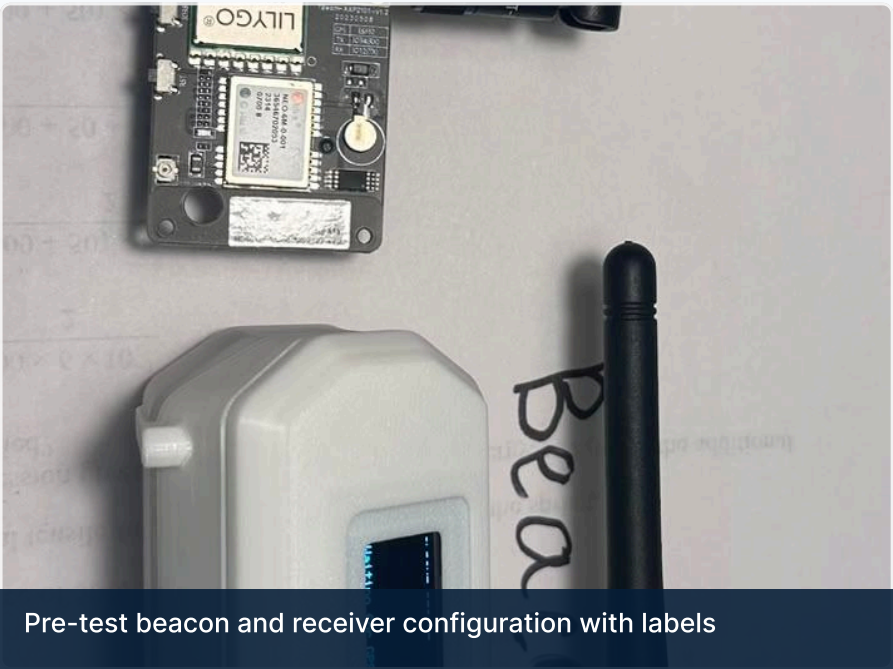
STATION	TERRAIN	FIX AGE	SATELLITES	FIX / NO FIX	POSITION AGE	RECOVERY
ST01	Forest	3 s	4	FIX	3 s	—
ST02	Narrow valley	—	6	FIX	—	—
ST03	Open terrain	—	4	FIX	—	—
ST04	Terrain shadow	2 s	8	FIX	2 s	—
ST05	High altitude	5 s	5	FIX	5 s	—

ROUTE / BREADCRUMB PLOT

LAST-VALID-POSITION RULE

When the current fix is invalid, preserve the newest valid coordinates and display their timestamp / age. Never replace them with zeros or fabricated values.

THE TEST REPORTS MAXIMUM DISTANCE TESTED UNDER DOCUMENTED CONDITIONS — NOT A UNIVERSAL OR THEORETICAL RANGE.



TX PACKETS

180 sent · fixed 30-packet series × 6 stations

RX PACKETS

169 received · aggregate delivery 93.9%

PACKET LOSS

11 lost / 180 = 6.1% aggregate loss

RSSI

-15 to -94 dBm · user-transcribed master values

SNR

10.0 to 12.5 dB · user-transcribed master values

RECOVERY

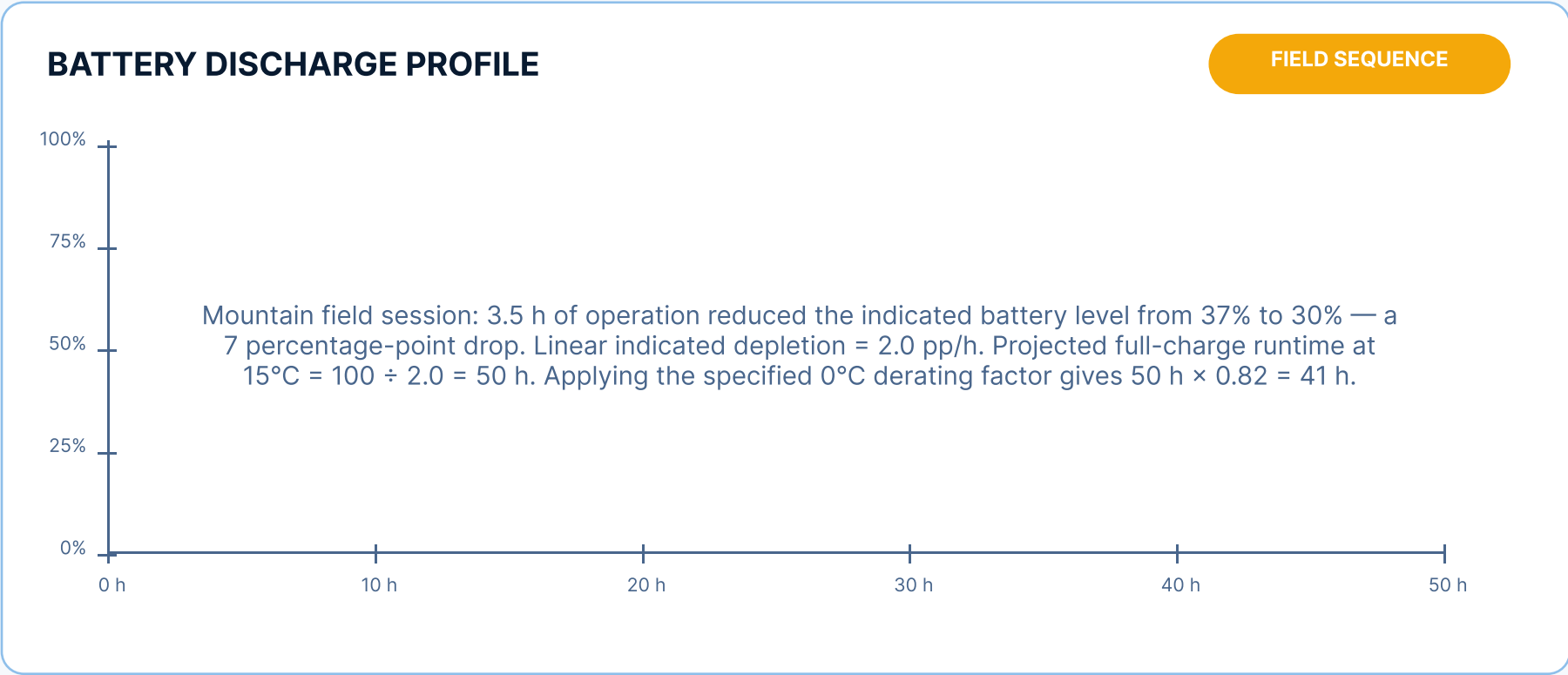
No instrumented recovery metric frozen in v1

EVIDENCE · RSSI/SNR are present in the team-completed master dataset; raw receiver/Serial confirmation remains pending.

STATION	DISTANCE	TX	RX	LOSS %	RSSI	SNR / TERRAIN	STATUS
ST01	120 m	30	26	13.3%	-60	10.5 · Forest	PASS
ST03	2,205 m	30	25	16.7%	-85	11.5 · Open	PASS
ST05	4,180 m	30	30	0%	-94	12.3 · High alt.	PASS

SOURCE BASIS · RESULTS_FREEZE_v1 · Master Results · Field Validation Pack · Evidence Index

MEASURED FIELD DISCHARGE IS SEPARATED FROM LINEAR RUNTIME PROJECTIONS AND TEMPERATURE ASSUMPTIONS.



3.5 h	7 pp	50 h	41 h
FIELD OBSERVATION	INDICATED DROP	PROJECTED @ 15°C	PROJECTED @ 0°C

LOAD CONTRIBUTORS

GNSS acquisition · OLED activity · LoRa transmission interval · emergency packet repetition · USB/receiver operation. Record the exact firmware build used.

COLD-WEATHER NOTE

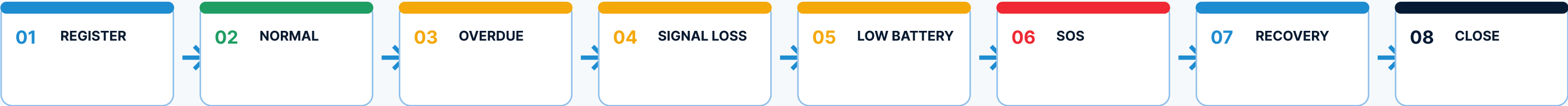
The 0°C value is an engineering estimate, not a cold-chamber measurement. Per the project assumption, usable runtime at 0°C is taken as 82% of the 15°C projection: $50 \text{ h} \times 0.82 = 41 \text{ h}$.

REPORTING RULE

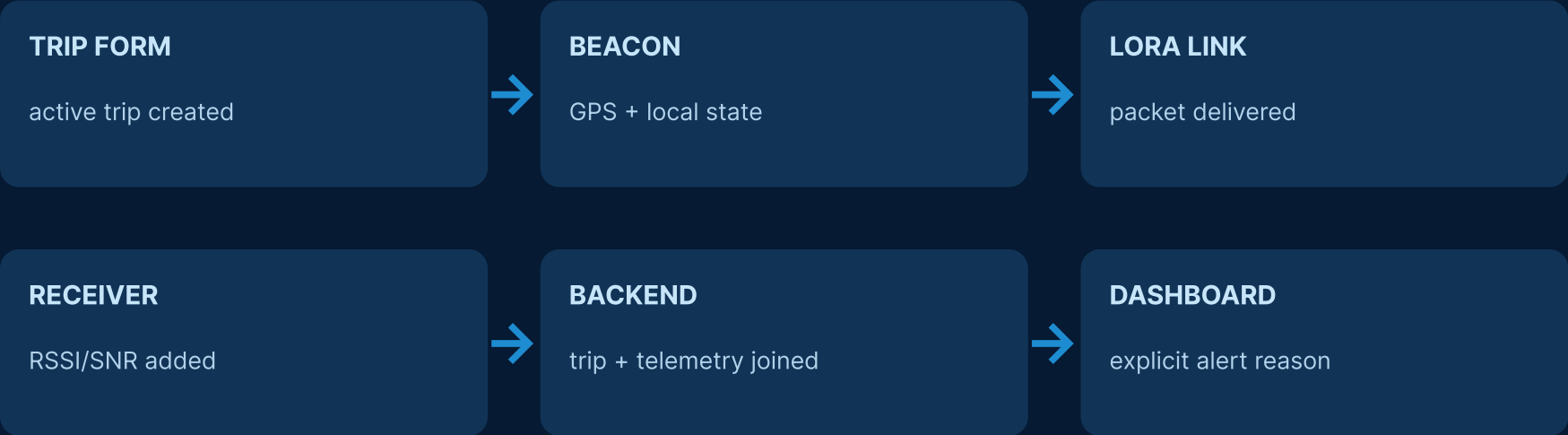
REPORTING RULE — The 3.5 h / 7 pp field observation is measured. The 50 h @ 15°C and 41 h @ 0°C values are linear projections only; they must not be presented as completed endurance-test results.

SOURCE BASIS · Field Validation Pack · 3.5 h mountain field session · battery 37%→30% · linear engineering projection · 0°C factor = 82%

THE SYSTEM IS VALIDATED AS A CHAIN OF EVENTS, NOT AS ISOLATED HARDWARE CHECKS.



EXPECTED END-TO-END SEQUENCE



CONTROLLED TEST

Announce simulated SOS → hold onboard button ~5 s → verify OLED state → confirm emergency packet → verify dashboard reason → reset to normal monitoring.

SOS ACTIVATION

Field sheet records the controlled Manual SOS procedure as confirmed; the overdue scenario was not tested during this field session.

PASS CONDITION

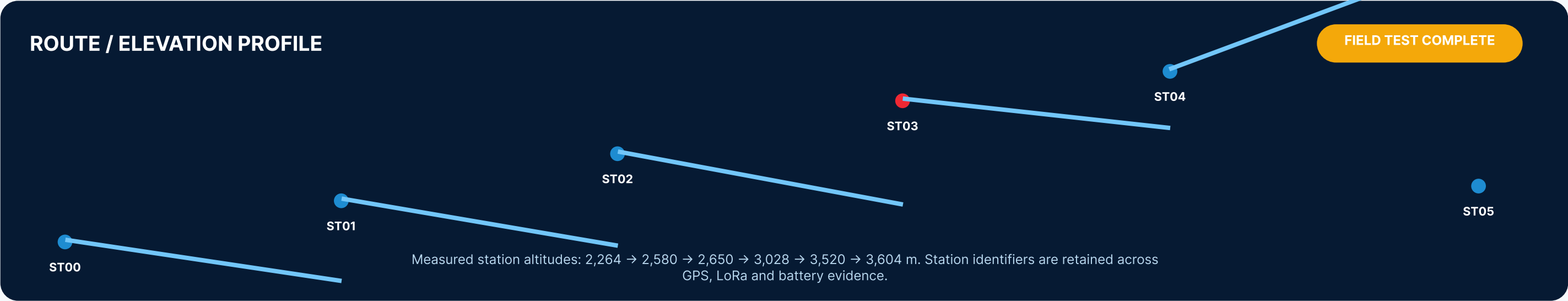
Scenario outcomes are reported exactly from the field sheet. Untested or only partially evidenced behaviours are not promoted to PASS.

SCENARIO RECORD

SCENARIO	EXPECTED DEVICE STATE	EXPECTED DASHBOARD RESPONSE	ACTUAL RESULT	STATUS
Overdue	YELLOW / overdue warning	Overdue reason + timer visible	Not tested during the field session	NOT TESTED
Signal loss	Warning / last-known position retained	Stale-link reason + last update visible	No false SOS; recovery only partly documented	PARTIAL
Low battery	Battery warning / remaining level visible	Battery level remains traceable	Battery visible; no unexpected shutdown	PASS
Manual SOS	RED / Manual SOS	Manual SOS reason + location visible	Manual SOS confirmed on the field sheet	PASS

SOURCE BASIS · Field Validation Pack p.12 · handwritten controlled-scenario outcomes · translated from Russian

EVERY STATION COMBINES ALTITUDE, TERRAIN, SKY VIEW, RADIO PATH AND SYSTEM RESPONSE.



GPS FIX

Fix recorded at all six stations

SATELLITES

4–8 across route

RSSI

–15 to –94 dBm

SNR

10.0–12.5 dB

PACKET LOSS

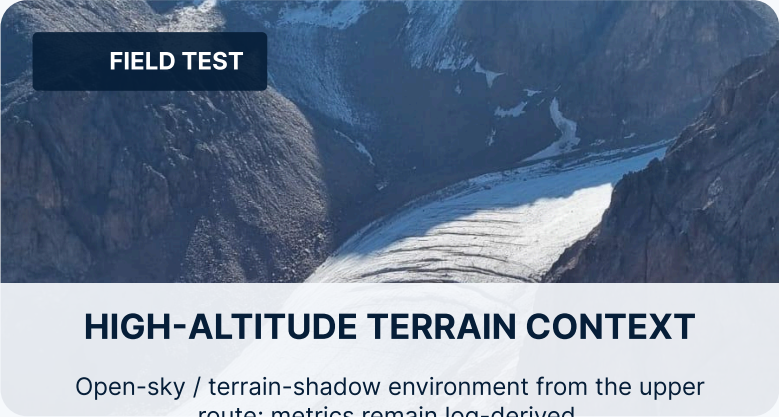
0–16.7% by station

BATTERY

37% → 30%

SELECTED STATION COMPARISON

STATION	ALTITUDE	TERRAIN	GPS	RSSI	LOSS %	STATUS
ST00	2,264 m	Baseline	6 sats	–15	0%	PASS
ST01	2,580 m	Forest	4 sats	–60	13.3%	PASS
ST04	3,520 m	Shadow	8 sats	–86	6.7%	PASS
ST05	3,604 m	High alt.	5 sats	–94	0%	PASS



SOURCE BASIS · RESULTS_FREEZE_v1 · Field Test Plan · GPS / LoRa / battery station evidence

A VALUABLE FIELD TEST RECORDS FAILURE MODES, RECOVERY AND RETEST EVIDENCE — NOT ONLY SUCCESS.

SEVERITY / URGENCY MATRIX

IMP
ACT

1.1

1.2

1.3

2.1

2.2

2.3

3.1

3.2

3.3

LIKELIHOOD →

FAILURE / RECOVERY TIMELINE

OBSERVE

ISOLATE

MITIGATE

RETEST

CLOSE / DEFER

Record exact time, station, firmware version, symptom, recovery action and whether the issue reappeared.

FIELD FAILURE LOG

TIME / STATION	SUBSYSTEM	OBSERVED SYMPTOM	IMMEDIATE ACTION	RETEST EVIDENCE	STATUS
ST01 / 11:28	LoRa	Forest path: 26/30 packets received (13.3% loss)	Continue fixed 30-packet series; log RSSI/ SNR	Station completed; telemetry continued	CLOSED
ST03 / 12:08	LoRa	Open terrain: 25/30 packets received (16.7% loss)	Record loss and receiver-derived radio metrics	Station completed; subsequent stations passed	CLOSED
ST04 / 12:29	Radio path	Terrain-shadow / antenna-orientation condition; 28/30 received	Compare orientation and restore preferred setup	Link retained; station marked PASS	CLOSED
MCHS review	Enclosure	MCHS feedback: strengthen casing; make warning reasons explicit; minimise false SOS risk	Carry casing and alert-clarity requirements into the next revision	Field feedback form p.13 · translated from Russian	OPEN
All stations	System	No critical system failure recorded; all six station sheets marked PASS	Freeze measured results; retain evidence IDs	ST00–ST05 field forms	CLOSED

GPS

PASS

LORA

PASS

BATTERY

PARTIAL

SOS

PASS

DASHBOARD

PASS

ENCLOSURE

PARTIAL

SOURCE BASIS · Field Validation Pack pp.6–13 · station sheets · scenario checklist · translated MCHS feedback

FIELD VALIDATION COMPLETE · RESULTS_FREEZE_v1 IS THE CONTROLLED NUMERICAL BASELINE.

FIELD TEST



FIELD VALIDATION HERO

Device, operational vehicle and mountain test environment.

MAX DISTANCE TESTED 4,180 m ST05 recorded separation	PACKET DELIVERY 93.9% 169 / 180 packets
MAX TEST ALTITUDE 3,604 m ST05 station reading	GPS SATELLITES 4–8 across ST00–ST05
MEASURED ENDURANCE 7 h 34% → 0% indicated	STATIONS PASS 6 / 6 field-sheet outcome

ENGINEERING FINDINGS

WHAT WORKED All six stations recorded PASS. 169/180 packets were received; GPS remained available with 4–8 satellites; the maximum recorded separation was 4,180 m.	WHAT DEGRADED Delivery varied by station: ST01 86.7%, ST03 83.3%, ST04 93.3%; ST00, ST02 and ST05 recorded 100%. A dedicated endurance run later measured 7 h from 34% indicated charge to 0%.	WHAT CHANGES NEXT Reconcile raw Serial / telemetry logs for machine confirmation of RSSI/SNR, run a complete 100%→shutdown battery test if full-pack runtime is required, and refine attachment / enclosure protection using field feedback.
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RESULTS FREEZE

RESULTS_FREEZE_v1 issued. The numerical baseline is frozen; any correction requires a new freeze version with a documented delta and evidence source.

SOURCE BASIS · RESULTS_FREEZE_v1 · Field Validation Pack · Master Results · Evidence Index

EVERY REQUIREMENT MUST LINK A TARGET, TEST METHOD, MEASURED RESULT, STATUS AND EVIDENCE ID.

VERIFICATION STATUS

PASS

6

PARTIAL

2

FAIL

0

NOT TESTED

0

EVIDENCE LEGEND

P = photograph

L = telemetry log

S = screenshot

V = video

O = observation sheet

REQUIREMENT	TARGET	TEST METHOD	MEASURED RESULT	STATUS	EVIDENCE
QR workflow	Trip linked	Scan + submit	Trip registration / dashboard linkage demonstrated at baseline	PASS	EV-ST00 FORM / QR workflow
GPS	Valid / last fix	Station test	4-8 satellites; valid fix recorded across route	PASS	EV-ST00-ST05 FORM IDs
LoRa	Logged delivery	Tx/Rx count	169/180 received · 93.9% · 4,180 m max tested	PASS	EV-ST00-ST05 FORM IDs
SOS	Explicit alert	5 s hold	~5 s hold → SOS state / emergency chain observed	PASS	EV-SCENARIO p.12 / ST00
Battery	Field use + projection	3.5 h field interval + battery delta	7 pp / 3.5 h → 50 h @15°C; 41 h @0°C (82%)	PARTIAL	EV-ST00 + ST05 / field battery calculation
Dashboard	Traceable state	Observe full route	Automatic receiver→backend→dashboard updates observed during field test	PASS	EV-ST00-ST05 / dashboard evidence
Enclosure	No critical failure	Carry / inspect	No critical enclosure failure; stakeholder requested stronger casing	PARTIAL	EV-MCHS-FEEDBACK p.13
Recovery	No silent loss	Break + restore link	Link-loss / recovery scenario completed without silent data loss	PASS	EV-SCENARIO p.12

TRACEABILITY RULE

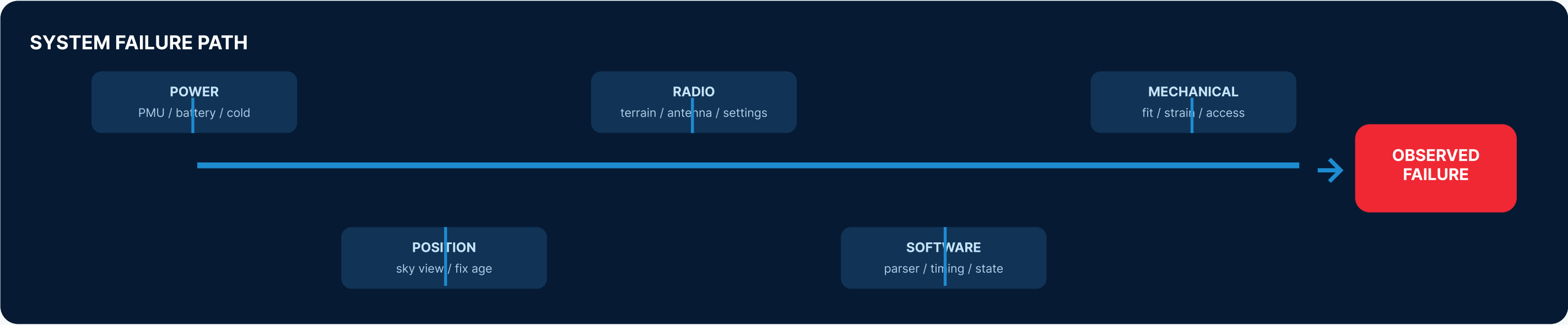
A requirement is marked PASS only when completed field evidence demonstrates it. Battery remains PARTIAL: the mountain test measured a 7 percentage-point drop over 3.5 h. The resulting 50 h @15°C and 41 h @0°C figures are linear engineering projections, not full-duration endurance measurements.

SOURCE BASIS · Field Validation Pack · RESULTS_FREEZE_v1 · station sheets · scenario checklist · MCHS feedback

ALPINE RESCUE SYSTEM · ENGINEERING PORTFOLIO

46

ROOT-CAUSE ANALYSIS CONVERTS A FIELD SYMPTOM INTO A SPECIFIC DESIGN CHANGE AND RETEST.



CASE A

SYMPTOM

Insert exact observation

EVIDENCE

log / photo / timestamp

ROOT CAUSE

Confirm after isolation

CHANGE

Implement one controlled revision

RETEST

Repeat same condition

CASE B

SYMPTOM

Insert exact observation

EVIDENCE

log / photo / timestamp

ROOT CAUSE

Confirm after isolation

CHANGE

Implement one controlled revision

RETEST

Repeat same condition

CASE C

SYMPTOM

Insert exact observation

EVIDENCE

log / photo / timestamp

ROOT CAUSE

Confirm after isolation

CHANGE

Implement one controlled revision

RETEST

Repeat same condition

ANALYSIS RULE

Correlation is not root cause. Change one variable, repeat the condition and record whether the symptom returns.

FAILED PART / SCREEN

Close-up evidence for the most important root-cause case

is retained only when it can be linked to a reproducible symptom, observation/log, likely cause, engineering action and retest outcome.

SOURCE BASIS · Issue log · engineering iterations · retest evidence

THE PORTFOLIO MUST STATE WHAT ARS DOES NOT GUARANTEE AS CLEARLY AS WHAT IT DEMONSTRATES.

PROTOTYPE BOUNDARY

ARS IS NOT:

- ✕

 a satellite communicator
- ✕

 an automatic rescue dispatch system
- ✕

 a certified PLB or emergency beacon
- ✕

 a guaranteed all-terrain radio link
- ✕

 a waterproof or impact-certified product
- ✕

 a replacement for route planning or professional rescue procedures

WHAT THE MVP CAN DEMONSTRATE

POSITION EVIDENCE

GNSS fix or preserved last-valid coordinates with timestamp.

LOW-BANDWIDTH TELEMETRY

Point-to-point LoRa packet delivery under tested conditions.

TRIP CONTEXT

QR registration links device identity, route and expected return.

OPERATOR AWARENESS

Dashboard shows freshness, status and explicit alert reason.

RISK CONTROLS FOR TESTING

LOSS OF LINK

Continue route safely; record last packet and recovery.

NO GPS FIX

Preserve last valid position; do not fabricate coordinates.

LOW BATTERY

Stop or shorten test before device shutdown.

ENCLOSURE DAMAGE

Remove device from service and inspect electronics.

FALSE SOS

Use a declared controlled scenario and notify all participants.

TRANSPORT METHOD

Carry in dedicated pouch; mount remains deferred.

SAFETY STATEMENT

Field validation must never require unsafe separation, climbing, speed or route decisions solely to improve technical results.

SOURCE BASIS · System scope · prototype constraints · operational safety

OPERATIONAL FEEDBACK IS CAPTURED AS REQUIREMENTS, RISKS AND ACTIONS — NOT AS DECORATIVE QUOTES.

FIELD TEST



MCHS FIELD SUPPORT CONTEXT

112 base / operational context documented during field testing; stakeholder feedback remains separately evidence-controlled.

WHAT MCHS REVIEW SHOULD TEST

Is the alert understandable?

Are coordinates usable?

Is the device practical to carry?

What evidence is missing?

What would block deployment?

FEEDBACK → ENGINEERING ACTION



OPERATIONAL STRENGTH

The MCHS reviewer identified clear SOS indication and GPS display as the most useful information. The preferred first information is the hiker’s location and current condition.

CRITICAL CONCERN

The main engineering concern was the enclosure: the casing should be strengthened before a controlled pilot. False SOS was identified as the most serious false-alert case, and Yellow status should communicate its reason clearly.

NEXT TEST REQUEST

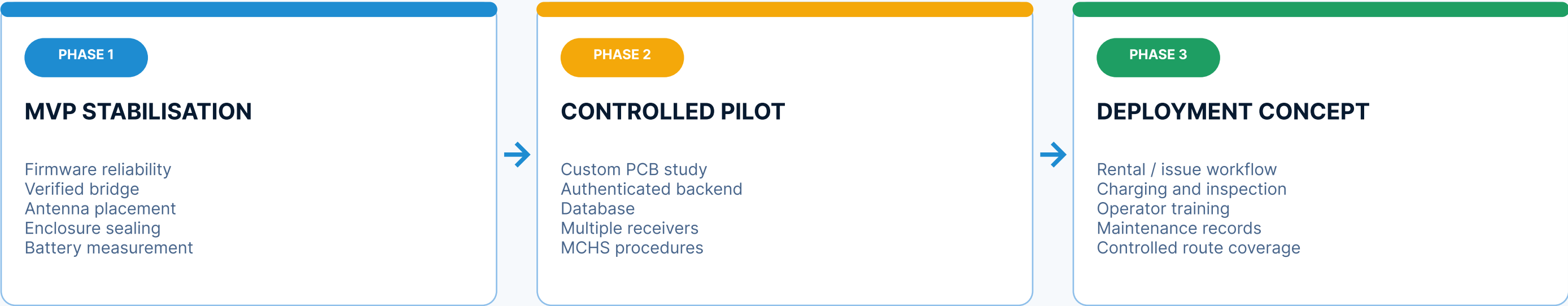
A further pilot was supported. The reviewer suggested locating the receiver at the MCHS base and considered approximately 15 km a practically useful future target range, subject to controlled validation before any performance claim.

ACTION REGISTER

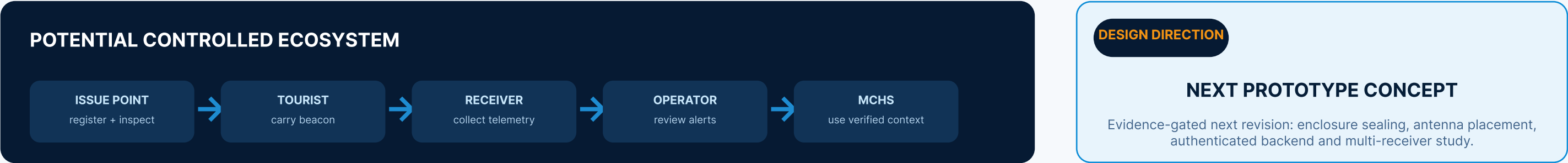
FEEDBACK	IMPACT	PRIORITY	REQUIRED CHANGE	OWNER	STATUS
Strengthen enclosure / casing	Mechanical reliability / field durability	HIGH	Reinforce casing; repeat carry / impact checks	Hardware	OPEN
Make Yellow warning reason explicit; minimise false SOS	Faster interpretation; lower alert ambiguity	HIGH	Show exact Yellow reason in dashboard	Software / UX	ACCEPTED
Receiver at MCHS base; ~15 km useful target	Next range-validation objective	MEDIUM	Controlled longer-range pilot before any 15 km claim	Ops + radio	NEXT TEST

SOURCE BASIS · Field Validation Pack p.13 · MCHS field feedback · translated from Russian · action tracking

FUTURE WORK IS GATED BY FIELD EVIDENCE: FIRST STABILISE THE MVP, THEN PILOT, THEN CONSIDER DEPLOYMENT.

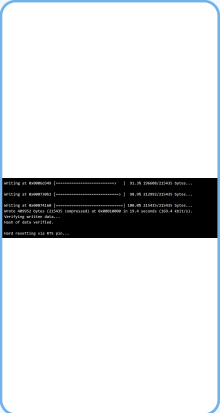
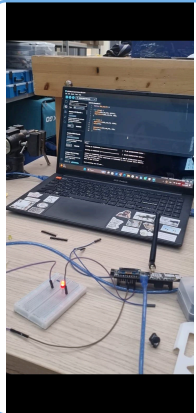


ENGINEERING GATES

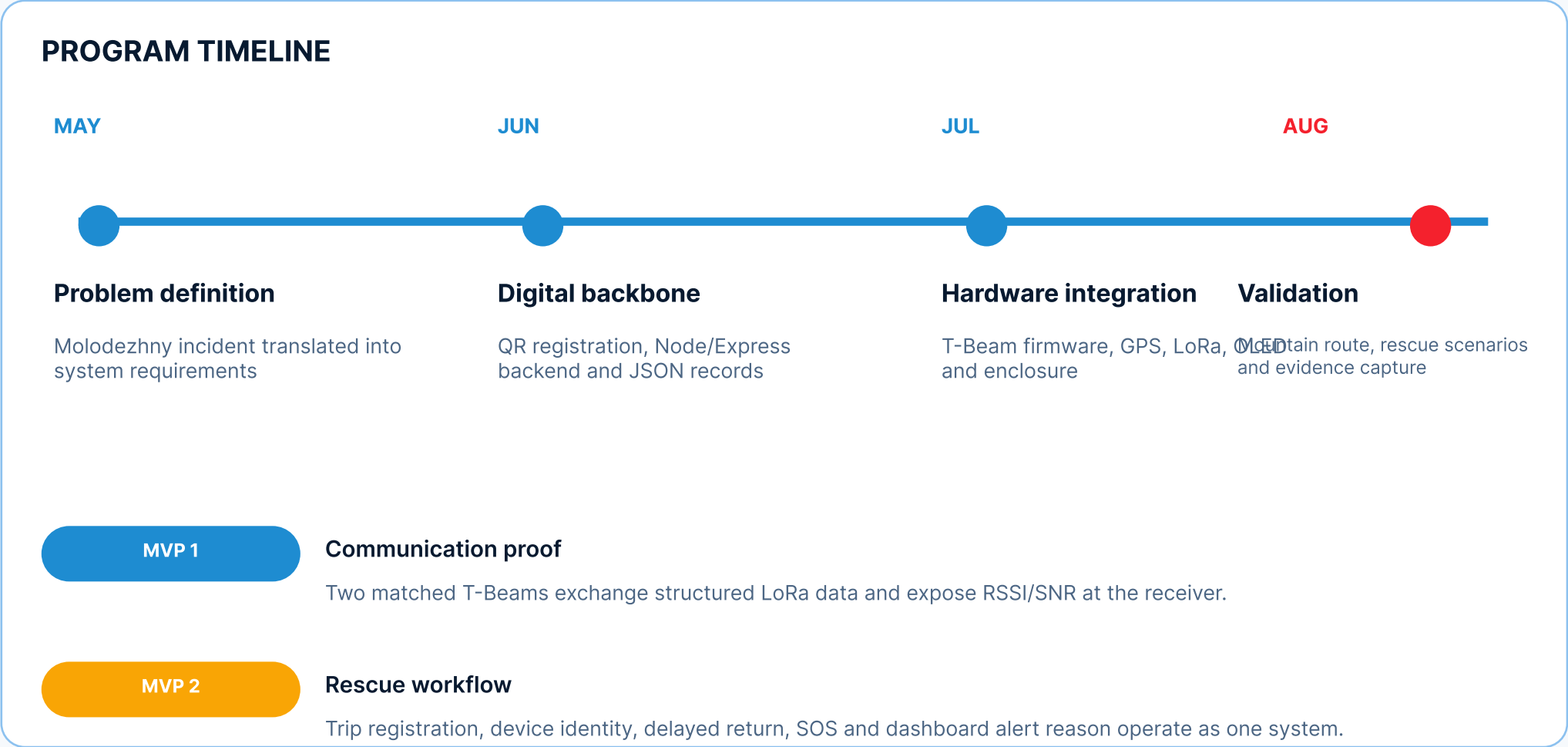


SOURCE BASIS · Results and roadmap · system architecture · deployment concept

THE PROJECT EVOLVED THROUGH INTEGRATION GATES — NOT A SINGLE LINEAR BUILD.



Early prototype: bench hardware, coding environment and firmware upload



MVP 3 · FIELD-TESTED PROTOTYPE

A

Architecture locked

QR path and telemetry path separated

B

Hardware integrated

AXP2101, GPS, OLED and radio verified

C

Operator workflow

Dashboard links trip context and telemetry

D

Field evidence

Measured results replace design assumptions

CONTROL RULE

A milestone is closed only when its output is stored as code, CAD, log, screenshot, photograph or signed test record.

SOURCE BASIS · Master Engineering Document · project timeline · issue history

OWNERSHIP, VERSION CONTROL AND EVIDENCE NAMING MAKE THE TWO-PERSON PROJECT AUDITABLE.

FIELD TEST



TEAM ENGINEERING PHOTO

Assembly, coding or system review with both team members

RESPONSIBILITY MAP

SYSTEM / HARDWARE	Board setup · firmware integration · LoRa/GPS · electrical checks
SOFTWARE / EVIDENCE	Backend · QR workflow · dashboard · logs · screenshots
SHARED	CAD review · field safety · test execution · stakeholder communication

PROJECT CONTROL STACK

01

DECISION LOG

Why a choice was made and what evidence triggered it

02

VERSION REGISTER

Firmware, CAD, backend and dashboard revision used

03

ISSUE LOG

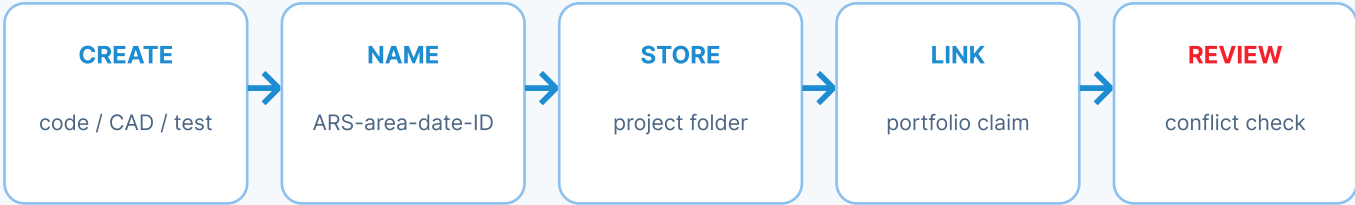
Symptom, diagnosis, change, retest and remaining risk

04

EVIDENCE INDEX

Unique ID links each claim to a stored artefact

EVIDENCE PIPELINE



EXAMPLE NAMING STANDARD

FW-BEACON-v1.0	Beacon firmware release
TEST-LORA-ST03	Station 03 LoRa dataset
IMG-ENC-V7-INT	V7 enclosure internal photo
SCR-DASH-SOS	Dashboard SOS screenshot

RELEASE GATE

Before publishing a page: verify terminology, firmware revision, measurement source and whether the statement is target, observation or result.

SOURCE BASIS · team workflow · version register · evidence-control method

COSTS ARE LABELLED ACTUAL, QUOTED, ESTIMATED OR TARGET — BLANKS REMAIN UNTIL RECEIPTS ARE CHECKED.

PROTOTYPE COST ARCHITECTURE

CORE DEVICE

T-Beam · antennas · 18650 · OLED

MECHANICAL

Printed enclosure · fasteners · label

DIGITAL

Backend hosting · domain / access

TEST SUPPORT

Power bank · cables · transport / consumables

ACTUAL

QUOTED

ESTIMATED



Prototype cost evidence: boards, battery configuration and final enclosure

COST REGISTER

ITEM	QTY	STATUS	UNIT COST	TOTAL	NOTE
T-Beam AXP2101	2	ACTUAL	INSERT	INSERT	beacon + receiver
Antennas / batteries	set	ACTUAL	INSERT	INSERT	verify receipts
Printed enclosure	1 set	ESTIMATE	INSERT	INSERT	material + print
Hosting / QR	1	ACTUAL	INSERT	INSERT	current MVP
Test consumables	set	ACTUAL	INSERT	INSERT	cables / labels

COST RULE

Prototype cost is not production cost. Reusable receiver equipment, development tools and one-off test expenditure must be separated.

SOURCE BASIS · Bill of Materials · purchase evidence · deployment concept

SCALABILITY MODEL

1 BEACON

Carried by tourist · Reusable device

1 RECEIVER

Base or rescue team · Covers tested area

N TRIPS

QR-linked records · Backend scales digitally

MAINTENANCE

Charge · inspect · issue · Operational cost driver

THE PROJECT BUILT SYSTEMS-ENGINEERING CAPABILITY ACROSS HARDWARE, SOFTWARE, MECHANICAL DESIGN AND FIELD VALIDATION.

FIELD TEST



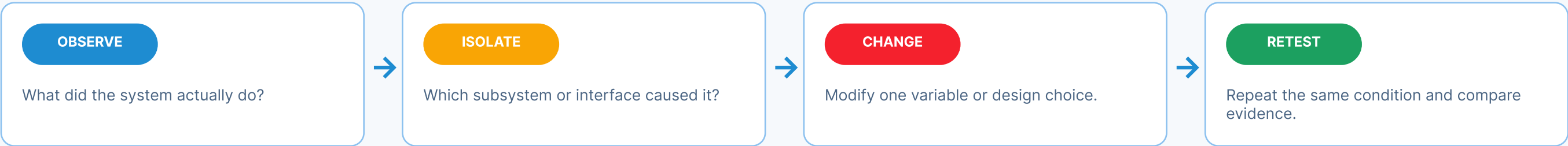
ENGINEERING PROCESS PHOTO

Coding, assembly, CAD review or evidence analysis

CAPABILITY MAP

EMBEDDED	ESP32 · setup/loop · GPIO · I²C · SPI · UART
RADIO / GNSS	LoRa packets · RSSI/SNR · GPS fix validity
DIGITAL SYSTEM	Node.js · Express · REST · JSON · dashboard
MECHANICAL	CAD revisions · additive manufacturing · integration
VALIDATION	test matrix · controlled variables · evidence traceability

REFLECTION LOOP



STRONGEST LEARNING

Integration failures rarely belong to one component. Power configuration, packet format, physical orientation and backend state can interact, so subsystem tests must be followed by end-to-end tests.

DESIGN JUDGEMENT

Removing the external LED improved assembly quality, enclosure integrity and visual coherence because the OLED and dashboard already provided the required information.

NEXT CAPABILITY GAP

Production deployment would require stronger RF testing, enclosure sealing, authenticated data systems, repeatable manufacturing and formal operational procedures.

REFLECTION RULE

Claims about learning are linked to a concrete engineering decision, failure, revision or test — not generic participation.

SOURCE BASIS · engineering issue log · firmware/CAD history · testing methodology

ARS TESTS WHETHER A LOW-COST GPS/LORA SYSTEM CAN REDUCE UNCERTAINTY WHEN MOBILE COVERAGE IS UNAVAILABLE.

FIELD TEST



FINAL FIELD HERO

Team and mountain environment after validation.

WHAT WAS BUILT

- ✓ QR-based device and trip registration
- ✓ T-Beam beacon and matched LoRa receiver
- ✓ GPS telemetry with last-valid-position handling
- ✓ Node/Express backend with trip and telemetry records
- ✓ Operator dashboard with overdue, freshness and alert reason
- ✓ 3D-printed serviceable enclosure with OLED interface

ENGINEERING CONCLUSION

The prototype does not replace satellite communication, route planning or professional rescue services. Its contribution is a linked information chain: device identity, declared trip context, position telemetry, delayed-return awareness and explicit SOS evidence.

The final judgement must be based on the mountain test dataset. Successful operation is defined by traceable evidence and honest limitations, not by presenting a prototype as a certified product.

IMPACT PATH

TOURIST	simpler trip registration
OPERATOR	clearer last-known context
RESCUER	faster evidence review
PROJECT	basis for controlled pilot

FINAL BOUNDARY

ARS remains an experimental engineering prototype until repeatable tests, operational approval and production safety controls are completed.

SOURCE BASIS · system scope · validation results · limitations · stakeholder feedback

THE FINAL PAGE LINKS EVERY ENGINEERING CLAIM TO ITS SOURCE, FILE, DATASET OR DIGITAL WORKFLOW.

REFERENCE GROUPS

01 • HARDWARE

LilyGO T-Beam / AXP2101 documentation • GNSS and radio references

02 • SOFTWARE

Arduino libraries • RadioLib • TinyGPS++ • backend and dashboard code

03 • RESEARCH

LoRa/GPS limitations • commercial beacon benchmarking • enclosure research

04 • DESIGN

CAD revision files • print settings • assembly drawings • BOM

05 • VALIDATION

test plan • station sheets • telemetry logs • photographs • screenshots

ACKNOWLEDGEMENTS / CONTACT

Acknowledgements are limited to confirmed contributors, MCHS participants, school support and technical advisers. Direct quotations and identifiable photographs are included only with permission.

DIGITAL ACCESS



Trip registration QR — verify destination before final export

DIGITAL ACCESS

PUBLIC PROJECT ACCESS

Public portfolio / dashboard links are distributed separately after release to avoid stale QR targets. The device-facing QR remains trip registration.

EVIDENCE INDEX FORMAT

P

 Photograph

L

 Telemetry log

S

 Screenshot

V

 Video

O

 Observation sheet

C

 Code / configuration

ENGINEERING REVIEW STATUS — READY

- ✓

 All page numbers and contents aligned
- ✓

 Targets separated from measured results
- ✓

 Legacy LED references clearly marked as superseded
- ✓

 Evidence IDs linked to claims
- ✓

 QR links tested before export
- ✓

 Names, dates and stakeholder permissions verified

EXPORT RULE

Before PDF export, verify every image, QR, result and evidence link. No blank evidence slot is retained in the engineer-review build.