TAOGLAS®

# Edge Universe – NAVISP Final Presentation

Ref. ESA Contract No: 4000133883/21/NL/MP/mk

Date 28 January, 2022

# Introductions & Overview

# Agenda

1. Introduction to Taoglas
2. Introduction to Project
3. Engineering Design
4. Q&A

## Presenters

**Ronan Quinlan**
Co-CEO and Co-Founder
Taoglas

**John Dillon**
Head of IoT Marketing

**Fergal Brennan**
Head of Engineering IoT Solutions

**Neil Woodhouse**
Engineering Manager

# About Taoglas

Delivering Trusted Technology for a Smarter World

**400** Employees Globally

Currently, over **400 employees** Globally

**10 Centers Worldwide**

with latest design, and test equipment, including **state of the art** Anechoic Chambers, 4G LTE Call Boxes, RF Simulation and Environmental & Reliability testing

QUALITY MANAGEMENT SYSTEM IATF16949

ISO 9001 CERTIFICATION EUROPE™

**IATF16949 certified production facility** in Tainan, Taiwan to support mainstream automotive product manufacturing centres focus on IoT business

Strategic focus on **IoT** business

We drive **IoT innovation: 5G, Autonomous AI Vision**

**90** Patents Approved & 117 Pending

Thousands of successful **IoT/M2M** projects completed globally

# Taoglas Businesses

### Components

- Antenna, cable and connector portfolio for IoT solutions
- Design and testing services

### IoT Solutions

- IoT devices, management platform, connectivity
- Design and testing services

### Digital Strategy

- Digital transformation consultancy for IoT project planning and management.
- Analytics and Insights solutions

# ESA Project Overview

- Overall Objective
  - Advancing the capability and use of GNSS in commercial products
- Proposed 4 products to address 3 customer segments

| | |
|---|---|
| 1. EDGE Connect with Switchable Antenna | Asset Tracking |
| 2. EDGE Rugged | Fleet Management (including Heavy Transport Vehicles and Equipment) |
| 3. EDGE Industrial | Fleet Management (including Heavy Transport Vehicles and Equipment) |
| 4. EDGE Micro | Shared micro-mobility |

- Product Objectives
  - Competitive Product Pricing
  - Flexible and easy integration
  - Low power
- Project Execution
  - Taoglas hardware and software development team from prototype to pilot production
  - Extensive RF testing, validation and verification work completed
  - All 4 products completed to Production Validation (PVT) stage

# ESA Project Team

**Olivier Smeyers**
ESA Lead

## Engineering and Operations Lead

- **Fergal Brennan** — Head of Engineering IoT Solutions
- **Kamil Gardziejczyk** — General Manager
- **Philip Corri** — Head of Operations

## Proposers

- **Adrian Burns** — Chief Architect of IoT Solutions
- **Cliona O'Connell** — Project Manager - Technical
- **John Slowey** — IOT Financial Controller

## Hardware Team

- **Bartosz Ziółek** — Embedded Hardware Engineer
- **Pawel Jarzewicz** — Embedded Hardware Engineer
- **Stanislaw Klimek** — Hardware Engineer

## Software Team

- **Pawel Okon** — Validation Lead
- **Dawid Grochowalski** — Software Engineer
- **Niall Keating** — Software Engineer
- **Adam Hryniewicz** — Software Engineer

## Supply Chain / EMS

- **Ken Long** — Manager, IoT Cost Engineering
- **Grzegorz Jablonowski** — Sourcing/production Specialist

# Market Analysis - Strong Growth Forecasts

- Asset Tracking
  - 51% CAGR though 2024
- Fleet Management, Heavy Transport & Equipment
  - 14% CAGR though 2024
- Micro mobility
  - 15% CAGR though 2024

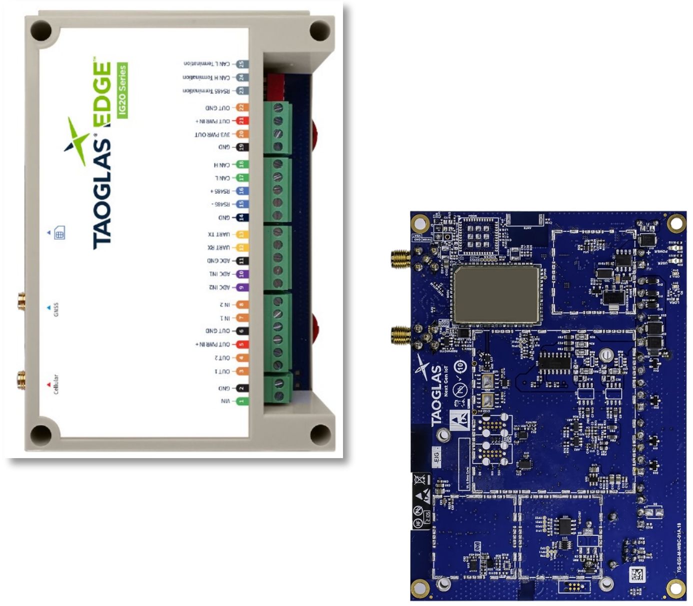
- Common Theme
  - “Balance power consumption, form factor, cost”

Ref. ABI Research

# Market Analysis – Customer Challenges

- Technical capability
- Costly maintenance schedules
- Security
- Regulatory and compliance
- Durability and longevity

# Taoglas solution proposals

### EDGE Rugged and Edge Micro

- **Cost reduced**
- IP67 rated
- Integrated GNSS Antenna
- Global cellular connectivity
- Motion sensors
- Small **Form Factor**
- WiFi/ BLE for proximity services
- Ultra **low power** consumption
- Highly **secure** architecture
- Integration to Taoglas Insights platform

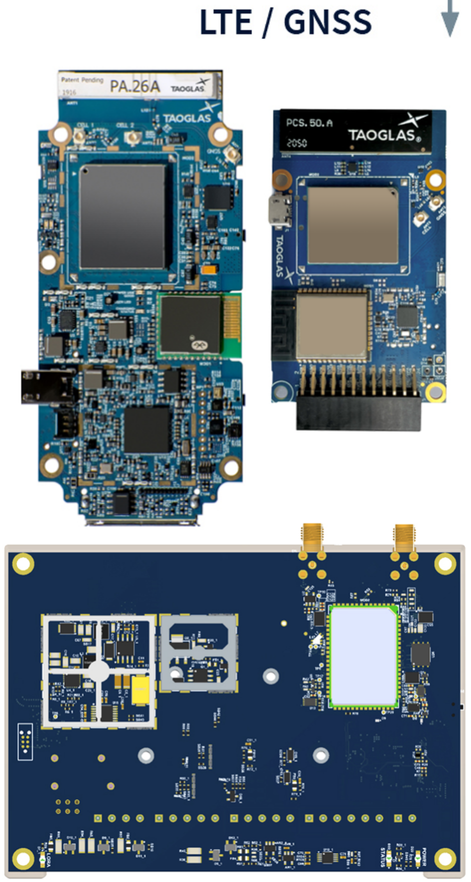
### EDGE Connect

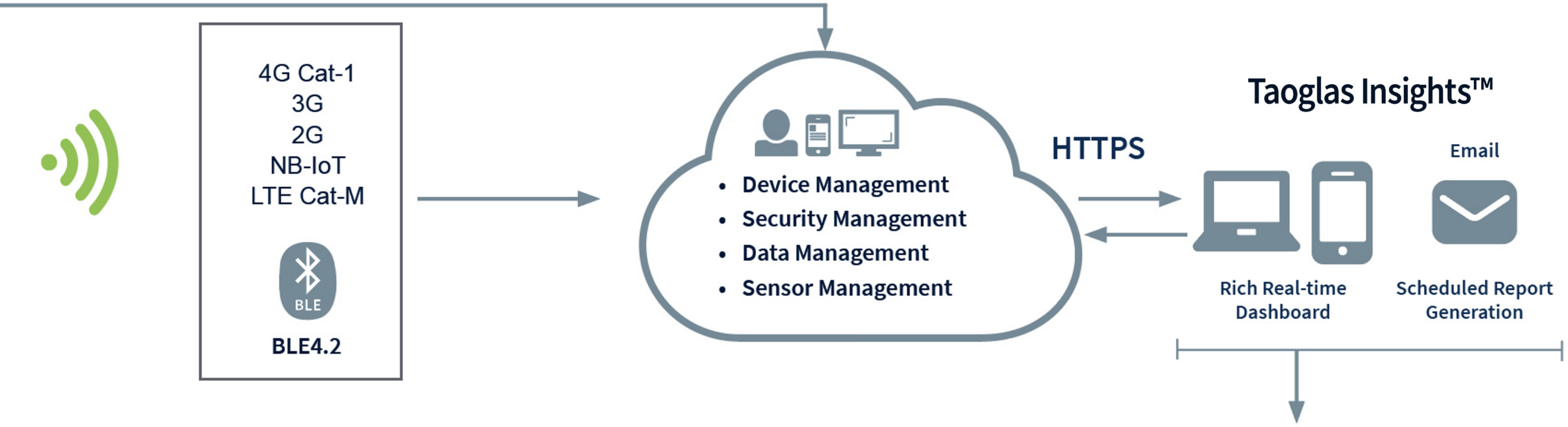
- Cost reduced
- Single antenna for cellular & GNSS
- Global cellular connectivity
- Support removable plastic 4ff SIM
- Environment & motion sensors
- WiFi/ BLE for proximity services
- Rechargeable battery
- Low power consumption
- Highly secure architecture
- Integration to Taoglas Insights platform

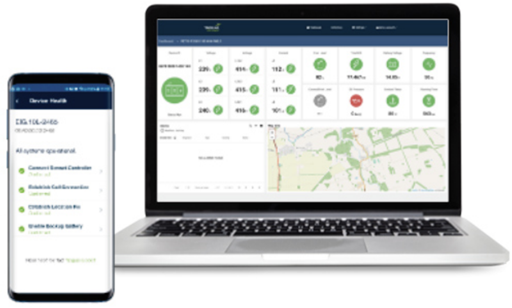
### EDGE Industrial

- Industrial communication protocols (RS485/CANBus) and RS232
- Integrated digital and analog I/Os
- Industrial grade connectors
- WiFi/ BLE for proximity services
- DIN rail mountable
- Low power consumption
- Global cellular connectivity
- Highly secure architecture
- Integration to Taoglas Insights platform

# Taoglas Insights™ Platform and Cloud Architecture



- Sensor Acquisition
- EDGE Computing
- Location

*Real-time Actionable Insights*

- **Real-time Actionable Insights - Out-of-the-box**
- **Onboard sensors data with historical and instant views**
- **GNSS location**
- **Device management**
- **Remote Firmware Updates**
- **Alarms and notification settings**
- **Enterprise level configuration**

*Customizable capabilities*

- Geofencing
- Anti Tampering
- Predictive Algorithms

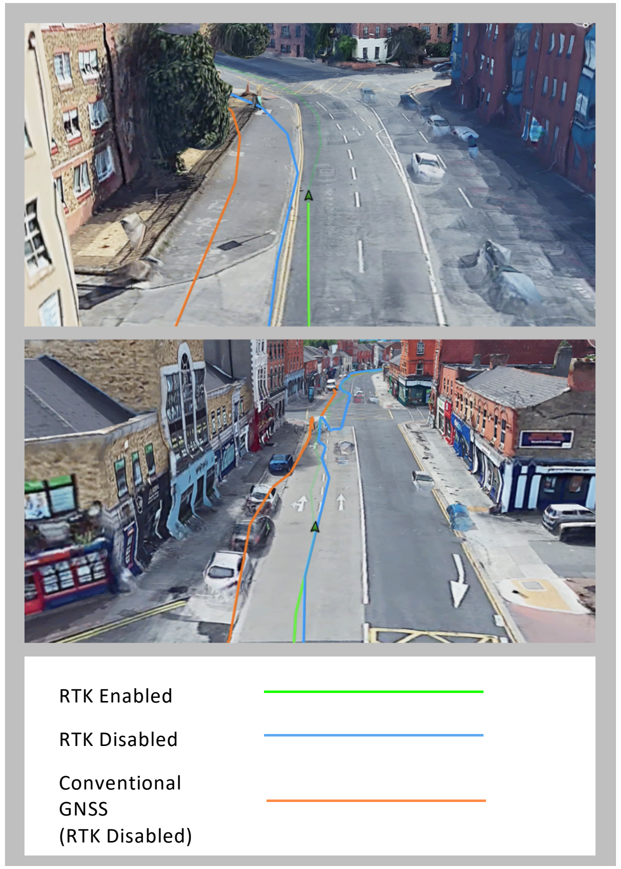
# Pilot Phase – EDGE 5 / EDGE Micro / EDGE Rugged

Pilot Definitions:

- The pilot with Moby consisted of adding the EDGE 5, EDGE Micro and EDGE Rugged with RTK capabilities to validate position gathering and compare precision of the different levels of positioning accuracy

Results:

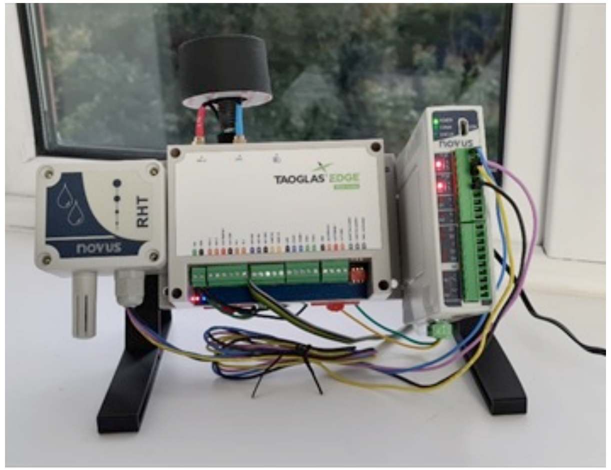
- Plug and play device
- Easy tracking and sensor acquisition
- Global access to data and location
- Established proof-of-concept with cm-level positioning without any customization



# Pilot Phase – EDGE Industrial

Pilot Definitions:

- The pilot with Novus consisted of adding the capabilities to gather data from industrial grade sensor and send it over cellular data.
- This information was then displayed with the onboard sensor and GNSS in the cloud-based dashboard.


Results:

- Proved industrial grade sensing capabilities
- Easy tracking and sensor acquisition
- Global access to data and location
- Proof of concept for industrial applications

# Market Ready Devices and SoMs

# Engineering Design

# Engineering Design

Overview of design process

Taoglas Engineering assets and tools

Overview of design for each unit

Testing and Validation

# Engineering Design – Process Overview

**Concept / Requirements**

- Feasibility Studies
- Proof of Concept

**EVT**

**Engineering Verification**

- Engineering Design and Prototyping
- Design goals and Specifications
- Software Alpha Phase

**DVT**

**Design Verification**

- Mechanical Design
- Electronic design verification
- DFM/DFT
- Hardware Testing
- Software Beta Phase
- CI/CD Setup

**PVT**

**Production Verification**

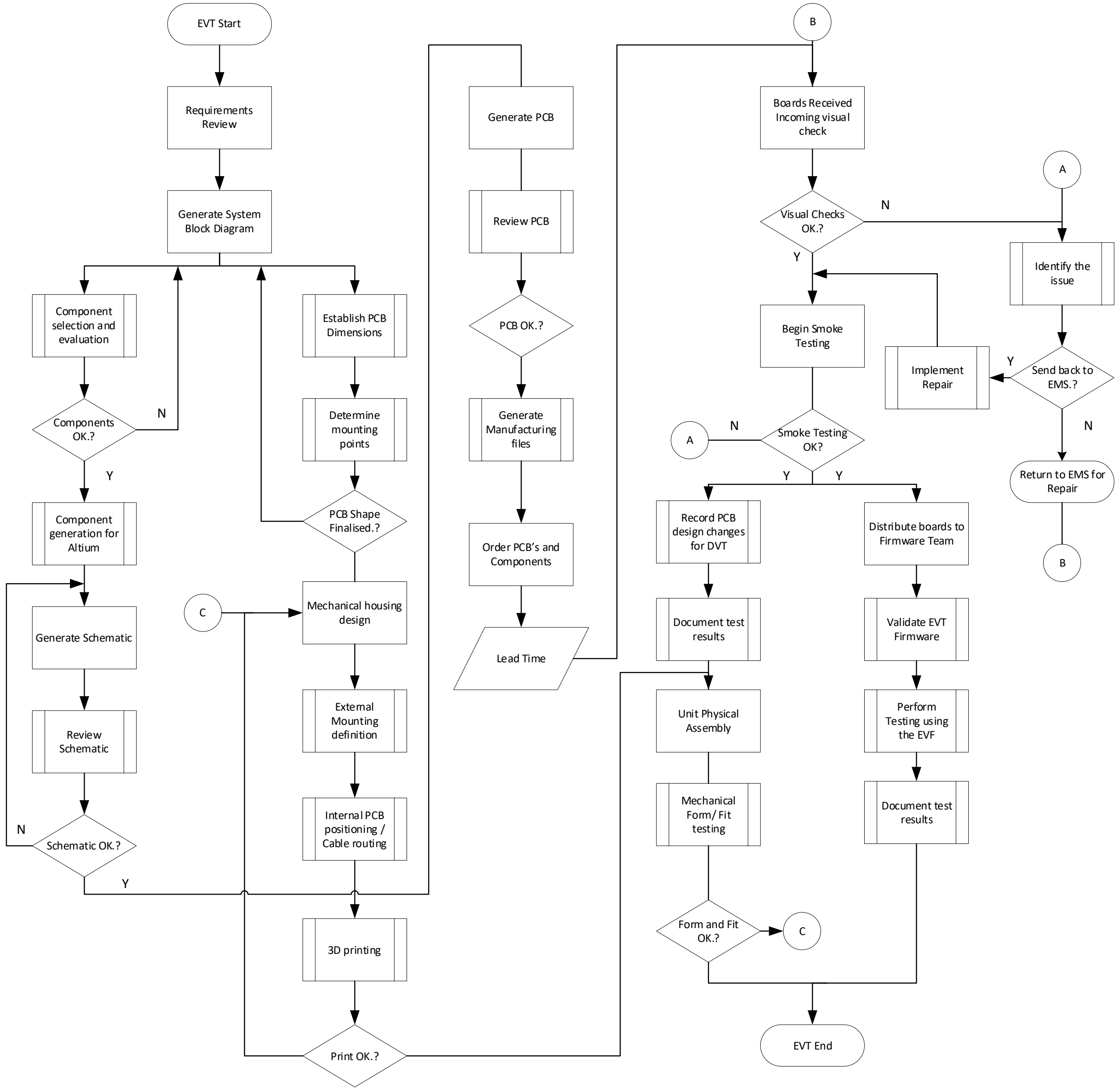
- Mechanical Tooling
- Hardware NPI & TOI
- Production Test
- Certification
- Software Release Candidate Phase
- CI/CD Operational

**MP**

**Mass Production**

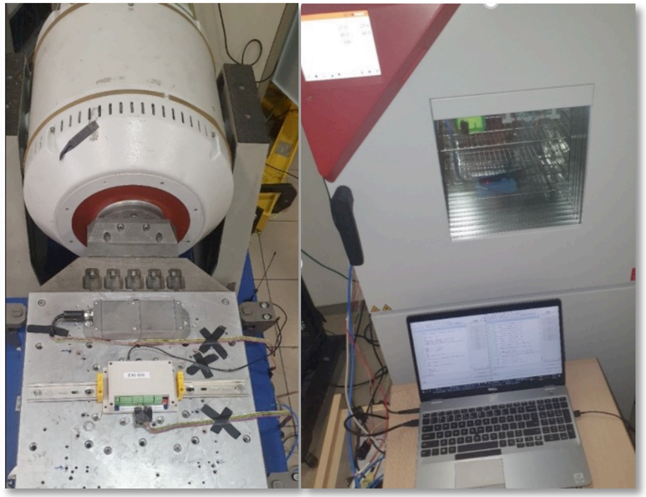
- Continuing Engineering Phase
- Failure Analysis
- Yield Monitoring

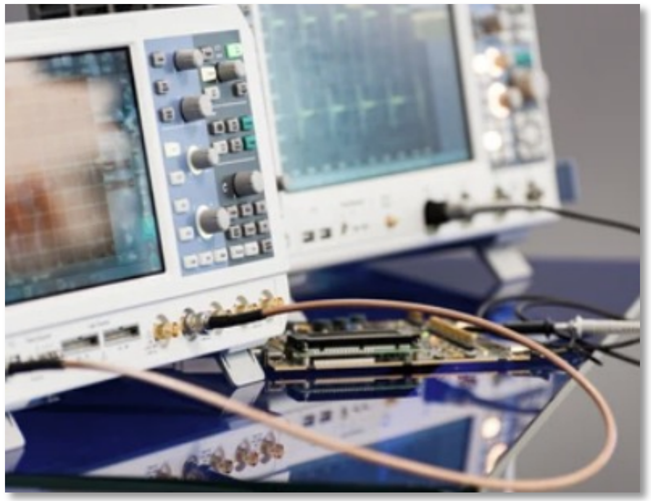
# Engineering Design – Process Overview

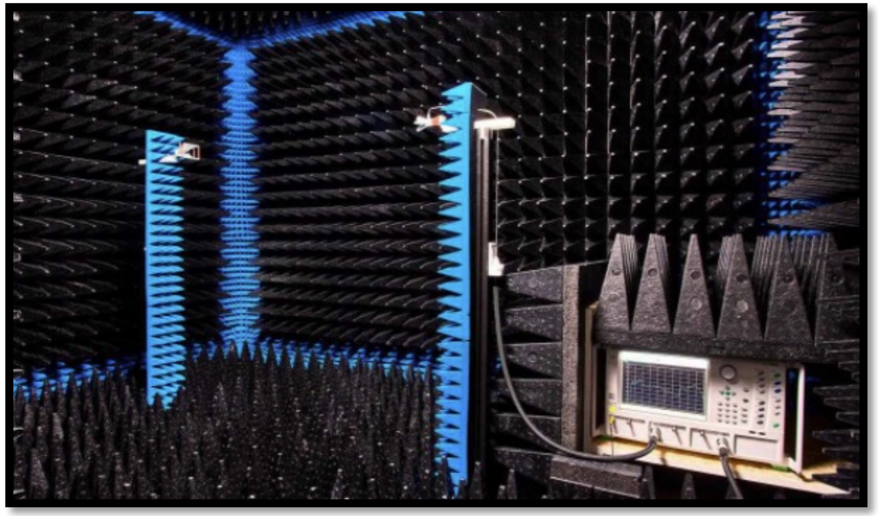



- Each phase followed outline design flow
- Pass / Fail criteria based around user requirement
- Project Management controlled the flow through the phases of the project

# Engineering Design – Assets and Tools







**Environmental Testing**

- Vibration
- Shock
- Temperature
- Power profiling

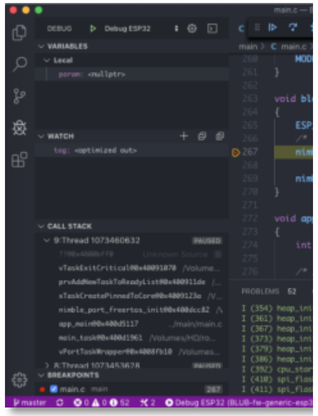
**Test and Development Lab**

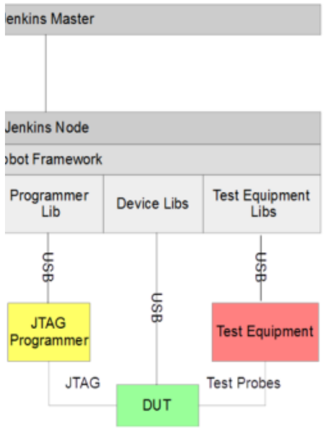
- Electronics design
- Software design
- Mechanical design
- Assembly and Test
- Verification and Validation

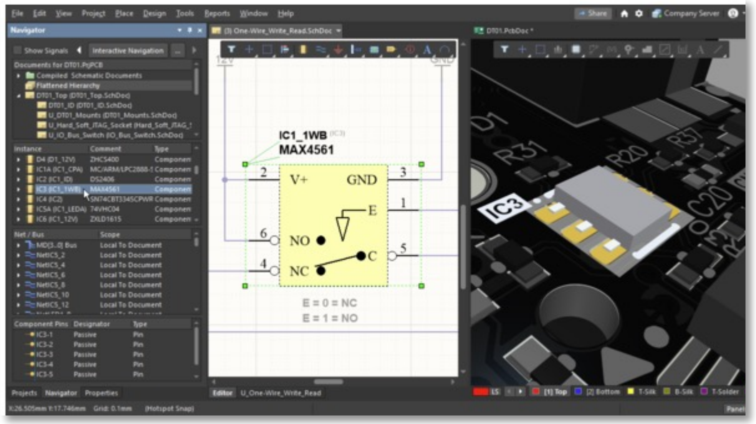
**RF Test chamber**

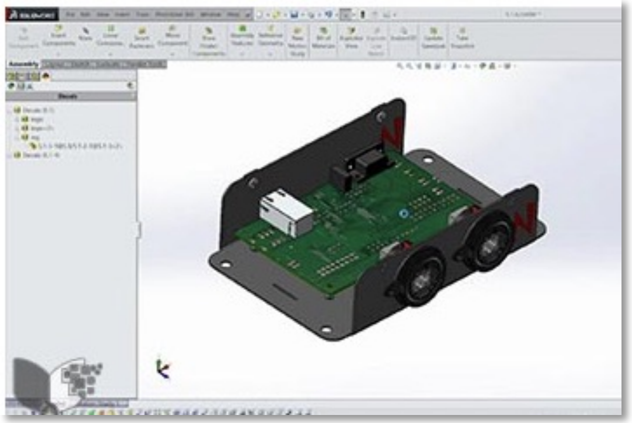
- GNSS testing
- Cellular Testing
- Antenna analysis and Tuning

# Engineering Design – Assets and Tools





**Software Development**

- Device Software development
- Automated Testing Environment
- Processor configuration
- Power optimization
- Interfacing and control

**Altium Designer Electronic CAD**

- PCB Design

**Solidworks CAD**

- Mechanical design
- Industrial Engineering

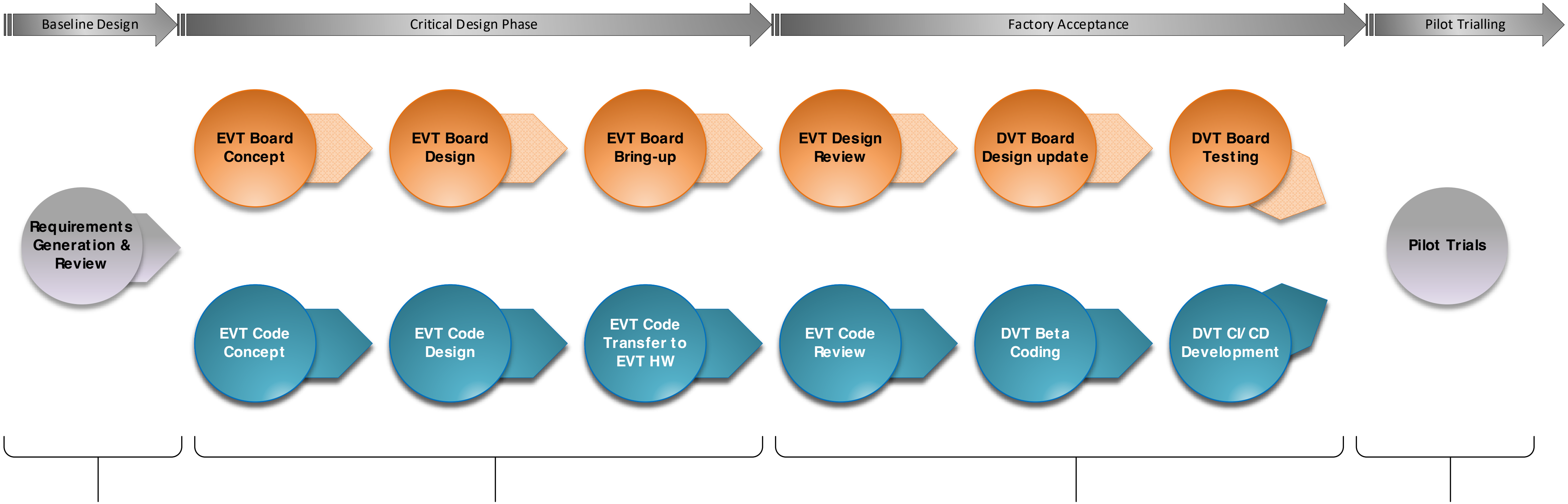

**High Precision GNSS Receiver**

- RTK Correction service
- GNSS Reference

# Engineering Design

## Edge Micro SOM

# Engineering Design – Edge Micro SOM




Review of the user requirements, generation of design ideas to meet the requirements

There were two board design iterations within this phase as we transferred to Thales Modem

Creation of AT Command Stack for Thales Modems

Power profiling and validation of low power state

BLE, WiFi & Cellular functional testing

Supply Chain team involved in BOM analysis

Environmental testing and Systems testing underway here

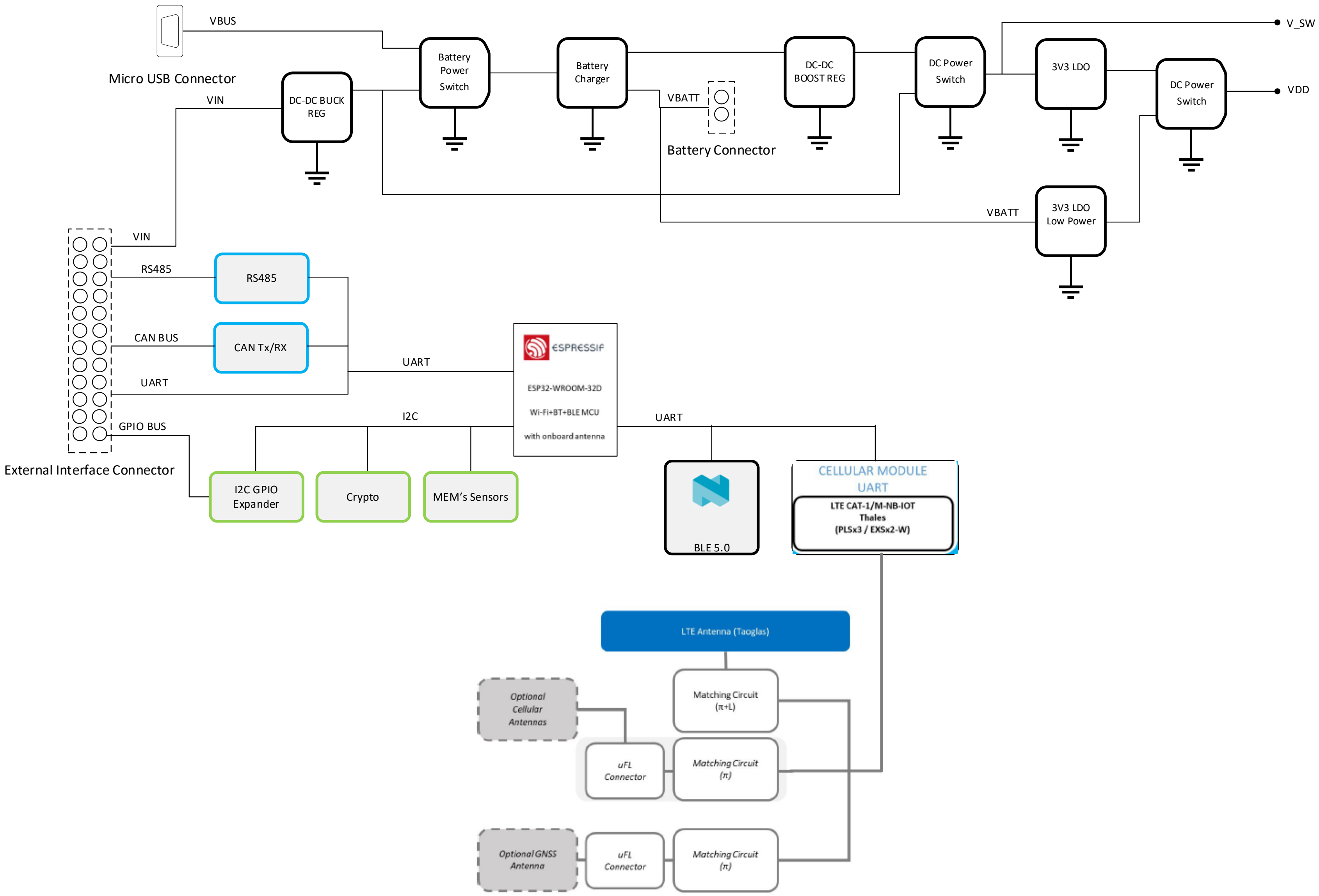
RF performance testing, GNSS accuracy, Antenna efficiency, RF Front-End Testing. Issue with RF Efficiency discovered, analysis concluded change to Antenna type needed

Issue with Thales Modem spotted, relating to power down sequencing

Most of the Trials completed as part of Edge Rugged as the Edge Rugged uses this device

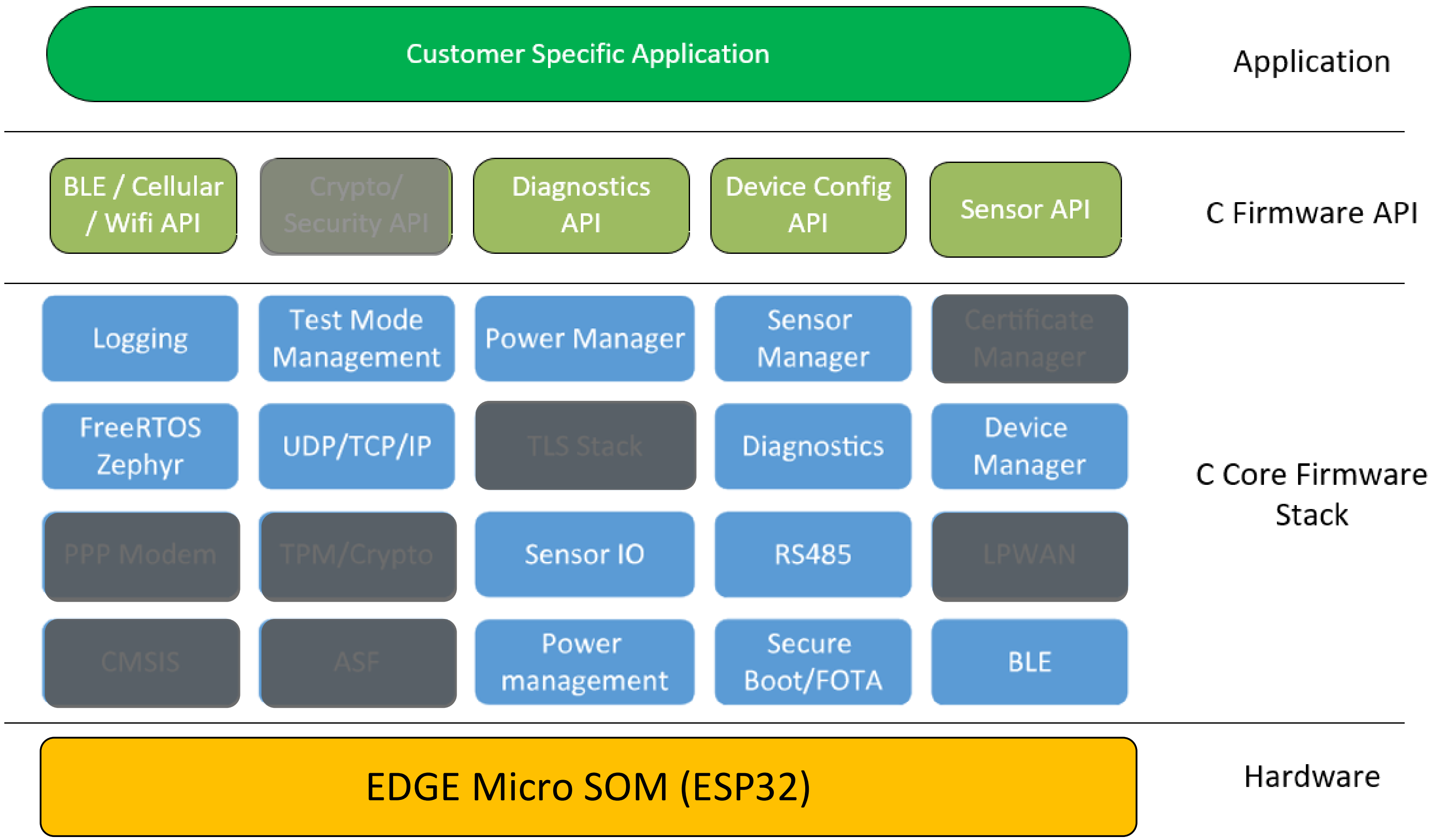
Some SOM only testing completed with respect to connections and interfacing

# Engineering Design – Edge Micro SOM




- General purpose IoT SOM
- Industrial Communications interfaces
- BLE 4.2 & BLE 5
- WiFi
- Cellular & GNSS
- Switched Antenna circuits for Cellular & GNSS external Antenna
- 4 Tuned Antenna Circuits
- Battery / Direct power

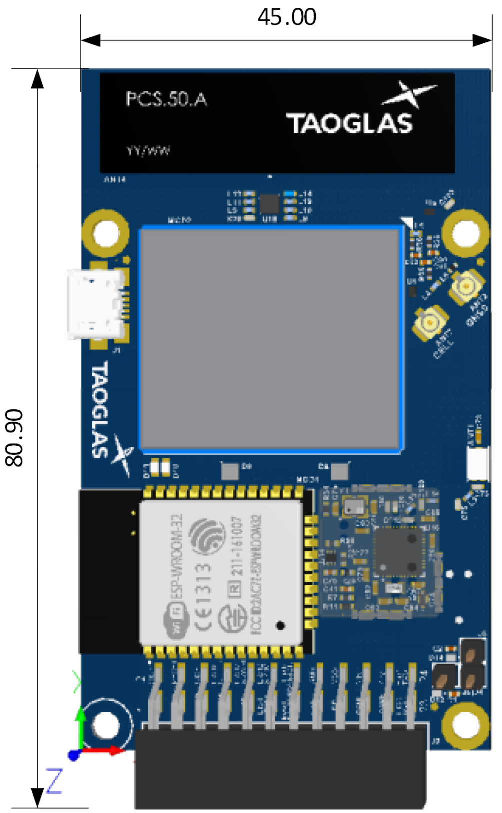
# Engineering Design – Edge Micro SOM

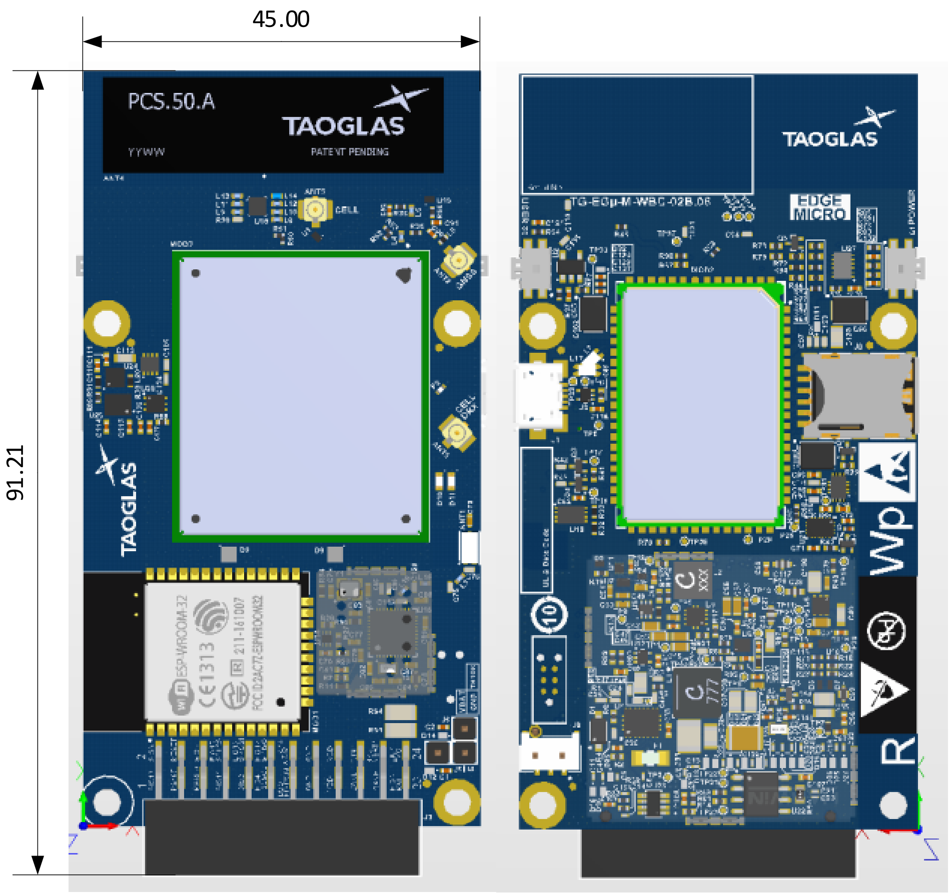



Firmware Development

- Based on existing Architecture
- Major function blocks Identified as part of EVT to meet requirements
- Functions either ported or re-written for the ESP32 MCU
- Setup of Continuous Integration platform

# Engineering Design – Edge Micro SOM



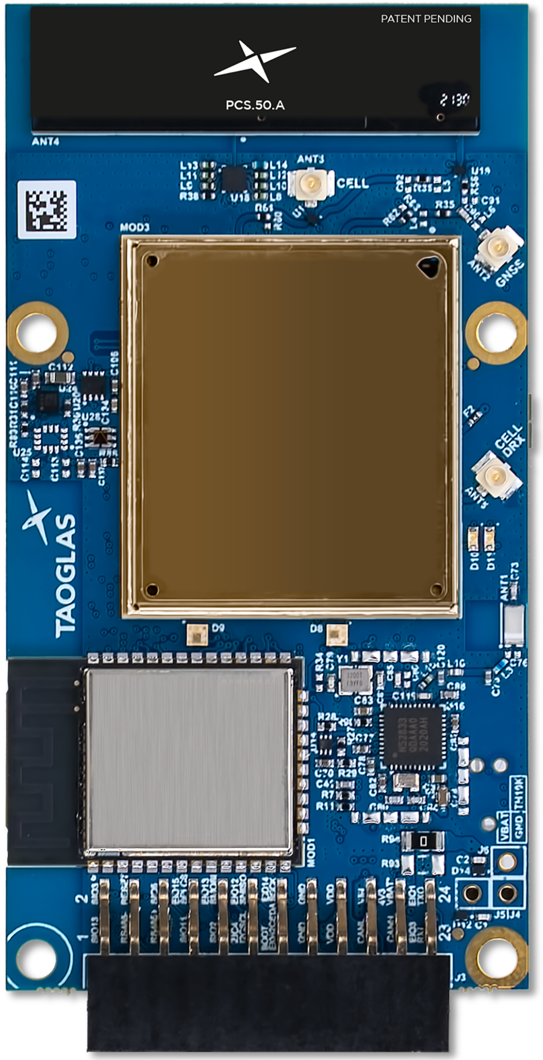

**Version 1**

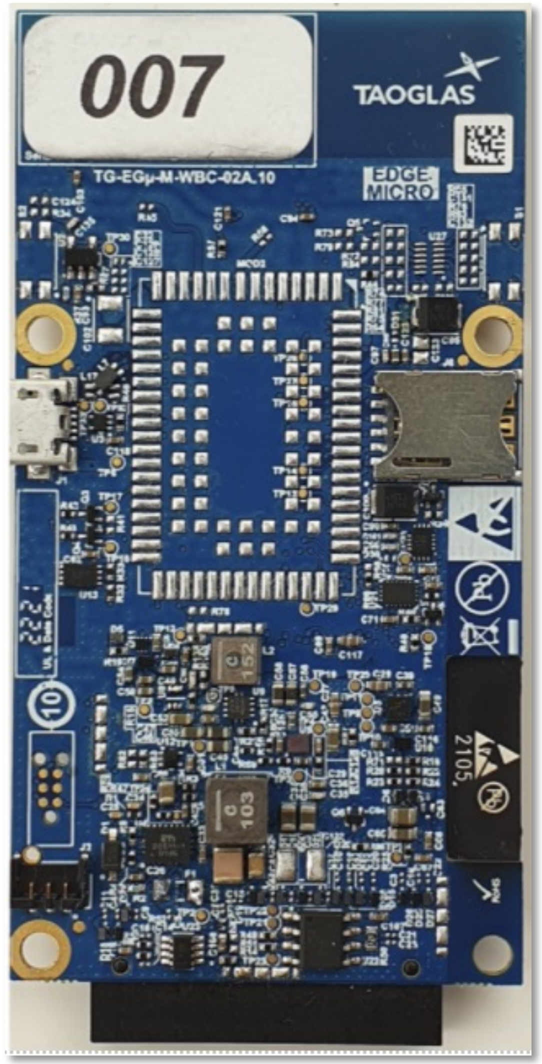
- First Modem Supplier  Integration
- Small footprint
- Switched Antenna Paths

**Version 2**

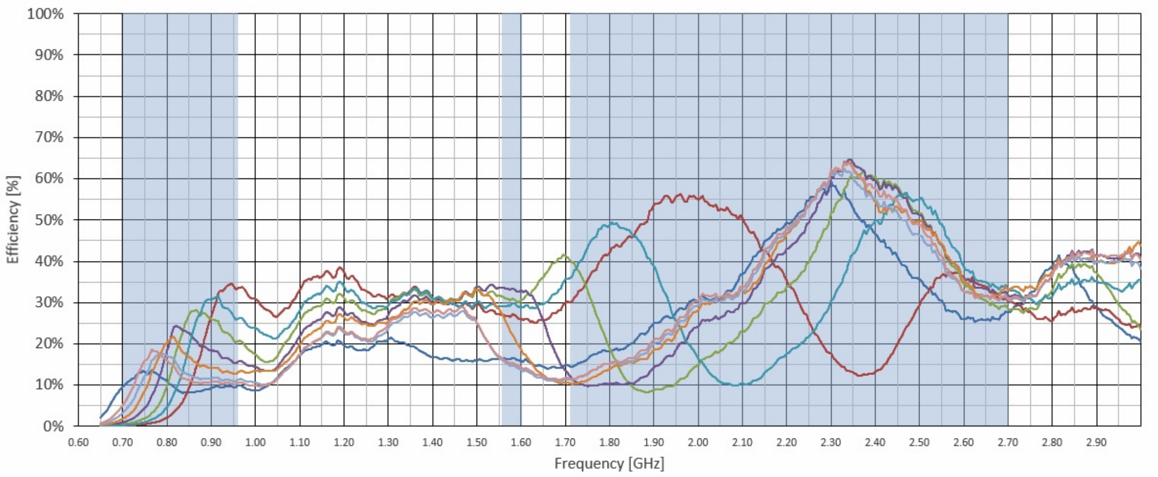
- Move to second supplier Modem
- Two different Modem's
- Single PCB design – multi footprint
- Longer PCB – unforeseen consequence

# Engineering Design – Edge Micro SOM

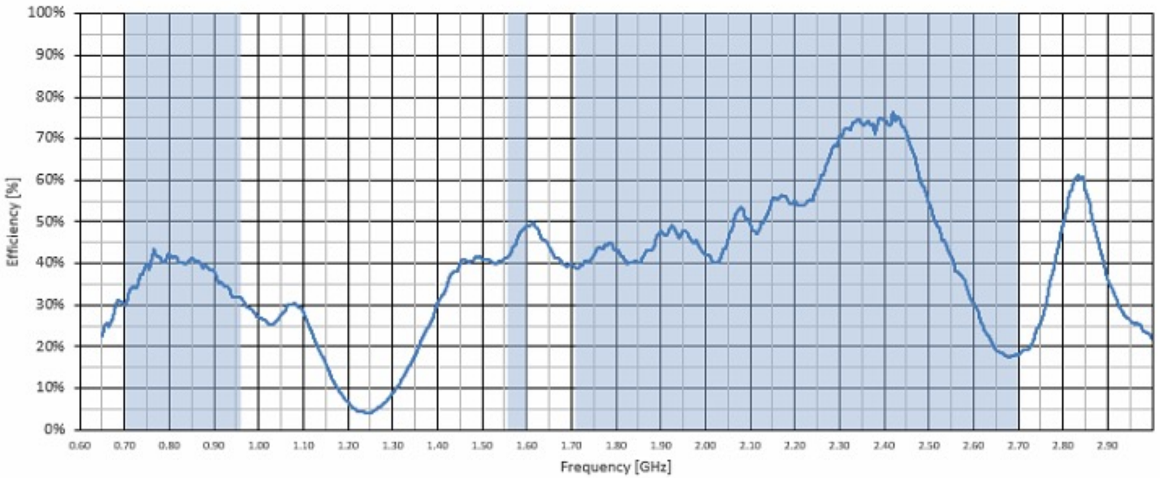


# Engineering Design – Edge Micro SOM




Efficiency for Micro with PCS.50 Antenna




Efficiency for Edge Connect WSA

Edge Micro SOM EVT-2

- Second Supplier Modems
- Hardware operating as designed
- Low Power consumption
- Tests show all circuits operational
- Using PCS.50 Antenna
- RF Testing showed low RF Efficiency

EDGE Connect WSA

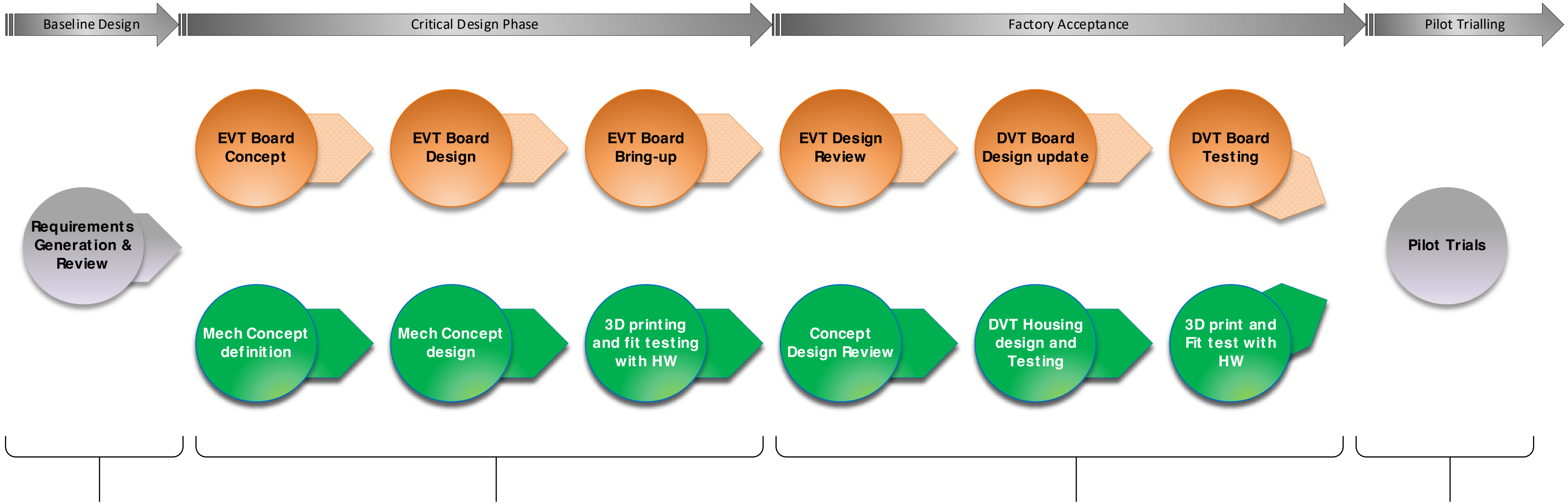
- Same Modems as Edge Micro
- Similar PCB length
- Simpler Antenna FE
- Different Chip Antenna (PA.26)

Solution: Use Antenna from Edge Connect WSA to achieve higher efficiency with one matching circuit

# Engineering Design

## Edge Rugged

# Engineering Design – Edge Rugged




Review of the user requirements, generation of design ideas to meet the requirements

For the Rugged concept, new design work on Hardware was based on design of the interconnect board that holds the Edge Locate in place and design of the Mechanical housing

Supply Chain team involved in BOM analysis

Environmental testing and Systems testing underway here

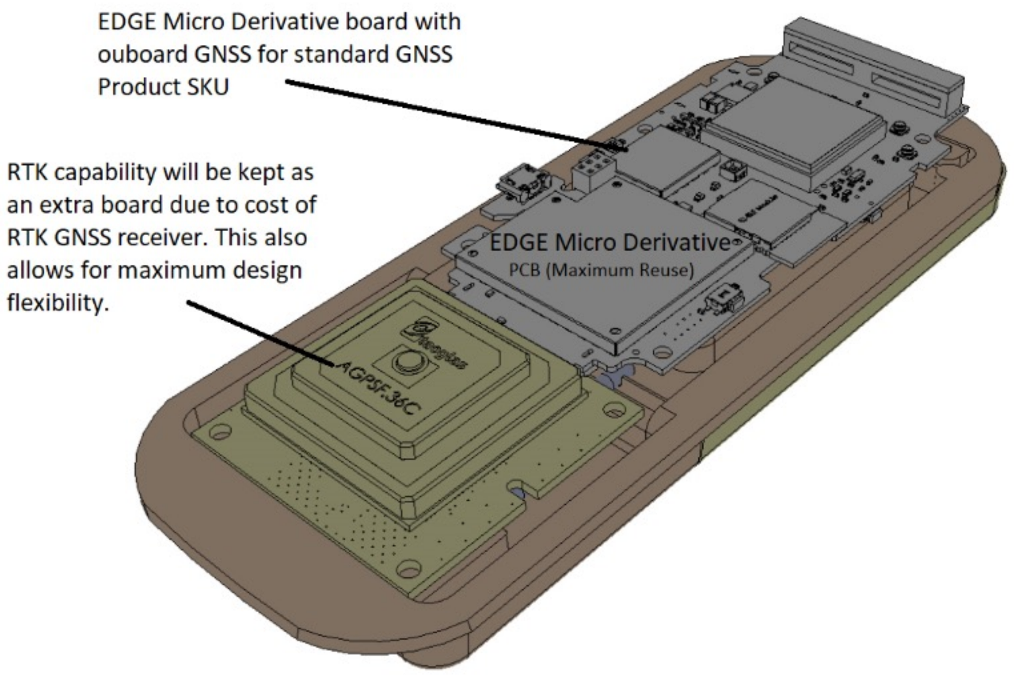
At this point, we reexamined the design of the EVT-1 housing. Based on a design review, we undertook new design concept to address initial unit shortcomings

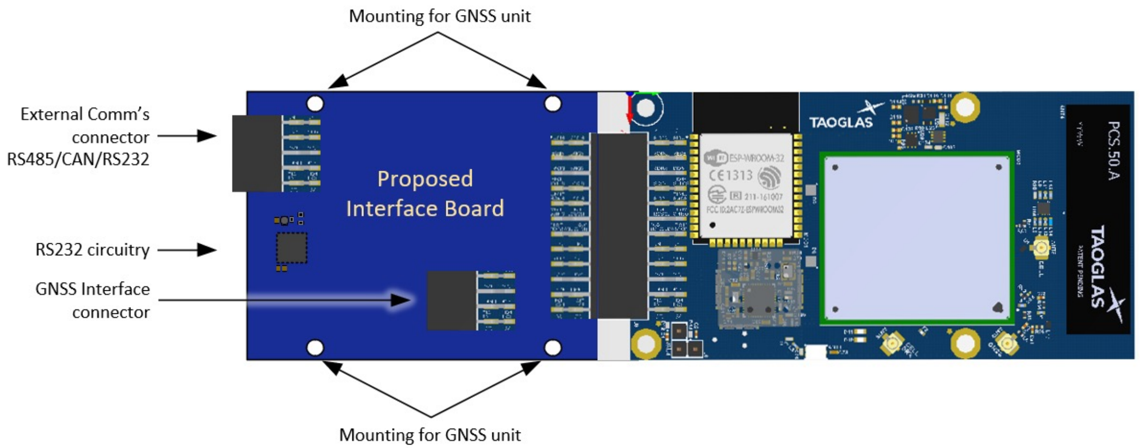
RF Testing showed good results in static outdoor testing on roof of our office with/without RTK correction

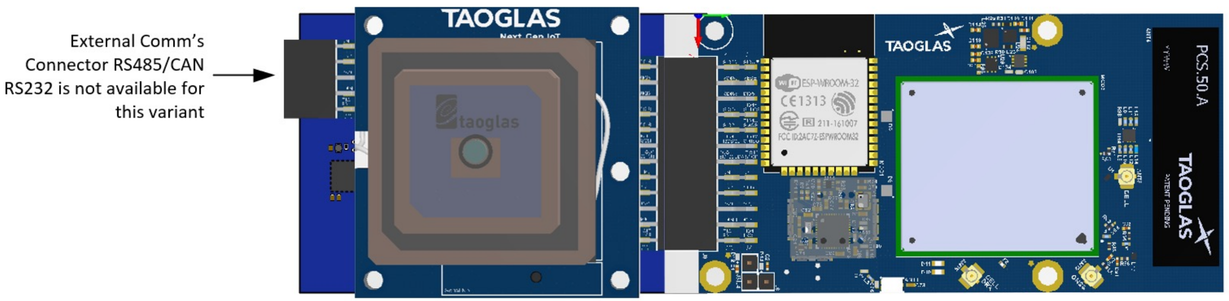
Static trials based on establishing positional accuracy in multiple locations carried out.

Significant impact on positioning accuracy as a function of RTK base-station observed. (53KM)

# Engineering Design – Edge Rugged




- Combine GNSS RTK module with Edge Micro SOM
  - CM level positioning
  - Solar Charge capability
  - Industrial Communications for gateway operation

# Engineering Design – Edge Rugged EVT

- Hollow chassis
- Sealing detail outside of assembly screws – affects IP rating

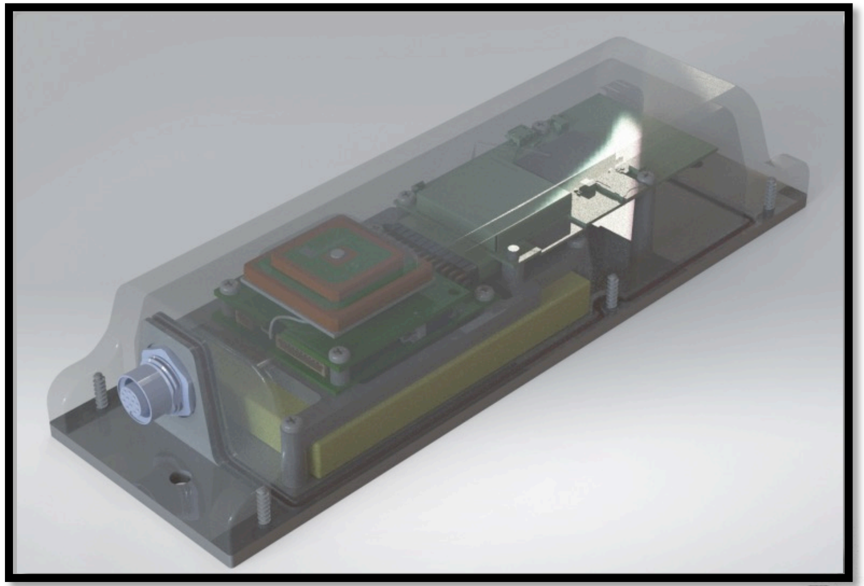
- Difficult to test unit during assembly
- Hard to Assemble
- No battery security

- Screws on top of unit causing a security risk for the device

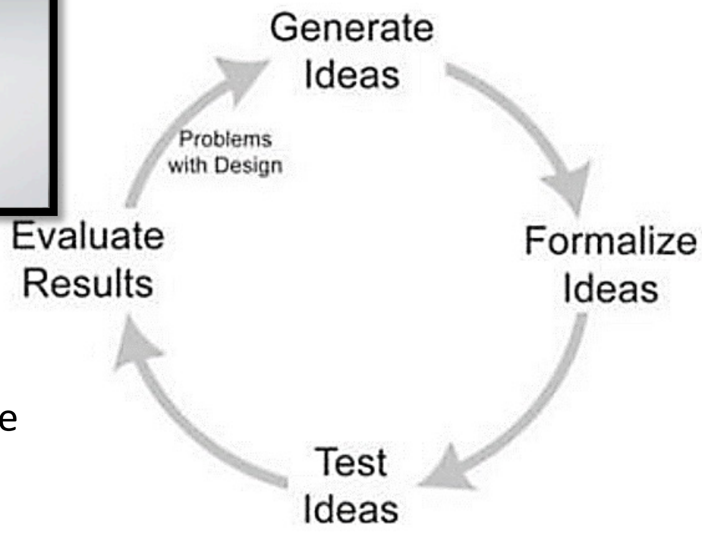
- Design is rugged and able to withstand forces
- Used for environmental testing

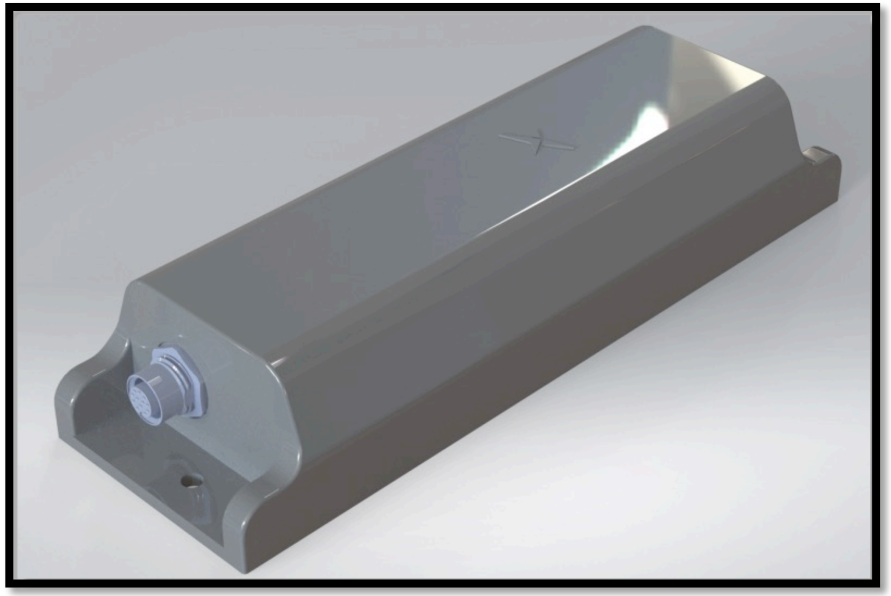
EVT-1 design met most requirements but required further effort to seal screws. Assembly time would increase manufacturing cost. Security risk identified with top mounting screws. Design is not flexible

# Engineering Design – Edge Rugged DVT



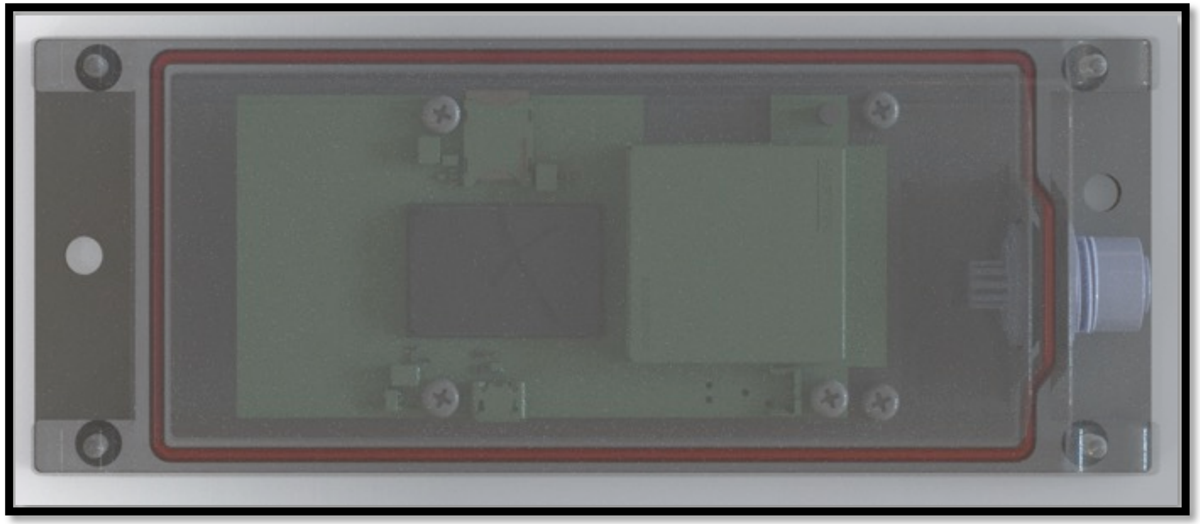
- Consider how to add variance to this design
  - RTK and non RTK
  - Internal Patch Antenna
  - Solar Charging options



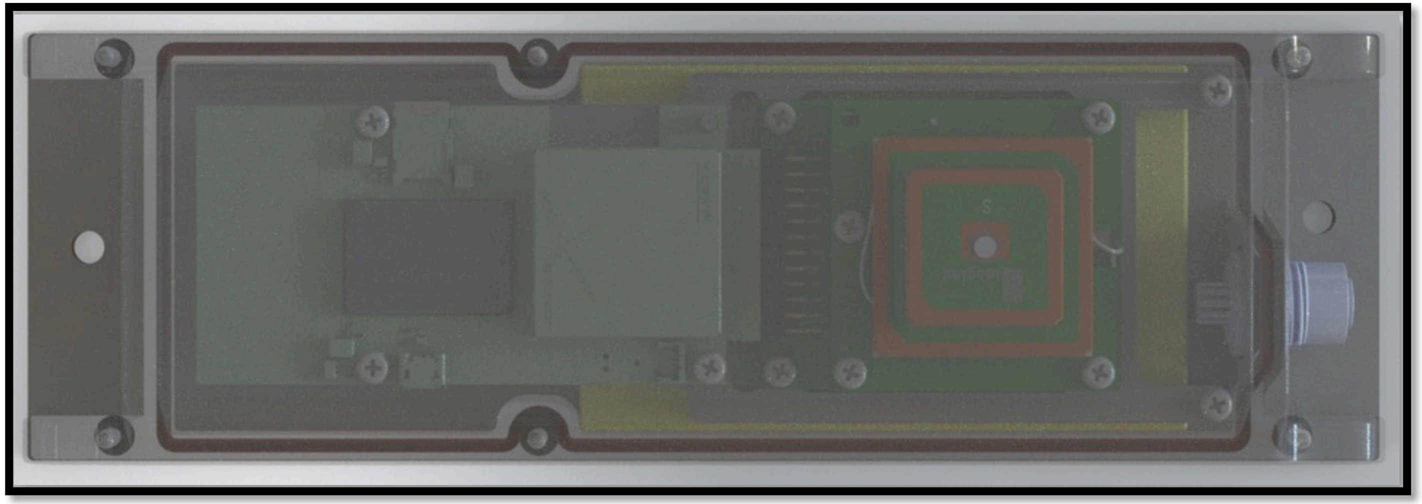



- Review the design to address the issues we noted in EVT
- Match the work to the Customer need
  - Cost
  - Security
  - Performance

# Engineering Design – Edge Rugged DVT



- Non-RTK Version
  - Lower BOM cost
  - Lower Precision
  - Lower Power
  - Taoglas Patch Antenna for GNSS
  - Good results
  - Meets a lot of customer requirements



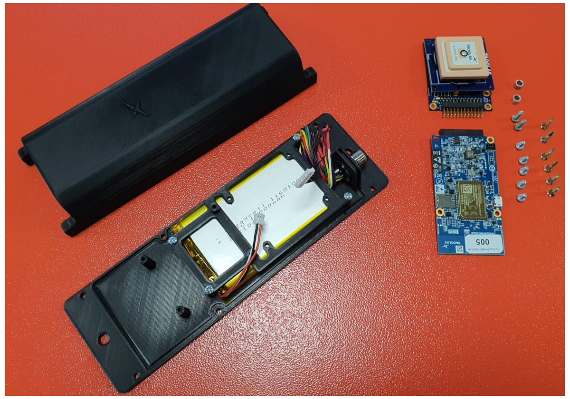
- RTK Version
  - High Precision GNSS
  - RTK Corrections
  - CM level results
  - Exceeds customer requirements

# Engineering Design – Edge Rugged DVT

- Non-RTK Version
  - Lower BOM cost
  - Lower Precision
  - Lower Power
  - Taoglas Patch Antenna for GNSS
  - Good results
  - Meets a lot of customer requirements

- RTK Version
  - High Precision GNSS
  - RTK Corrections
  - CM level results
  - Exceeds customer requirements

# Engineering Design – Edge Rugged DVT

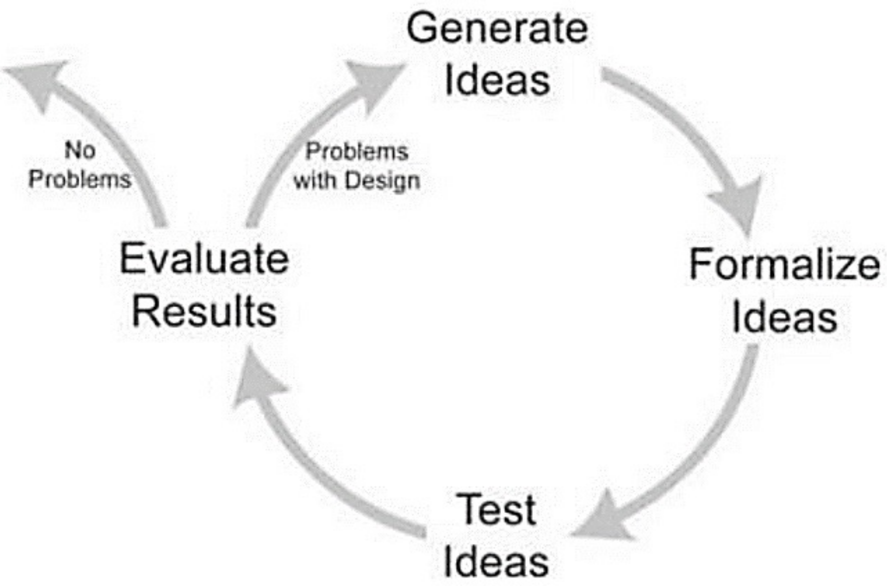


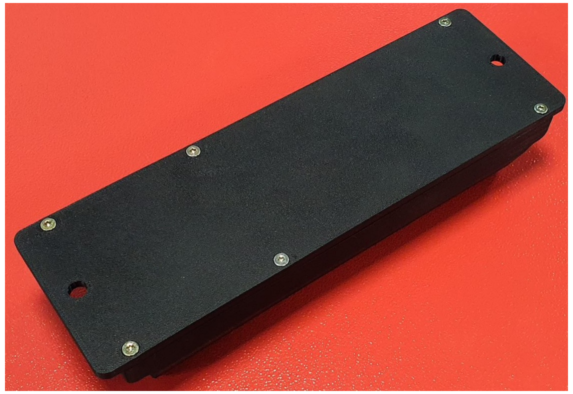
- Electronics mounted on base ‘chassis’
- Battery mechanically secured

- Electronic test on sub-assembly
- O-Ring Seal also applied to base ‘chassis’

3D printing to rapid prototype

High Quality Printing for detailed evaluation



- Assembly screws at rear of unit, not accessible when unit is mounted

# Engineering Design – Edge Rugged

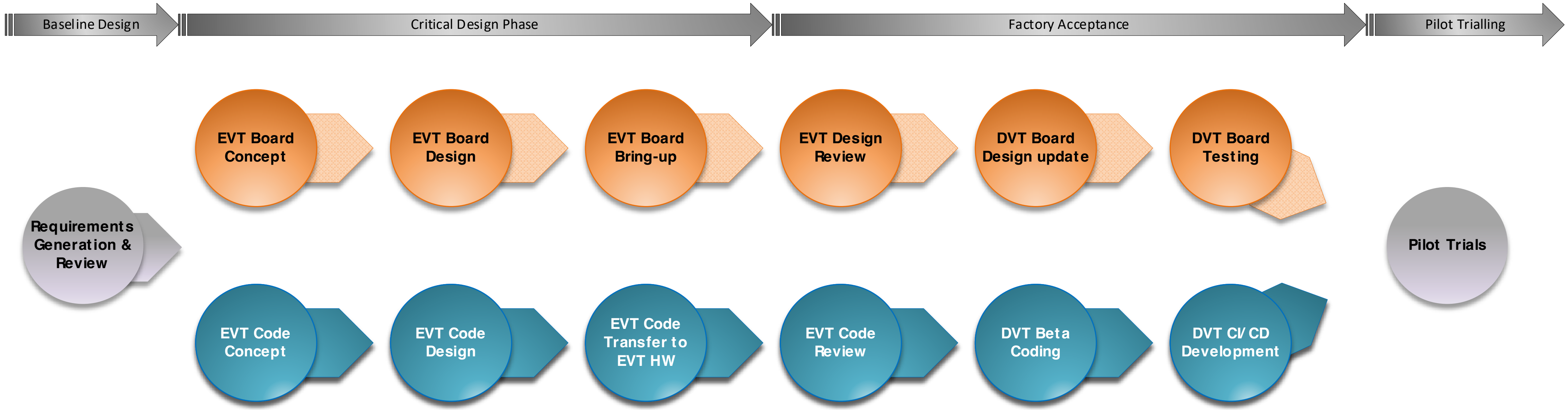
EVT Unit Mounted on Moby Bike for Static outdoor position testing

DVT Unit Mounted on Moby Bike for outdoor trials, note that non-RTK version also mounted for comparison

# Engineering Design

## Industrial Gateway

# Engineering Design – Industrial Gateway




Review of the user requirements, generation of design ideas to meet the requirements

I/O design based on the requirements, addition of RS232 direct on the unit and termination resistor switch for CAN and RS485

Power profiling and validation of low power state

BLE, WiFi & Cellular functional testing

Supply Chain team involved in BOM analysis

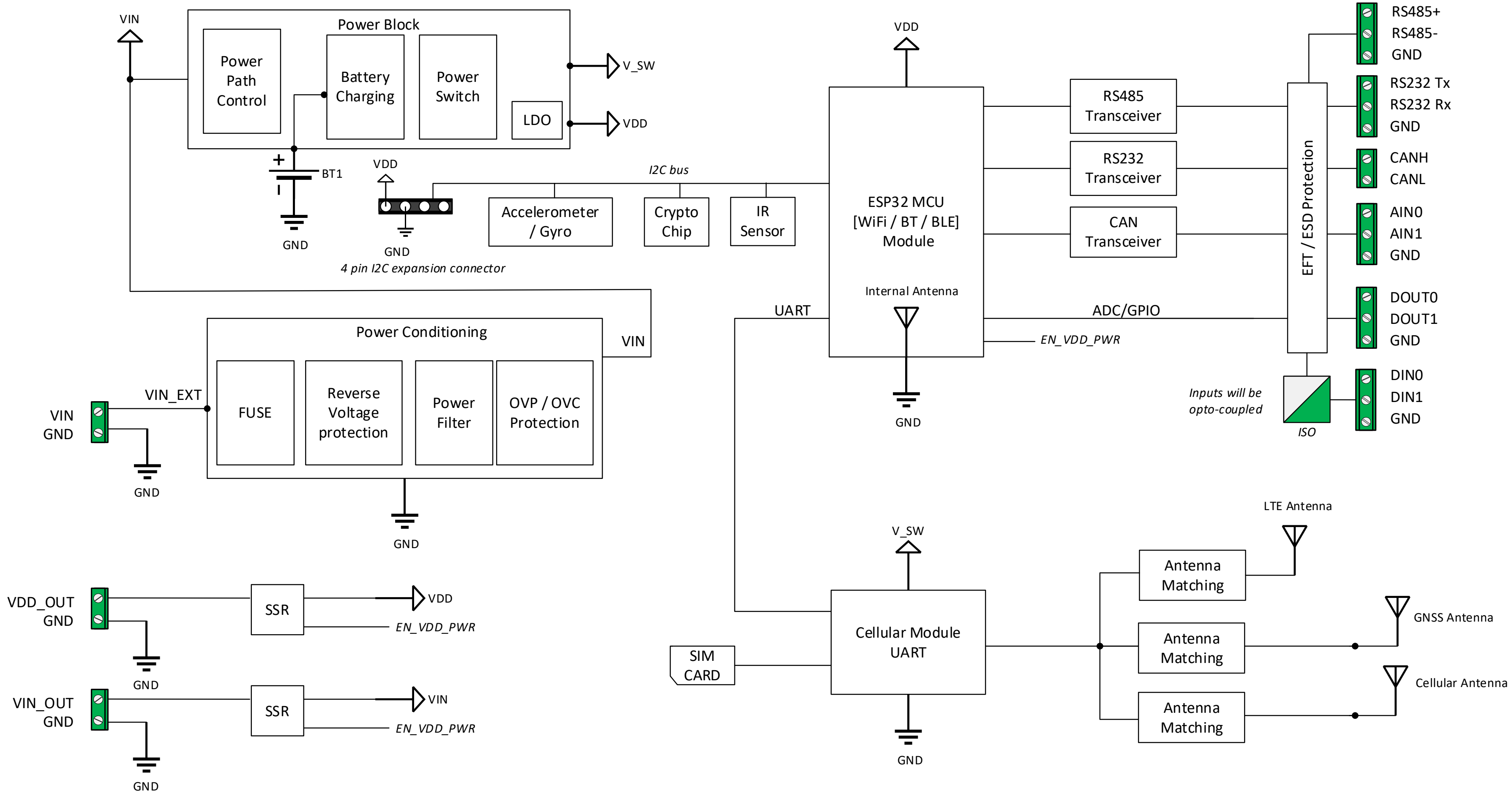
Environmental testing and Systems testing underway here

RF performance testing, GNSS accuracy, Antenna efficiency, RF Front-End Testing.

Issue with Thales Modem spotted, relating to power down sequencing – same as Edge Micro SOM

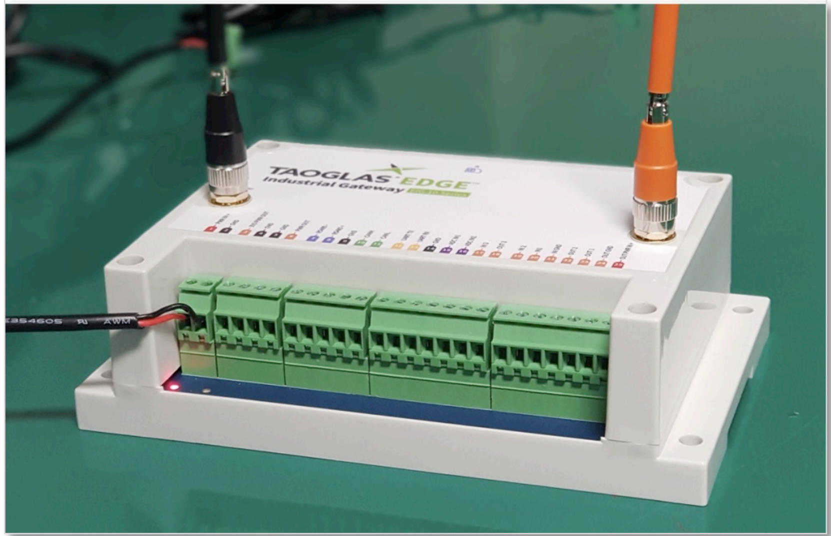
Trials used 3rd Party IoT hardware from Novus, including MODBUS operation and direct sensor readings

# Engineering Design – Industrial Gateway

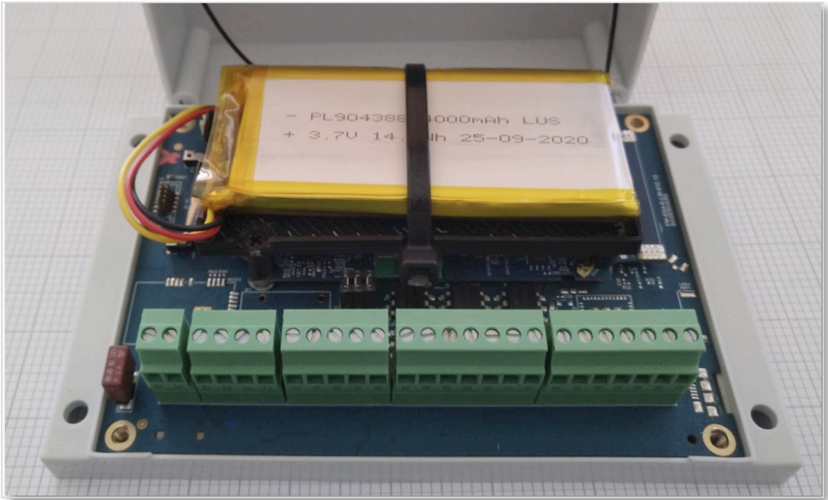



- Cost down redesign of existing gateway
- Industrial Communications interfaces
- BLE 4.2 & BLE 5
- Addition of WiFi / LoRa
- Cellular & GNSS
- Switched Antenna circuits for Cellular & GNSS external Antenna
- Battery backup
- Single PCB design

# Engineering Design – Industrial Gateway

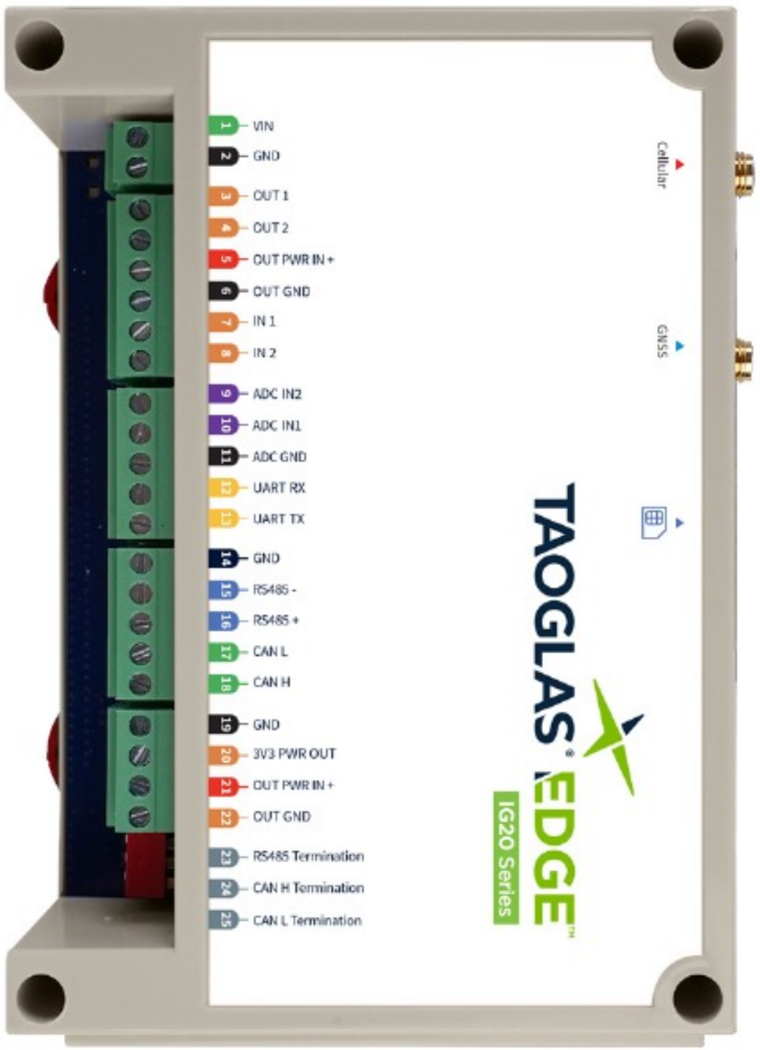






# Engineering Design – Industrial Gateway

- Learnings from the field – BLE issues on two board solution – single board implementation to deal with this
- PCB mounted antenna – better performance due to ground plane – top mounted maintained to support customer preference
- RS232 interface added in place of 3.3V UART interface
- User Switchable termination resistors added for RS485 and CAN BUS
- Improved battery holder to enable different size (cost) battery options
- Modem choice for Cat 1 or NB-IoT
- Addition of LoRa Module and WiFi on board



# Engineering Design – Industrial Gateway

## Pinout Description

- CAN L Termination
- CAN H Termination
- RS485 Termination
- GND
- Switched Power Output (5V - 48V DC)
- 3.3V DC Output (Max 1A)
- GND
- CAN High
- CAN Low
- RS485 +
- RS485 -
- GND
- Serial TX (UART 3.3V)
- Serial RX (UART 3.3V)
- GND
- Analog Input (0V - 36V)
- Analog Input (0V - 36V)
- Digital Input (Isolated 7.5V -27V DC)
- Digital Input (Isolated 7.5V -27V DC)
- GND
- Power Input for Isolated Digital Outputs
- Digital Output 2 (Isolated)
- Digital Output 1 (Isolated)
- Power Input - (GND)
- Power Input +(5V - 48V DC)


## Connections Capabilities

- RS485/Modbus RTU
- CAN bus
- UART
- Analog Inputs
- Multiple Digital Inputs/Outputs

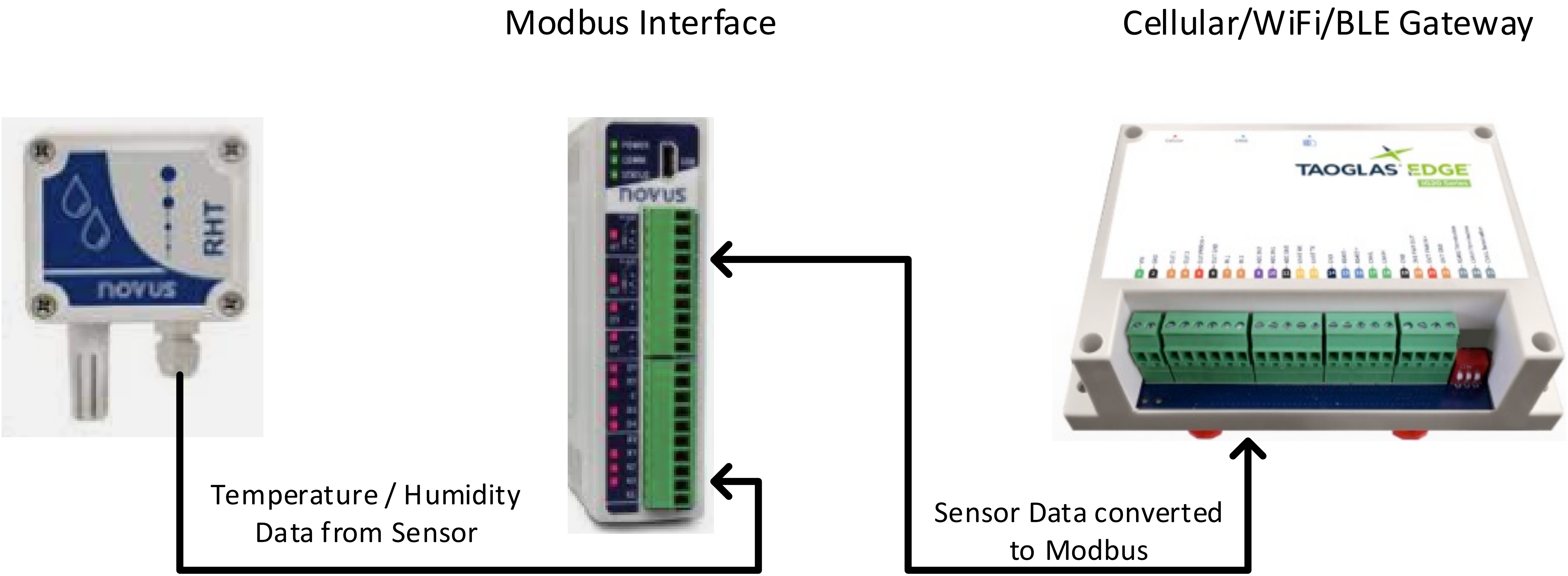
4G Cat-1
3G
2G
Wi-Fi
NB-IoT
LTE Cat-M

GPS
GLONASS
Galileo
BeiDou

BLE

BLE4.2
BLE 5

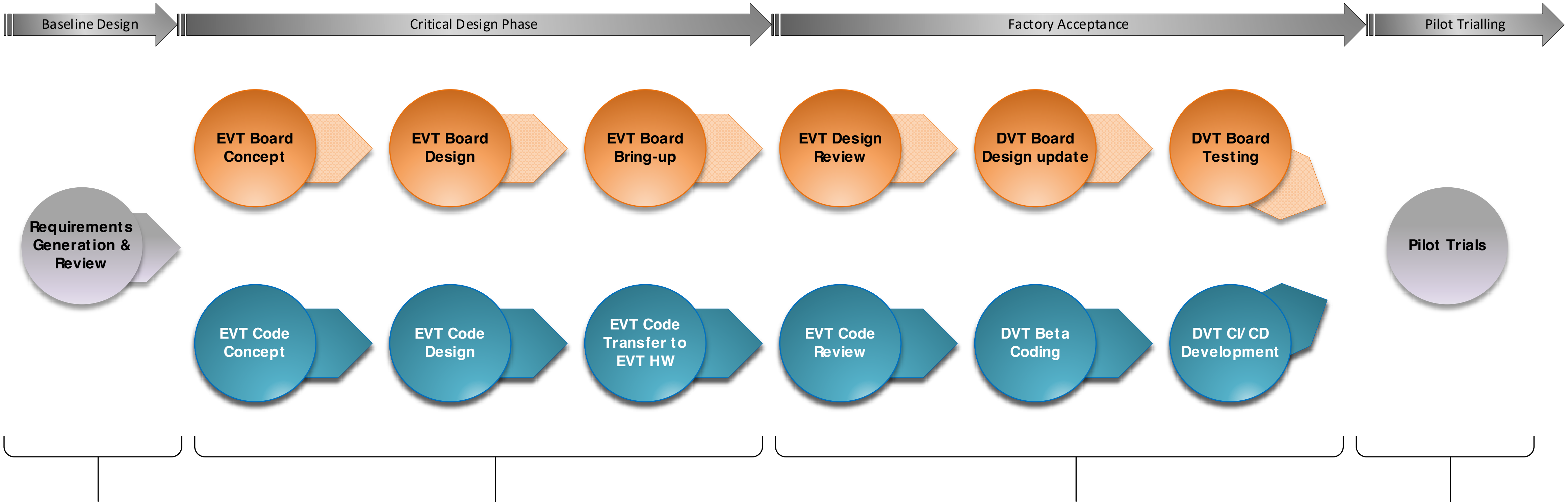
# Engineering Design – Industrial Gateway



# Engineering Design

## Edge Connect WSA

# Engineering Design – Edge Connect WSA




Review of the user requirements, generation of design ideas to meet the requirements

There were two board designs required to cover the Cat-M and Cat-NB-IoT user requirements

Mechanical confirmation on fitting for use in the Edge Connect housing

Power profiling and validation of low power state

Porting of Code from Edge 4 to Edge 5

Supply Chain team involved in BOM analysis

Environmental testing and Systems testing underway here

RF performance testing, GNSS accuracy, Antenna efficiency, RF Front-End Testing.

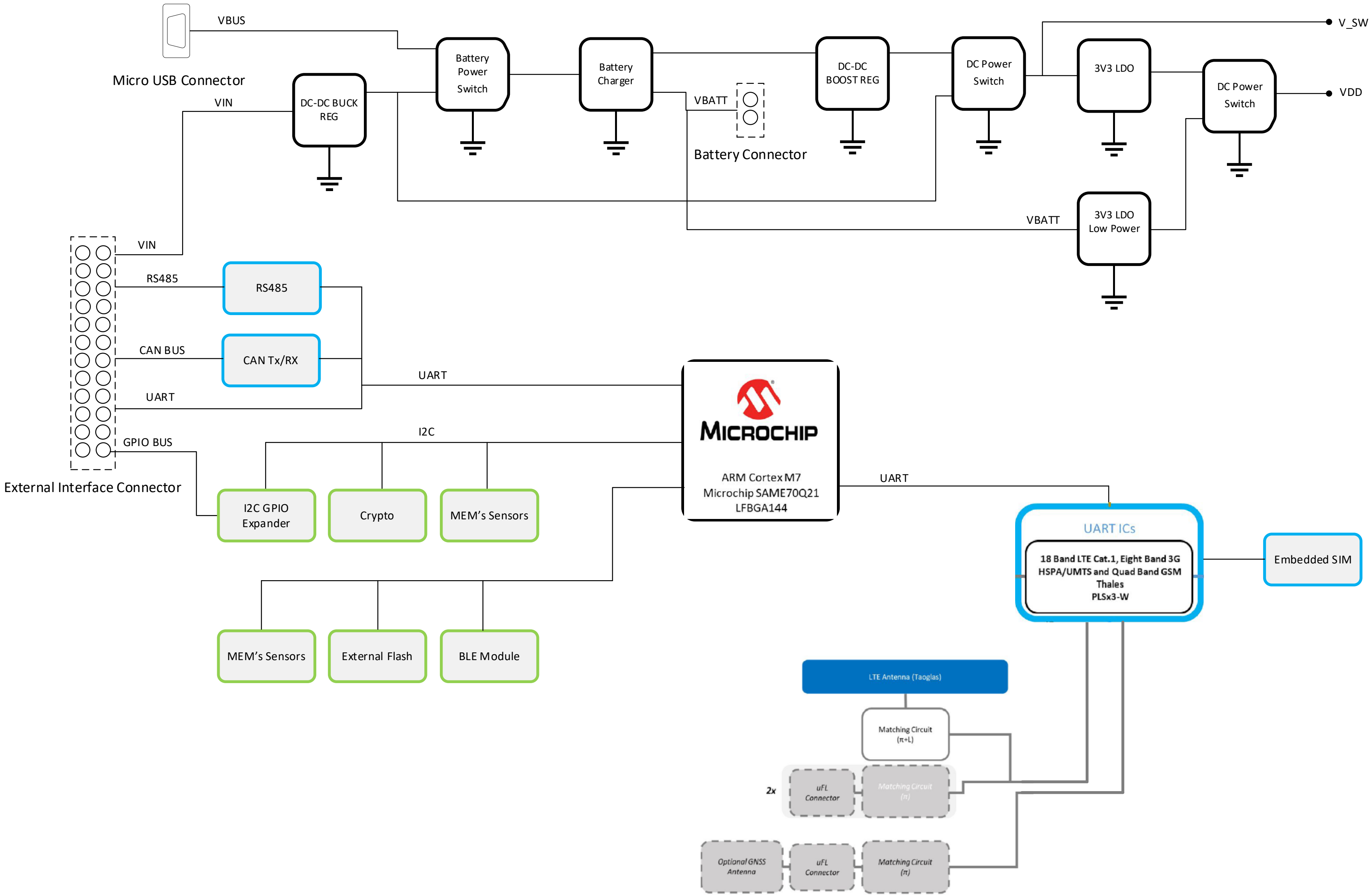
Issue with Thales Modem spotted, relating to power down sequencing – same as Edge Micro SOM

Testing also completed with CO2 sensor and Temperature sensor using Environmental sensor Expansion board

Trials completed indoors and outdoors to demonstrate capability to sample environmental data and upload to cloud

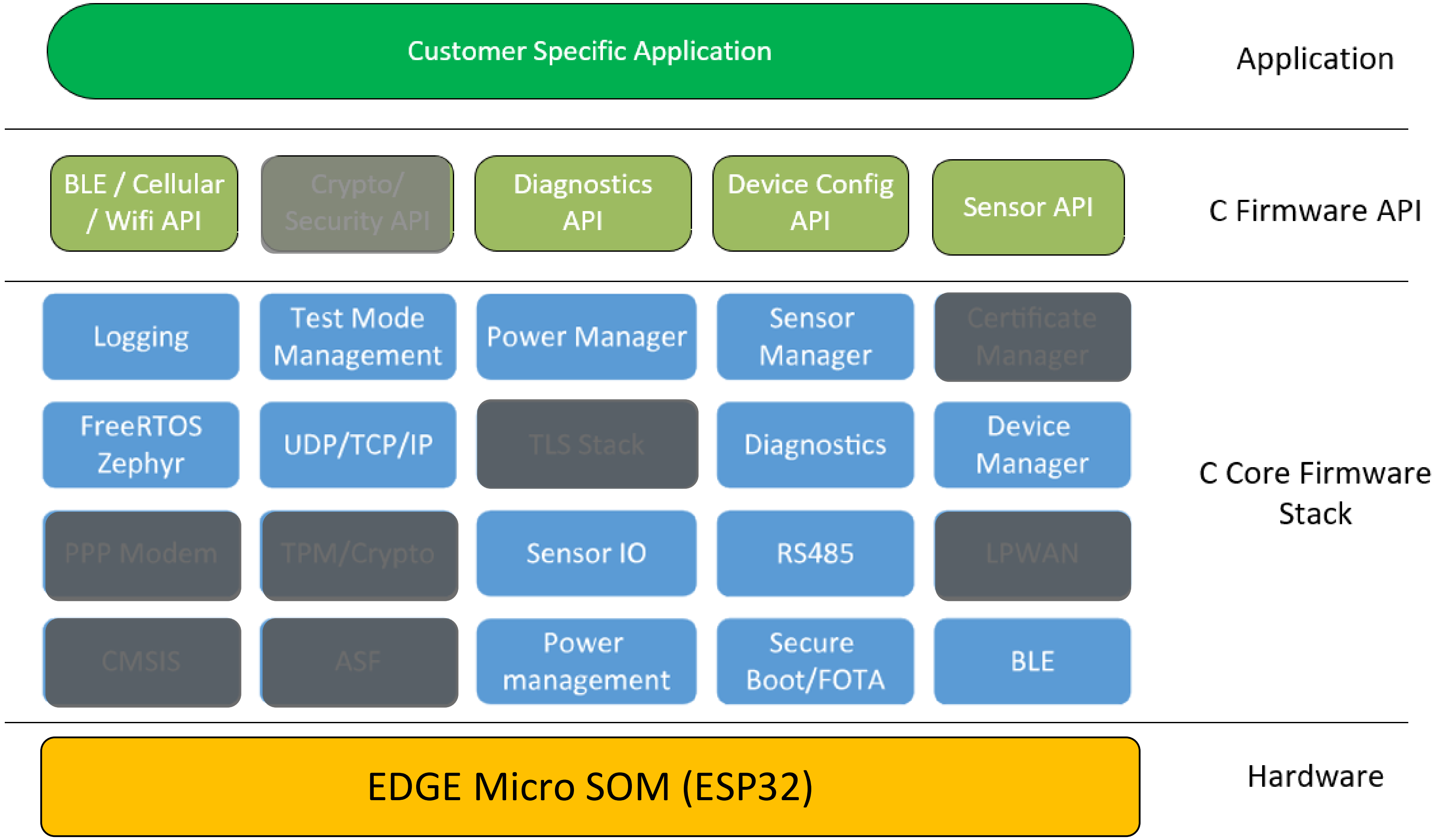
Additional testing carried out using Expansion board

# Engineering Design – Edge Connect WSA




- General purpose IoT SOM
- Ambient Light, PTH, IMU and Compass MEM's
- BLE 4.2, Cellular & GNSS
- Switched Antenna circuits for Cellular & GNSS external Antenna
- ARM Cortex M7 Based MCU onboard
- Battery / Direct power

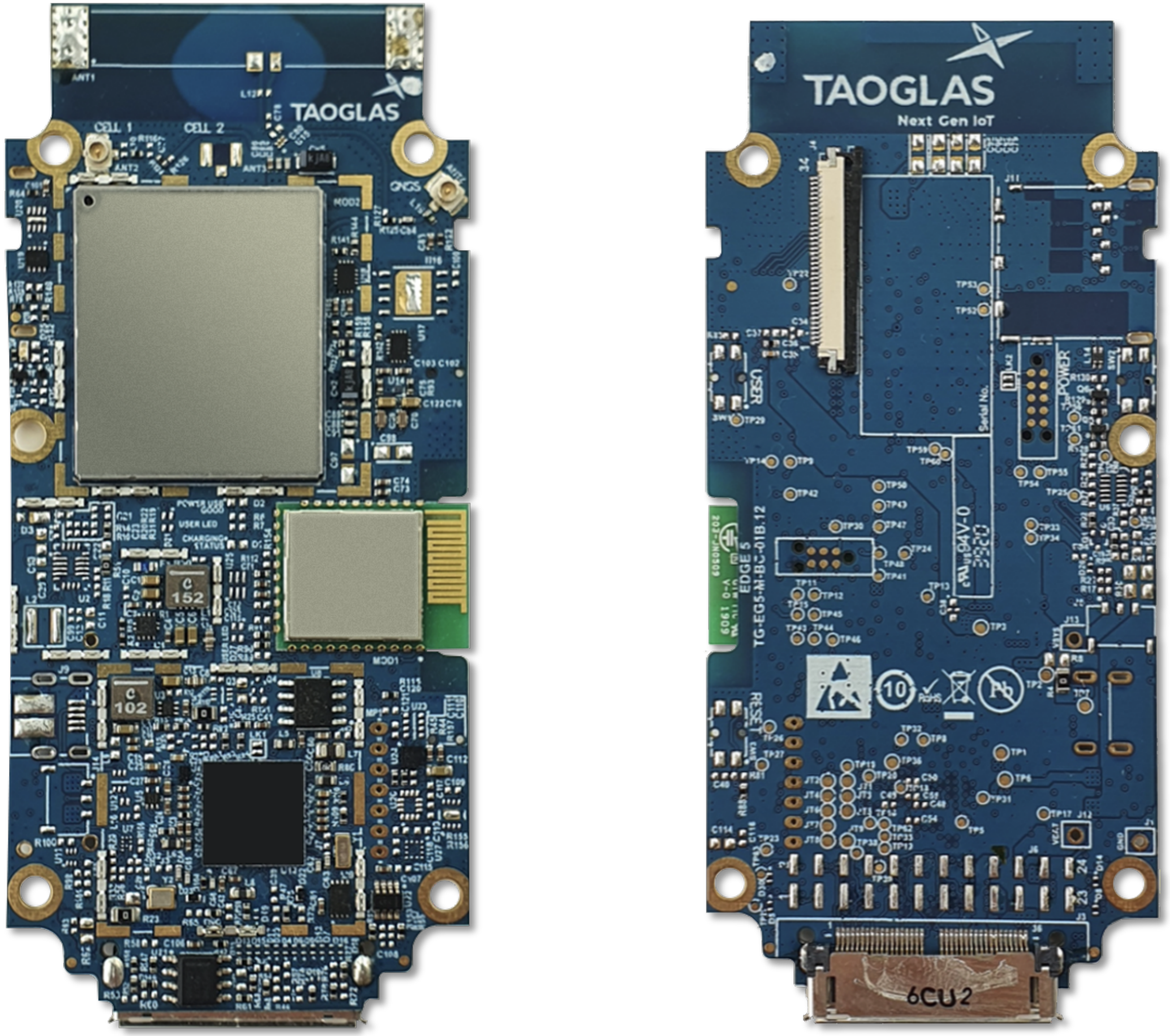
# Engineering Design – Edge Connect WSA



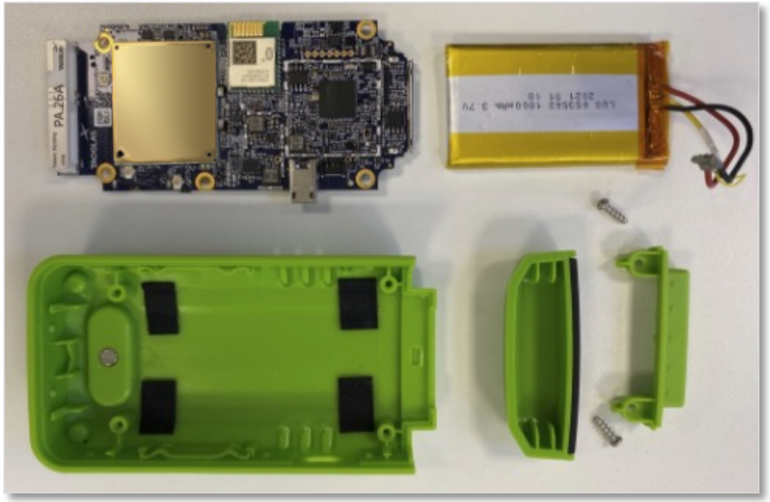

Firmware Development

- Based on existing Architecture
- Major function blocks Identified as part of EVT to meet requirements
- Preparation of command stack for Cellular and GNSS Modem
- Setup of Continuous Integration platform

# Engineering Design – Edge Connect WSA



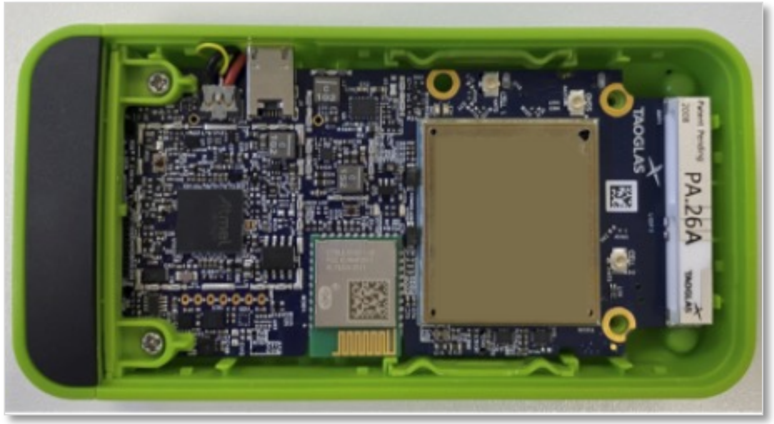
# Engineering Design – Edge Connect WSA



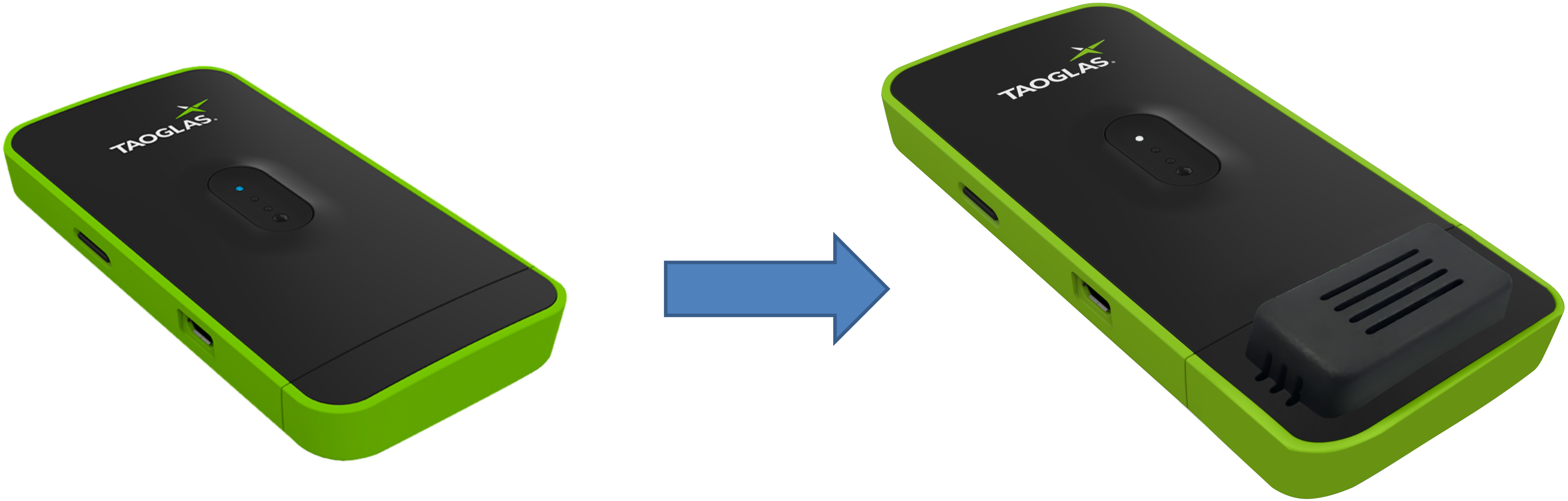
Costed down design compared to Edge 4

Same form factor and housing

Same external interface connector and pinout




# Engineering Design – Edge Connect WSA



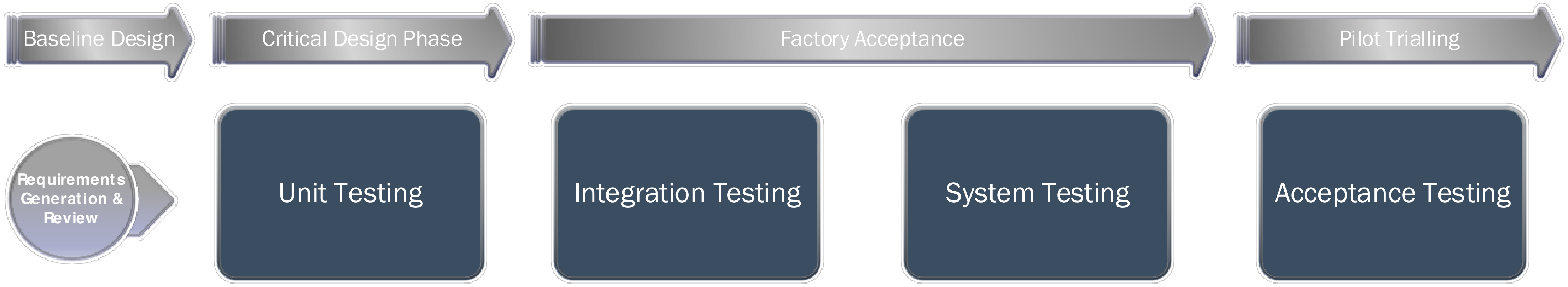

- Addition of Expansion board to Edge Connect WSA
- Adds $CO_2$ sensor, Ambient Temperature sensor, Humidity sensor and Audio sensor
- Integration into Taoglas Insights Dashboard

# Engineering Design

## Testing and Validation

# Engineering Design
## Testing and Validation

# Testing and Validation – Overall Strategy




- Unit Testing
  - Individual functions in H/W and F/W
  - Rapid prototyping of Mechanical concepts
- Integration Testing
  - Custom H/W and F/W together
  - Specification validation
  - Form and fit analysis
  - IP Rating, Shock, Thermal analysis
- System Testing
  - All-Up functional testing
  - Requirement’s verification
  - Environmental Testing (Thermal/Shock)
  - Performance analysis (GNSS, Power, Cellular)
- Acceptance Testing
  - Testing in representative environment or in representative configuration
  - Operational analysis

# Testing and Validation – Assets and Equipment

Baseline Design → Critical Design Phase → Factory Acceptance → Pilot Trialling

Requirements Generation & Review

## Unit Testing

TestLink

## Integration Testing

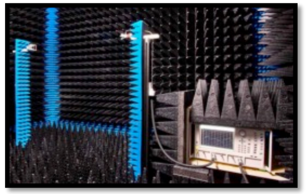
TestLink



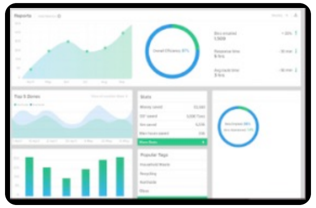
## System Testing

TestLink





## Acceptance Testing

# Engineering Design
## Edge Rugged

# Testing and Validation – Edge Rugged

## GNSS Testing

Testing was carried out in Ireland with the following scenario's considered

1. Static testing in 2 fixed locations, representing the use case of eBike parking zones, or fixed locations an asset may have been placed in

2. Dynamic test to generate a track using a vehicle similar to an eBike, or any mobile asset transiting.

3. A static test using an RTK correction service from a Base Station located >50KM from the device. We referenced this test against the test results we obtained from the RF teams static test using an RTK correction from a nearby RTK base station (<1KM)

# Testing and Validation – Edge Rugged

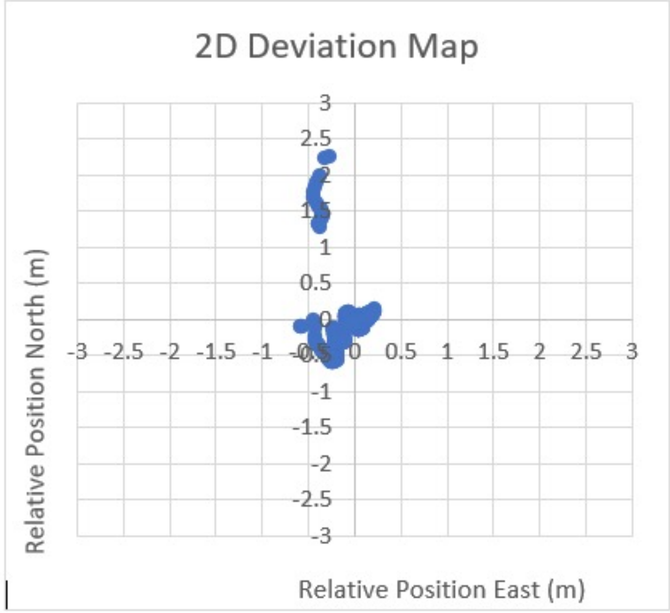
## Testing with RTK

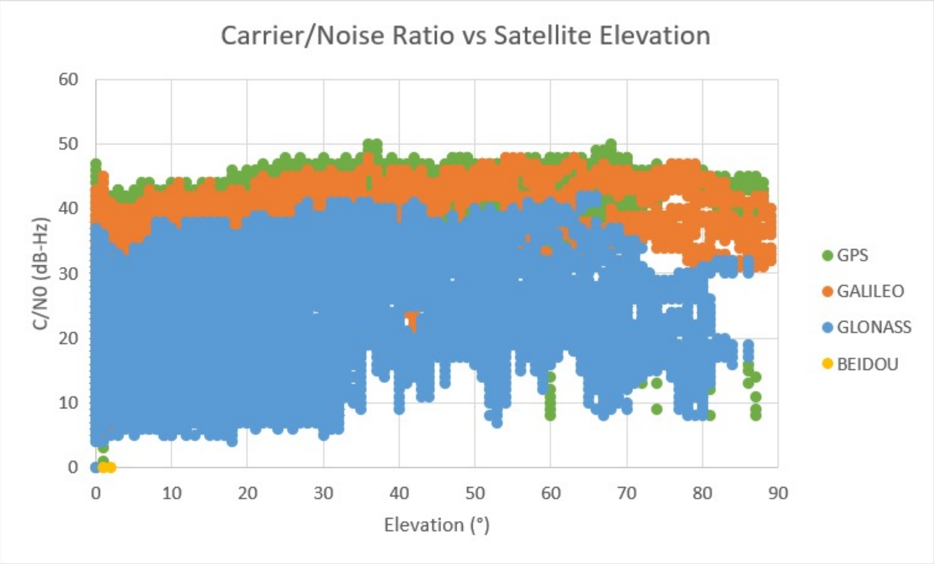
Conditions for field test:

- Open sky conditions
- Sunny
- Sapcorda [Ublox]
- 4h test

| Fix Mode | Time |
|---|---|
| A (Autonomous. Non-differential fix) | 26 s |
| D (Differential GPS Fix) | 47 s |
| F (Float) | 48 s |
| R (RTK Fixed) | 142 s |

| CEP (50%) | DRMS (68%) | 2DRMS (95%) |
|---|---|---|
| 8.5 cm | 10.33 cm | 20.67 cm |



# Testing and Validation – Edge Rugged

## Static Test #1

| Latitude (°) | Longitude (°) |
| --- | --- |
| 53.376595 | -6.270834 |

### Test Conditions

1. Weather: Overcast
2. Data polling interval: 1 second
3. Description of the location: On a windowsill on the 4th floor of an office block
4. Reference point was gathered from a point reference on Google Maps
5. How long we remained at the location: 14 minutes

| Timestamp | Elevation[m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 17-12-2021 12:15:00 | 63.099998 | 2.23 | 3 | 53.376452 | -6.270784 | 469 | 16.24309379 |
| 17-12-2021 12:15:20 | 63.2 | 2.22 | 3 | 53.376516 | -6.270756 | 67 | 10.19483109 |
| 17-12-2021 12:15:40 | 27.899999 | 2.11 | 4 | 53.376533 | -6.270824 | 46 | 6.926374201 |
| 17-12-2021 12:16:00 | 34.799999 | 1.62 | 5 | 53.376539 | -6.270816 | 32 | 6.340085974 |
| 17-12-2021 12:16:20 | 32.900001 | 1.62 | 5 | 53.376554 | -6.270806 | 12 | 4.923839158 |
| 17-12-2021 12:16:40 | 34.7 | 1.62 | 5 | 53.376552 | -6.270801 | 8 | 5.258421505 |
| 17-12-2021 12:17:00 | 40.7 | 1.62 | 5 | 53.376534 | -6.27079 | 12 | 7.384233226 |
| 17-12-2021 12:17:20 | 39.799999 | 1.62 | 5 | 53.376536 | -6.270786 | 12 | 7.292118602 |
| 17-12-2021 12:17:40 | 38.900001 | 1.62 | 5 | 53.376542 | -6.27079 | 8 | 6.575939964 |
| 17-12-2021 12:18:00 | 38 | 1.61 | 5 | 53.376548 | -6.27079 | 12 | 5.98468986 |

# Testing and Validation – Edge Rugged

## Static Test #2

| Latitude (°) | Longitude (°) |
|---|---|
| 53.27361304 | -6.329787298 |

### Test Conditions

1. Weather: Clear skies
2. Data polling interval: 1 second
3. Description of the location: At the back of a house in a housing estate close to a window.
4. Reference point was gathered from a point reference on Google Maps
5. How long we remained at the location: 3 hours

| Timestamp | Elevation[m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| 16-12-2021 14:08:00 | 63 | 1.889999 | 3 | 53.273728 | -6.33006 | 140 | 22.18603587 |
| 16-12-2021 14:09:00 | 148.5 | 2.259999 | 4 | 53.273535 | -6.329554 | 74 | 17.77497088 |
| 16-12-2021 14:10:00 | 122.199996 | 1.71 | 5 | 53.273567 | -6.32967 | 53 | 9.329778181 |
| 16-12-2021 14:11:00 | 123.599998 | 1.629999 | 7 | 53.273585 | -6.329616 | 22 | 11.80943212 |
| 16-12-2021 14:12:00 | 129.5 | 1.529999 | 8 | 53.273615 | -6.32958 | 16 | 13.78622665 |
| 16-12-2021 14:13:00 | 114.400001 | 1.529999 | 8 | 53.273631 | -6.329669 | 18 | 8.11571873 |
| 16-12-2021 14:14:00 | 108 | 1.539999 | 8 | 53.273628 | -6.329731 | 14 | 4.09654336 |
| 16-12-2021 14:15:00 | 112.900001 | 1.539999 | 8 | 53.273653 | -6.329697 | 12 | 7.470388562 |
| 16-12-2021 14:16:00 | 113.699996 | 1.539999 | 8 | 53.273646 | -6.329698 | 8 | 6.978228747 |
| 16-12-2021 14:17:00 | 115.699996 | 1.539999 | 8 | 53.273647 | -6.329686 | 12 | 7.722506546 |

# Testing and Validation – Edge Rugged

## Static Test with RTK >50KM from unit

The results in the table show that the use of RTK in this specific case is actually detrimental to the performance of the unit in terms of its location accuracy.

Note: for brevity, the number of measurements shown here is a sub-sample of the data set we gathered

| Timestamp | Elevation[m] | HDOP | Satellites | Latitude [°] | Longitude [°] | Error [m] |
|---|---|---|---|---|---|---|
| 11/04/2021 14:37 | 113 | 5.41 | 5 | 53.273543 | -6.329792 | 17 |
| 11/04/2021 14:37 | 113 | 5.41 | 5 | 53.273545 | -6.329795 | 17.2 |
| 11/04/2021 14:37 | 113 | 5.41 | 5 | 53.273545 | -6.329795 | 18 |
| 11/04/2021 14:38 | 113 | 5.41 | 5 | 53.273546 | -6.329795 | 18.6 |
| 11/04/2021 14:38 | 113 | 5.41 | 5 | 53.273546 | -6.329795 | 18.6 |
| 11/04/2021 14:38 | 113 | 5.42 | 5 | 53.273546 | -6.329795 | 19.4 |
| 11/04/2021 14:38 | 113 | 5.42 | 5 | 53.273546 | -6.329795 | 19.4 |
| 11/04/2021 14:38 | 113 | 5.42 | 5 | 53.273546 | -6.329795 | 20 |
| 11/04/2021 14:38 | 113 | 5.42 | 5 | 53.273546 | -6.329795 | 20.8 |
| 11/04/2021 14:38 | 113 | 5.42 | 5 | 53.273545 | -6.329795 | 20.8 |

# Testing and Validation – Edge Rugged

## GNSS Testing Conclusion

| Requirement | Description | Conclusion |
|---|---|---|
| Single Band L1 Testing* | | |
| PR-03-01-01: Nav Update Rate | Must support a navigation update of at least 1 Hz for real time asset theft monitoring. This is so that the asset can be tracked in real time by police who may be trying to track and monitor thieves once the asset is reported stolen.. | Completed |
| PR-03-01-02: GNSS TTFF | The GNSS TTFF must be < 45 seconds in open sky conditions (Roof test) | Completed<br><br>Referring to Tables we recorded TTFF of less than 45s |
| PR-03-01-03: GNSS Accuracy | The GNSS accuracy must be < 5 metres under open sky conditions (Roof test). | Completed<br><br>Referring to Tables we recorded an accuracy of less than 5 meters in static conditions[1] |
| Dual Band L1/L5 Testing with Edge Locate GNSS Module[2] | | |
| PR-03-02-01: Nav Update Rate | Must support a navigation update of at least 8 Hz for high precision and real time positioning. | Completed at 1Hz<br><br>The user requirements centre on static monitoring. Updates beyond 1Hz will incur additional network cost with little added value |
| PR-03-02-02: GNSS TTFF | The GNSS TTFF must be < 24 seconds in open sky conditions (Roof test). | Completed<br><br>Referring to Tables we recorded TTFF of less than 24s |
| PR-03-02-03: GNSS Accuracy | The GNSS accuracy must be < 2 metres without any ground correction service and < 20 cm with RTK-SSR and < 5 cm with RTK-OSR under open sky conditions (Roof test). | Completed<br><br>Tables show consistent accuracy of < 2 meters compared to the reference.<br><br>Table and Figure show that with correction we achieved accuracy of slightly more than 20cm with RTK<br><br>As the user requirements involve the tracking of an eBike, the requirement for 5cm accuracy was decided to be beyond the need |

# Testing and Validation – Edge Rugged

## GNSS Testing Conclusion

- We concluded the GNSS performance of the Edge Rugged is meeting the customer requirement for positioning accuracy.
- We noted that the GNSS module in an open-sky condition was able to achieved accuracy in the 0.2m range

### Effect of Base station location for RTK correction services

- We also noted that RTK corrections work well for instances where a base station is operating in close proximity to the device, but where the RTK station is a large distance from the device, it negatively impacts the location performance.

# Testing and Validation – Edge Rugged / Edge Micro SOM

## Testing with Patch Antenna

- The ADFGP.25E from Taoglas was used as the internal GNSS antenna.
- The antenna is Right-Hand Circular Polarised.
- This was an additional test/investigation that surfaced during general GNSS testing as a potential way to increase location performance for minimal additional cost


# Testing and Validation – Edge Rugged

**Static Field Test with Patch Antenna**

Conditions:

- Open sky conditions
- Sunny
- No corrections service
- 4h test

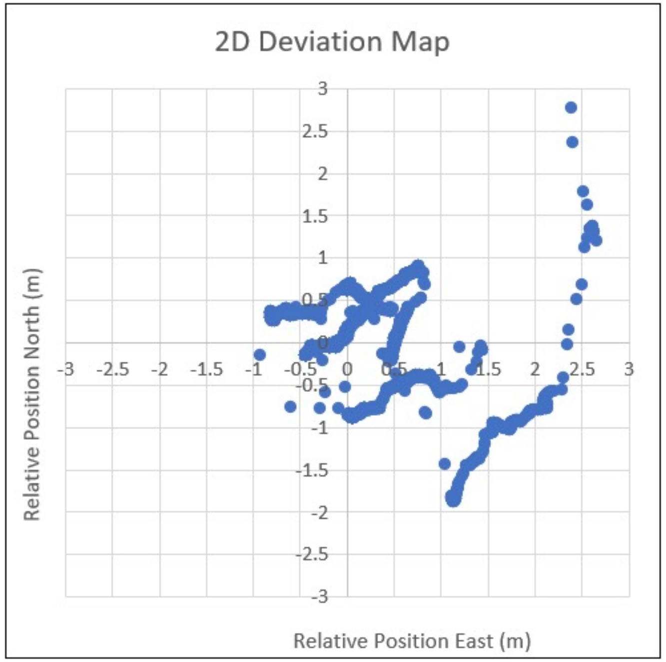
| Fix Mode | Time |
|---|---|
| A (Autonomous. Non-differential fix) | 16 s |
| D (Differential GPS Fix) | 24 s |

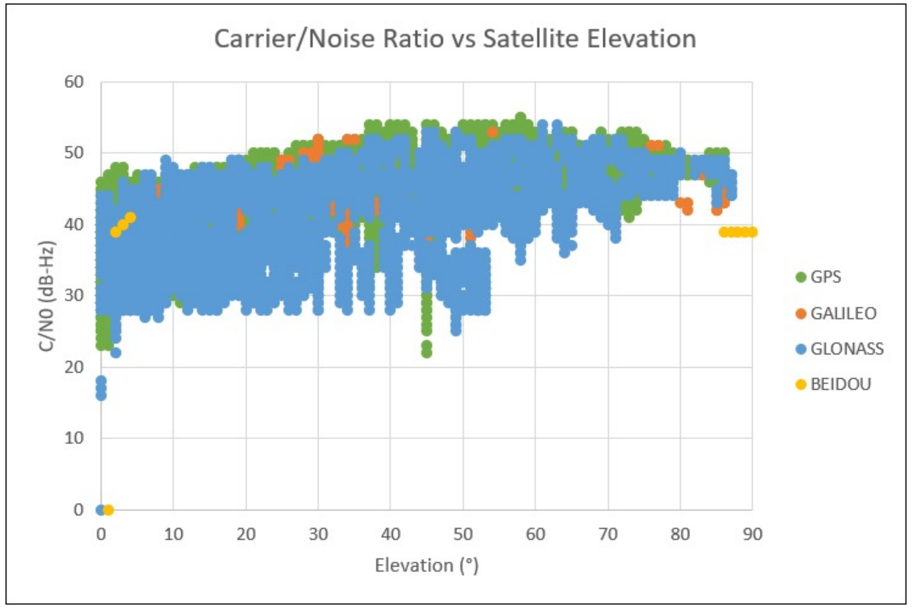
| CEP (50%) | DRMS (68%) | 2DRMS (95%) |
|---|---|---|
| 70.55 cm | 84.48 cm | 168.97 cm |

**Conclusion**

Our testing showed that this Antenna improved device performance for limited extra cost.

It will be included in our Product offering

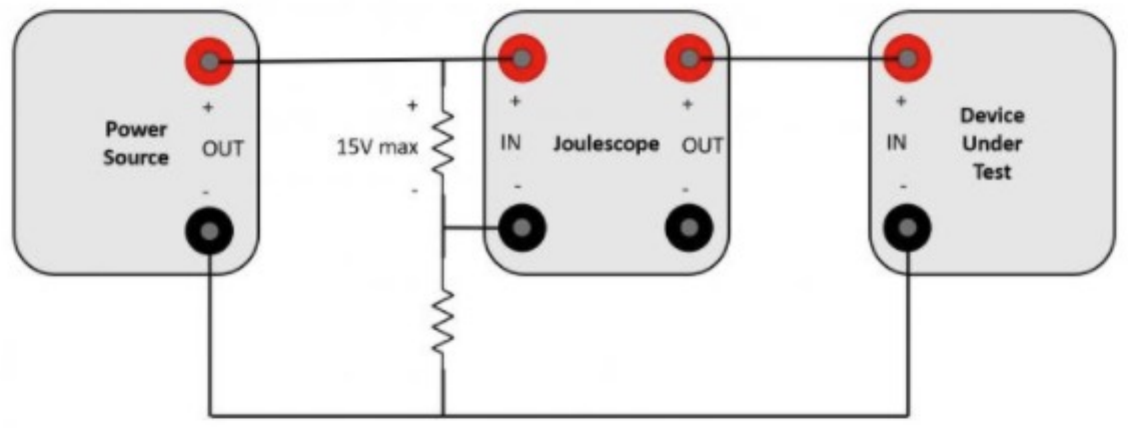


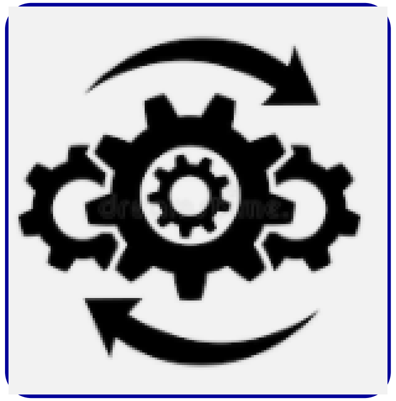
# Testing and Validation – Edge Rugged / Edge Micro SOM

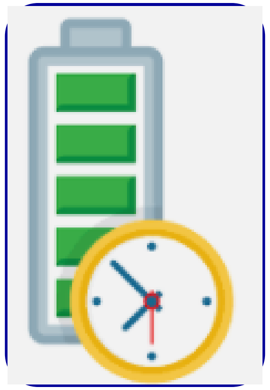
## Power Profiling

- This section provides results for the Edge Rugged and Edge Micro SOM for Cellular and WiFi connectivity.
- The power cycle of a test device consisted of
  - One active state a day with the rest of the time in sleep mode,
  - Continuous active state without entering sleep mode.
- Power measured with Joulescope.
  - Details can be found in the document titled "*Edge Rugged DVT Hardware Verification Report*" submitted for Factory Acceptance (MS3).



# Testing and Validation – Edge Rugged / Edge Micro SOM





Cycle the unit through its modes of operation

Measure the power consumed by the device

Use the power consumption values to determine the appropriate battery for a customer requirement

# Testing and Validation – Edge Rugged / Edge Micro SOM

| Marker | Mode | Power/Current draw |
|---|---|---|
| Green | Powerup, Wi-Fi not connected yet | 61mA, 1.67A peak for 250us |
| Blue | Connected to internet via Wi-Fi | 32mA average<br>421mA peak |
| Purple | Wi-Fi sending data, GNSS active | 86mA average |
| Teal | Modem idle, GNSS trying to reach the fix | 60mA average |
| Orange | Sleep mode | 6.31mA average, 75mW power consumption |
| Gray | Wi-Fi and GNSS Power down | 25mA average |
| High Power States | High Power modes | 59mA average over 140s 718mW power consumption |

This graph above was obtained from the Joulescope and records the power consumed by the device for modes of operation listed in the table

Our validation report for MS3 includes graphs and analysis for all modes

# Testing and Validation – Edge Rugged / Edge Micro SOM

| EDGE Rugged and Micro Power Profiling Test - Battery powered, Cellular network | | | |
|---|---|---|---|
| 1 attempt to connect to the cloud a day | | Continuous active state, no sleep mode | |
| Power (mW) active | 578,00 | Power (mW) active | 578,00 |
| Power (mW) sleep | 0,18 | Power (mW) sleep | 0,18 |
| Time active (seconds) | 140,00 | Time active (seconds) | 86400,00 |
| Time sleep (seconds) | 86260,00 | Time sleep (seconds) | 0,00 |
| Time active (hours) | 0,04 | Time active (hours) | 24,00 |
| Time sleep (hours) | 23,96 | Time sleep (hours) | 0,00 |
| Energy (mWh) active | 22,48 | Energy (mWh) active | 13872,00 |
| Energy (mWh) sleep | 4,38 | Energy (mWh) sleep | 0,00 |
| Energy per day (mWh) total | 26,86 | Energy per day (mWh) total | 13872,00 |
| Energy (mWh) in battery | 3885,00 | Energy (mWh) in battery | 3885,00 |
| Total days operation | 144,62 | Total days operation | 0,28 |

| EDGE Rugged and Micro Power Profiling Test - Battery powered, Wi-Fi | | | |
|---|---|---|---|
| 1 attempt to connect to the cloud a day | | Connection always active, no sleep mode | |
| Power (mW) active | 595,00 | Power (mW) active | 595,00 |
| Power (mW) sleep | 0,18 | Power (mW) sleep | 0,18 |
| Time active (seconds) | 82,00 | Time active (seconds) | 86400,00 |
| Time sleep (seconds) | 86318,00 | Time sleep (seconds) | 0,00 |
| Time active (hours) | 0,02 | Time active (hours) | 24,00 |
| Time sleep (hours) | 23,98 | Time sleep (hours) | 0,00 |
| Energy (mWh) active | 13,55 | Energy (mWh) active | 14280,00 |
| Energy (mWh) sleep | 4,39 | Energy (mWh) sleep | 0,00 |
| Energy per day (mWh) total | 17,94 | Energy per day (mWh) total | 14280,00 |
| Energy (mWh) in battery | 3885,00 | Energy (mWh) in battery | 3885,00 |
| Total days operation | 216,55 | Total days operation | 0,27 |

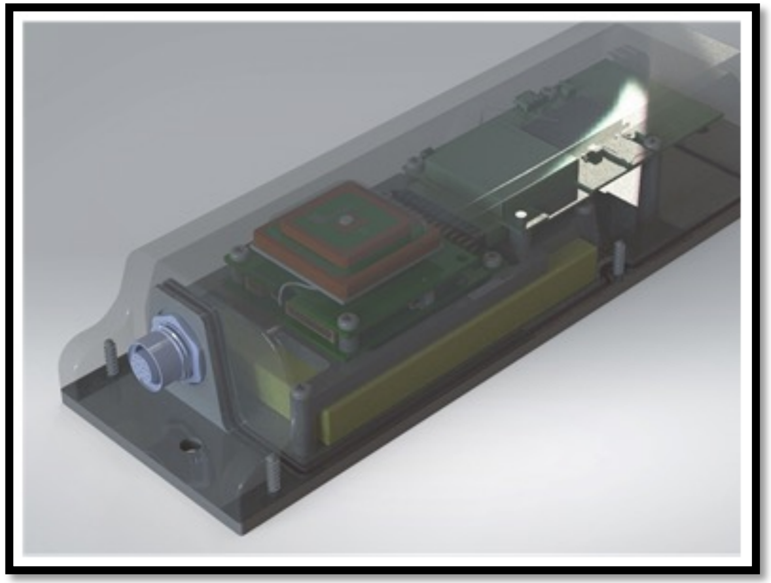
# Testing and Validation – Edge Rugged

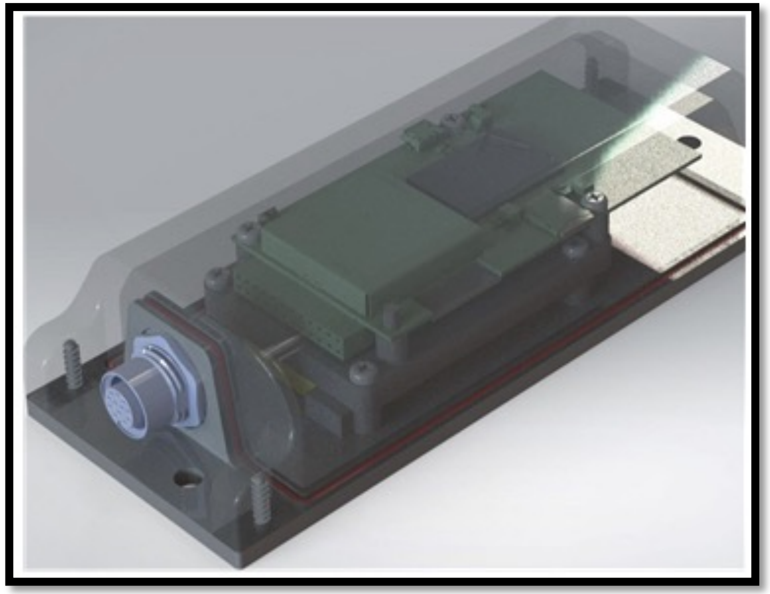
## Power Profiling conclusion

From the power measurements obtained, we are able to infer the battery size required for a given user requirement.

To support this, the mechanical design of the housing includes a capability to support batteries of different sizes and capacities. The enclosure can accept a battery size up to 10000mAHr.

Figure here shows a render of the device with two different battery sizes





# Testing and Validation – Edge Rugged / Industrial Gateway

## Vibration Testing

The purpose of Vibration testing was to determine how mechanically robust the device is when subjected to vibrations and shock of differing magnitude and duration.

The vibration testing was followed by an examination of the device to determine if there was any indication of damage to the unit.

Image of the Electrodynamic exciter TIRA vib used for this testing


Image of the Edge Rugged with communications cable attached to the unit. The top cover is off to show the internal connections.

# Testing and Validation – Edge Rugged / Industrial Gateway

## Vibration Testing

In addition, the unit was operating in a continuous self-test mode through the test cycle and was fixed to a test table via fasteners attached through its mounting points

## Vibration Test list

| Test | Displacement (mm) | Maximum **Acceleration (g)** | Start Freq (Hz) | Stop Freq (Hz) | Duration | Iterations | Axis |
|---|---|---|---|---|---|---|---|
| VT1 | (Sinusoidal )15 | 5 | 5 | 500 | 15 min | 3 | X,Y,Z |
| VT2 | (Shock) | 18 | | | 6 ms | 3 | X,Y,Z |

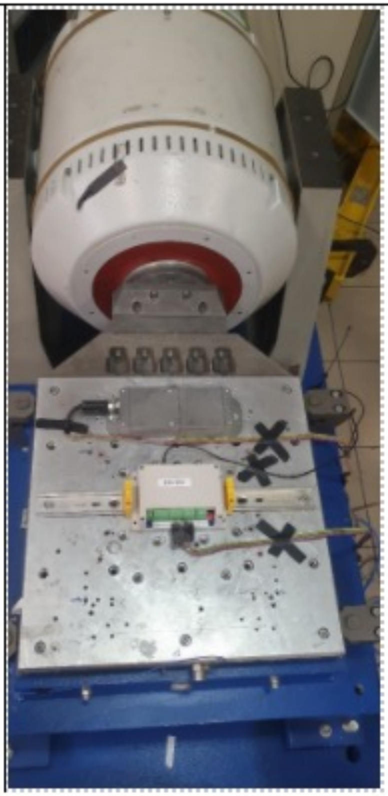


Photo of the Exciter connected to a test bed with the Industrial Gateway mounted on a DIN rail in its X and Y- axis test configuration

Photo of the Exciter connected to a test bed with the Industrial Gateway mounted on a DIN rail in its Z-Axis test configuration

# Testing and Validation – Edge Rugged / Industrial Gateway

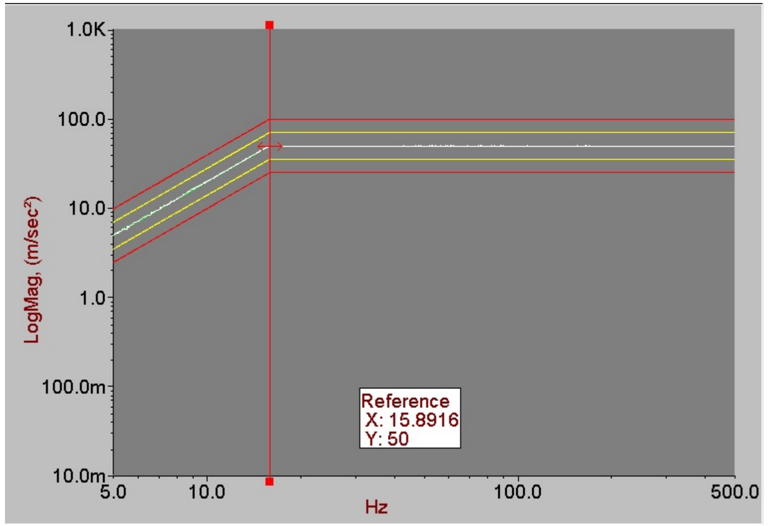
Test 1, VT1

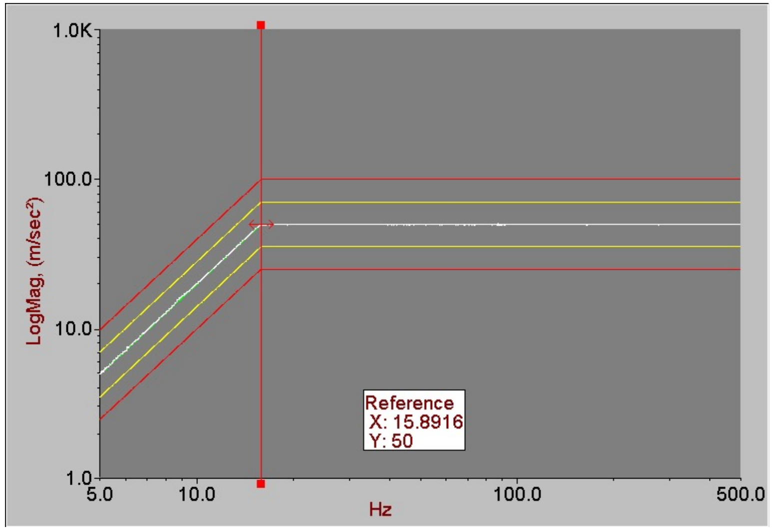
For this test, the device was subject to a sinusoidal displacement of 15mm with acceleration up to 5g.

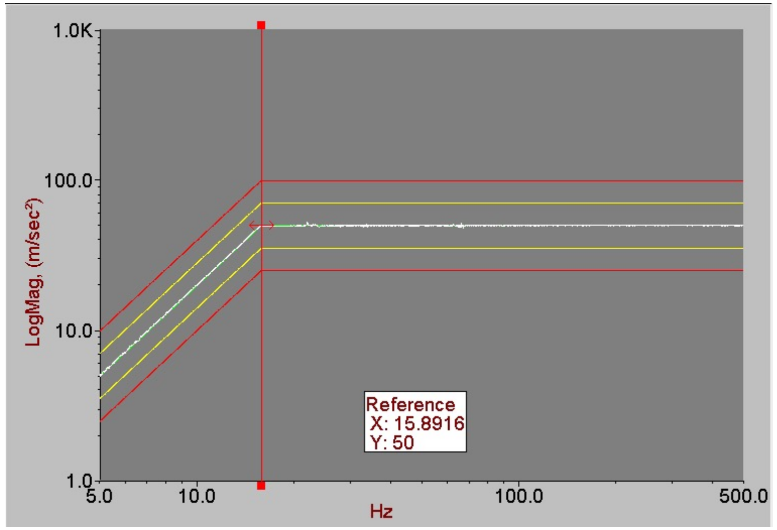
Starting frequency from 5Hz up to 500Hz and back to 5Hz.

Test duration was approx. 15 minutes.

Repeated three times, once for each of axis X,Y,Z.



# Testing and Validation – Edge Rugged / Industrial Gateway

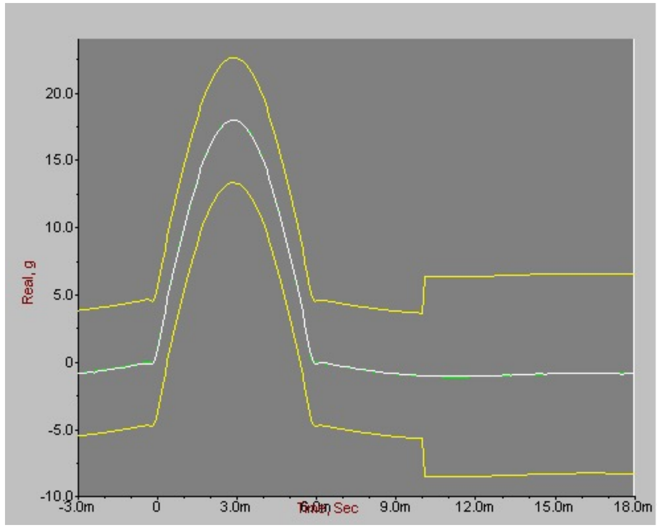
## Test 1, VT2

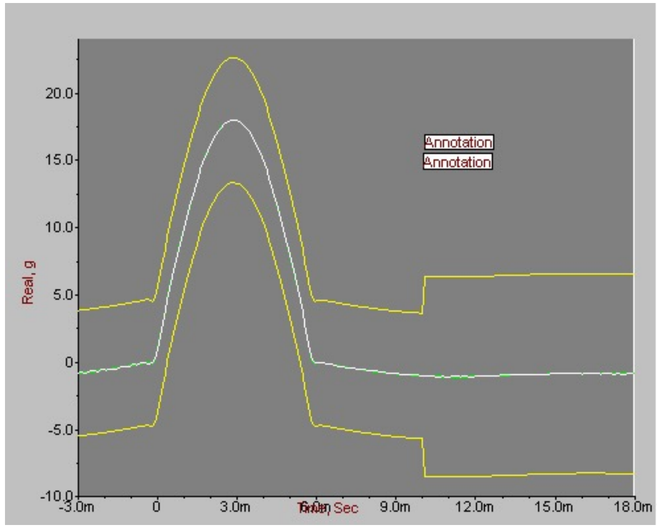
Shock (impact) was applied to the unit with a pulse acceleration of 18g for a 6ms duration.

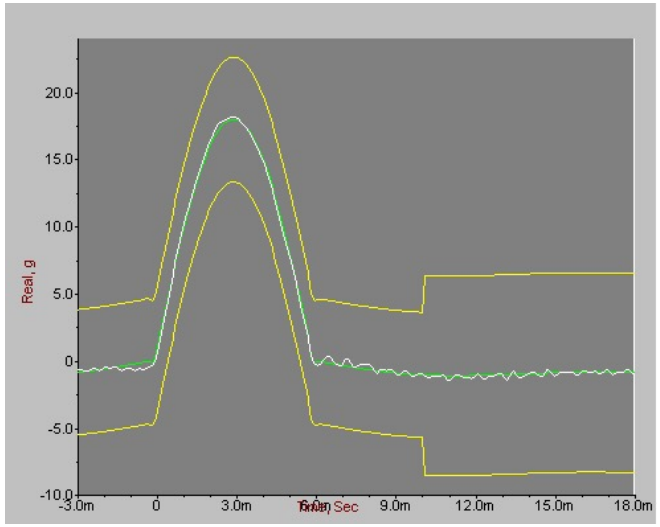
In total 500 shock pulses were applied to the unit during the test.

Total test time was about 10 minutes.

Executed three times, once per each axis



# Testing and Validation – Edge Rugged

## Post-test Checking

The following tables detail the checks carried out on the units after testing was completed.

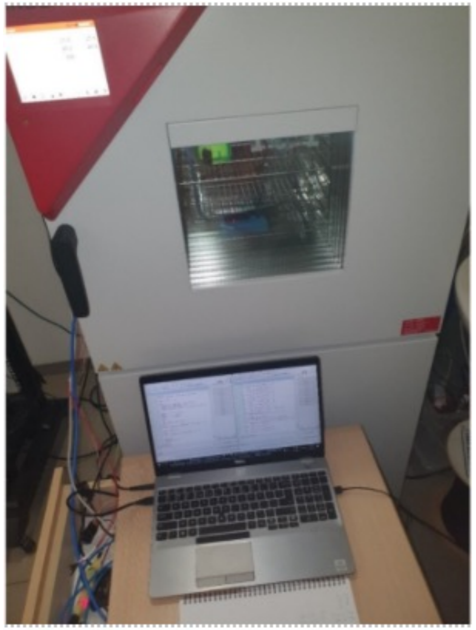
| Item | Test description | Method | Feedback | Status |
|---|---|---|---|---|
| 1 | Verify internal Electronic mounting points are not damaged | Manual assembly and feedback | Mounting points are correct for the PCB's and have not been damaged during testing | Pass |
| 2 | I/O connector cable management<br>Verify there has been no internal movement of the internal cables | Check cabling from I/O connector to the interconnect PCB | Cabling in place with no sign of strain or damage to cables or components near cables | Pass |
| 3 | Battery placement<br>Verify that the battery stayed in place and does not exhibit any surface damage or physical strain | Check battery location for evidence of movement.<br>Inspect battery to determine if there is any physical | Battery location verified as being secure with no movement detected.<br>Battery physically checked and no physical damage was observed | Pass |
| 4 | PCBA stress<br>Verify there was no strain on the PCBA's inside the unit following testing | Validate that the PCBA's did not experiencing stresses and the tolerance in the mech design prevented any stresses from damaging the PCBA's | Manual assembly checks on the unit validated that the PCB's were not bent or under stress and were securely mounted. | Pass |
| 5 | Sealing surface detailing<br>Verify sealing surface was not damaged during testing | Verify that the sealing surface has no damage | Sealing surface was visually checked, but as the DVT is a form of 3D print the surface finish is not at the standard we will get with tooled plastics.<br>It was verified that the sealing surface showed no visible damage | Pass |

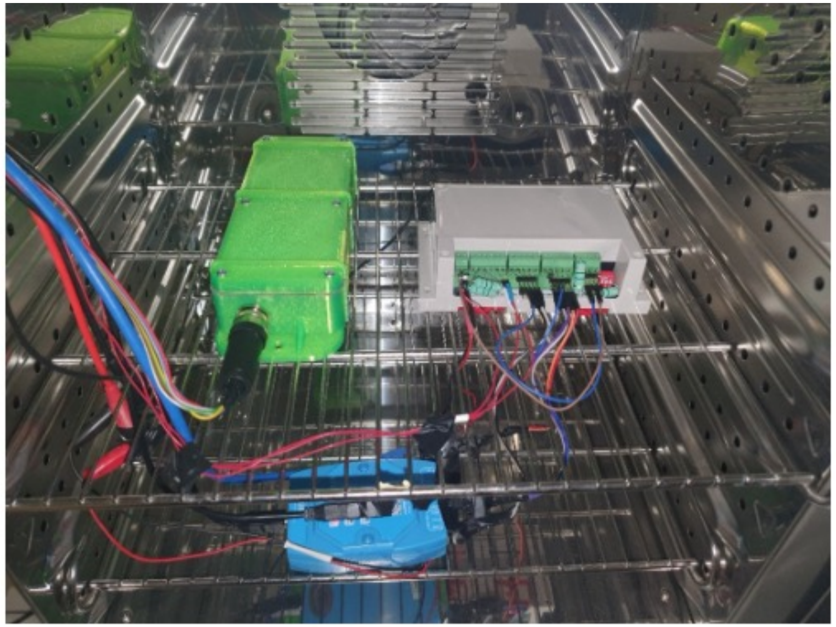
# Testing and Validation – Edge Rugged

## Thermal Testing

As part of DVT testing, climate chamber temperature and humidity cycling was performed on an operating unit.

The setup for these tests, and the list of functions on the DUT that would be tested are discussed here

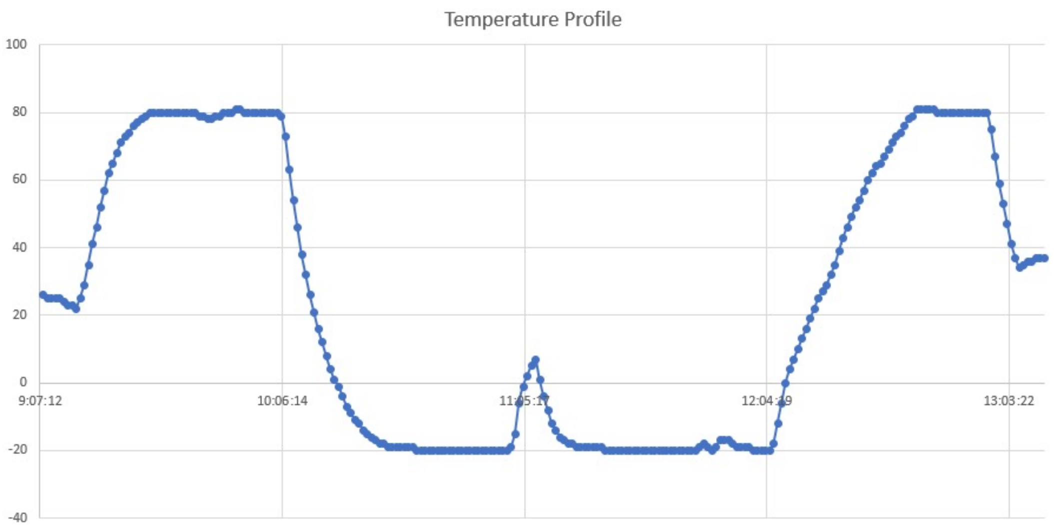


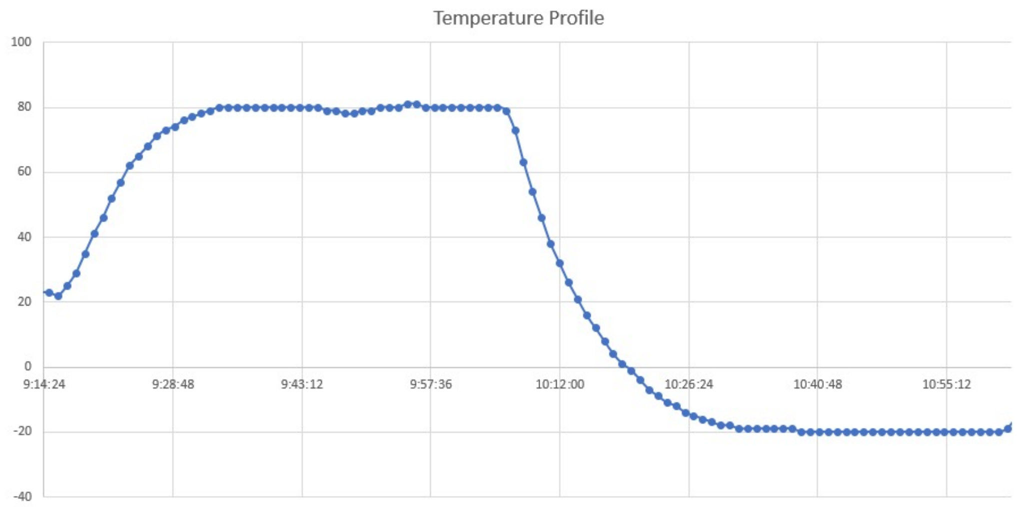


| Climate chamber test setup | |
|---|---|
| **Climate Chamber** | Binder, MK 56, 60 litre dynamic climate chamber |
| **Power supply** | External PSU 8V@2A connected to VIN |
| **Current Measurement** | JouleScope on VIN |
| **Communications and Telemetry** | USB-UART converter for logs<br>USB-RS485 converter |
| **Device Under Test** | Edge Rugged consisting of<br>1.Edge Micro SOM board-TGEGµMWBC02A10<br>2.Interconnect board-TGEGuI03A1<br>3.Centimeter Level GNSS board: FWEG4S01B1<br>4.LiPo battery LUS053562(1000mAh)<br>5.External 8pin connector with 1.5m cable<br>6.3D printed PETG enclosure |

| Climate chamber test list | |
|---|---|
| **Processor and Communications** | ESP32 MCU including file system verification<br>Nordic BLE module<br>PLS63 modem test<br>SIM card test<br>Antenna test (network providers listing)<br>Internal GNSS test (NMEA frames only, no positioning fix test) |
| **Industrial Communications (Wired)** | RS485 communication |
| **Sensor devices** | Accelerometer Testing (LISDH12) |

# Testing and Validation – Edge Rugged




## Test recording

For each two temperature cycling tests, specifically cycling over time and rapid cycling, the device was operating in a test loop running an internal test routine.

## Test conclusion

The test firmware implemented a continuous loop so after each test list the MCU was reset, and tests were repeated.

During the entire test period no resets, hangs or tests fails was observed on the unit.

For operation in environments that are not climate controlled, the PCBs should be conformally coated to prevent condensation from affecting the operation of the device.

# Engineering Design

## Industrial Gateway

# Testing and Validation – Industrial Gateway

## GNSS Testing

Testing was carried out in Ireland with the following scenario's considered

1. Static testing in 2 fixed locations, representing the use case of monitoring assets places in fixed locations

2. Dynamic test to generate a track using a vehicle similar to an eBike, or any mobile asset transiting.

# Testing and Validation – Industrial Gateway

## Roof Test

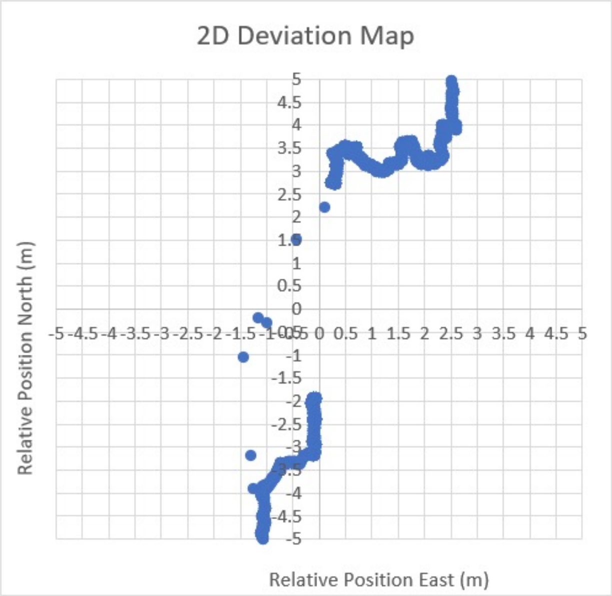
This test was carried out by the RF team with the device located on the roof of the Taoglas offices in DCU Alpha in Dublin.

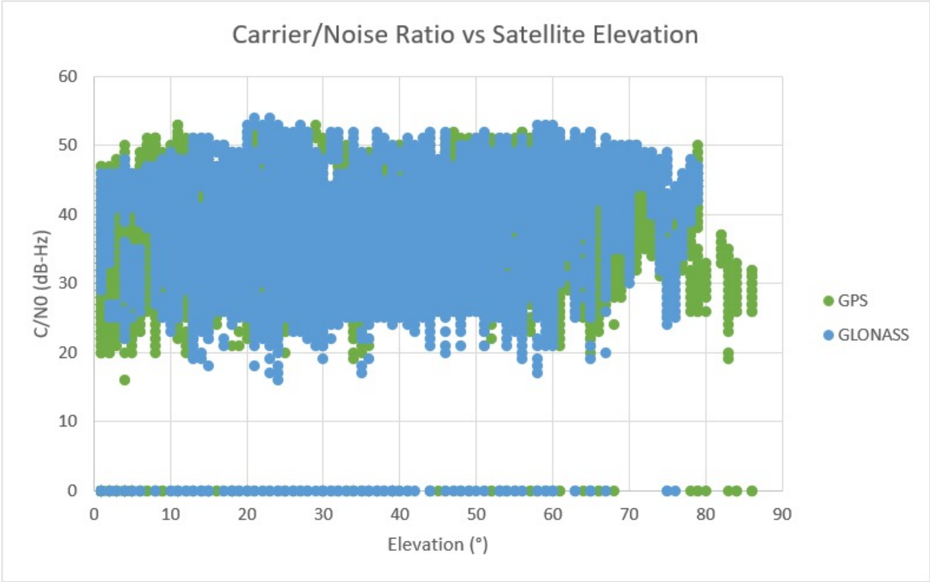
### Test Conditions

- Open sky conditions
- Sunny
- No corrections service
- 4h test

| Fix Mode | Time (TTFF) |
|---|---|
| A (Autonomous. Non-differential fix) | 18s |

| CEP (50%) | DRMS (68%) | 2DRMS (95%) |
|---|---|---|
| 222.31 cm | 287.38 cm | 574.75 cm |



# Testing and Validation – Industrial Gateway

## Static Test #1

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| **36** | 176.368 | 54.37464969 | 18.51759310 |

### Test conditions

1. Weather: Passing clouds, windy, foggy
2. Data polling interval: 3 minutes
3. Location: Shopping centre car park
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 1 hour

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| **16-12-2021 10:23** | **89.900001** | **2.599999** | **3** | **54.374255** | **18.518184** | **56** | **58,2313338** |
| **16-12-2021 10:26** | 62.000000 | 2.599999 | 3 | 54.374427 | 18.518449 | 12 | 60,7149641 |
| **16-12-2021 10:29** | 51.000000 | 2.599999 | 3 | 54.374099 | 18.518544 | 12 | 86,8495586 |
| **16-12-2021 10:32** | 124.000000 | 1.299999 | 3 | 54.374694 | 18.518080 | 12 | 31,9185969 |
| **16-12-2021 10:35** | 161.300003 | 1.000000 | 3 | 54.374792 | 18.517521 | 12 | 16,4985421 |
| **16-12-2021 10:38** | 153.800003 | 1.200000 | 2 | 54.374635 | 18.517578 | 8 | 1,90344681 |
| **16-12-2021 10:41** | 161.699996 | 1.100000 | 3 | 54.374688 | 18.517252 | 12 | 22,4996656 |
| **16-12-2021 10:44** | 159.600006 | 1.100000 | 3 | 54.374698 | 18.517276 | 12 | 21,2290271 |
| **16-12-2021 10:47** | 158.699996 | 1.100000 | 3 | 54.374710 | 18.517290 | 8 | 20,7454806 |
| **16-12-2021 10:50** | 156.399993 | 1.299999 | 2 | 54.374670 | 18.517335 | 12 | 16,8685893 |

# Testing and Validation – Industrial Gateway

## Static Test #2

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| 38 | 108.262 | 54.34071840 | 18.58212519 |

### Test conditions

1. Weather: Passing clouds
2. Data polling interval: 3 minutes
3. Location: parking on the street with open sky, no buildings i.e.
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 50 minutes

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| **16-12-2021 12:46** | 64.800003 | 1.700000 | 5 | 54.340844 | 18.582175 | 38 | 14,3342869 |
| **16-12-2021 12:48** | 63.799999 | 1.799999 | 5 | 54.340851 | 18.582103 | 10 | 14,81447 |
| **16-12-2021 12:51** | 62.200000 | 1.600000 | 5 | 54.340851 | 18.582102 | 6 | 14,8208565 |
| **16-12-2021 12:54** | 63.200000 | 1.700000 | 5 | 54.340865 | 18.582109 | 10 | 16,3349416 |
| **16-12-2021 12:57** | 65.400001 | 1.799999 | 5 | 54.340848 | 18.582142 | 10 | 14,4520089 |
| **16-12-2021 13:00** | 64.500000 | 1.799999 | 5 | 54.340841 | 18.582129 | 6 | 13,6343747 |
| **16-12-2021 13:03** | 64.000000 | 1.899999 | 5 | 54.340825 | 18.582113 | 10 | 11,8798164 |
| **16-12-2021 13:06** | 65.099998 | 1.899999 | 5 | 54.340799 | 18.582107 | 10 | 9,03981465 |
| **16-12-2021 13:09** | 66.400001 | 2.000000 | 5 | 54.340781 | 18.582114 | 10 | 6,99821909 |
| **16-12-2021 12:46** | 64.800003 | 1.700000 | 5 | 54.340844 | 18.582175 | 38 | 14,3342869 |

# Testing and Validation – Industrial Gateway

## GNSS Testing Conclusion

| Requirement | Description | Conclusion |
|---|---|---|
| **PR-04-01-01: Nav Update Rate** | Must support a navigation update of at least 1 Hz for real time asset theft monitoring. | Completed |
| **PR-04-01-02: GNSS TTFF** | The GNSS TTFF must be < 45 seconds in open sky conditions (Roof test) | Completed<br>Referring to Table 36, 38 & 39, we recorded TTFF of less than 45s for all measurements except 1.<br>The spread of TTFF timings show a minimum of<br>6s and a maximum of 56s which proved to an outlier. |
| **PR-04-01-03: GNSS Accuracy** | The GNSS accuracy must be < 5 metres under open sky conditions (Roof test). | Completed<br>This was achieved in open-sky testing, referring to Table 40, the device was measure to have a location error of ~0.574m<br>In other static testing the results did vary depending on the number of satellites seen by the device.<br>We noted a minimum of 4, preferably 5 would achieve this KPI in static locations |

# Testing and Validation – Industrial Gateway

## GNSS Testing Conclusion

The conclusions we have reached is that the device is meeting the customer requirement for positioning accuracy.

We spoke to the RF Team about the placement of the Antennas with the SMA connector mounted to the PCB and it was found that this was a better position than on the original device as it improved RF efficiency.

### Issue with Second Supplier Modem

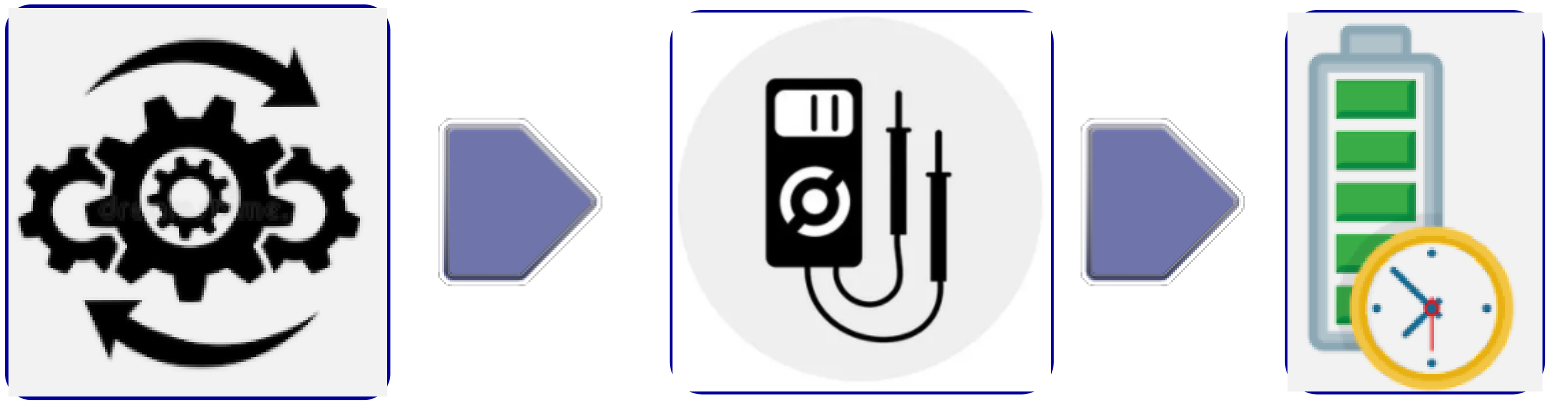
One discovery that was surprising was that one of the two Modems we are using on the devices cannot run GNSS and Cellular in parallel.

Specifically, the device must be configured for either GNSS or Cellular. This cost us several days of delay to discover as we initially thought our hardware might have been faulty.

In practice, this means that the Industrial Gateway will need to operate with a specific version of the modem to enable Cellular and GNSS functionality.

# Testing and Validation – Industrial Gateway

## Power Profiling – same process as Edge Rugged



Cycle the unit through its modes of operation

Measure the power consumed by the device

Use the power consumption values to determine the appropriate battery for a customer requirement

# Testing and Validation – Industrial Gateway

## Power Profiling Test Results

| 1 attempt to connect to the cloud a day | | 3 attempts to connect to the cloud a day | |
|---|---|---|---|
| Power mW active | 525,84 | Power mW active | 525,84 |
| Power mW sleep | 3,77 | Power mW sleep | 3,77 |
| Time active (seconds) | 195,00 | Time active (seconds) | 585,00 |
| Time sleep (seconds) | 86205,00 | Time sleep (seconds) | 85815,00 |
| Time active (hours) | 0,05 | Time active (hours) | 0,16 |
| Time sleep (hours) | 23,95 | Time sleep (hours) | 23,84 |
| Energy (mWh) active | 28,48 | Energy (mWh) active | 85,45 |
| Energy (mWh) sleep | 90,25 | Energy (mWh) sleep | 89,85 |
| Energy per day (mWh) total | 118,74 | Energy per day (mWh) total | 175,29 |
| Energy (mWh) in battery | 14800,00 | Energy (mWh) in battery | 14800,00 |
| **Total days operation** | **124,64** | **Total days operation** | **84,43** |

*Assume 4000mAHr Battery for these numbers*

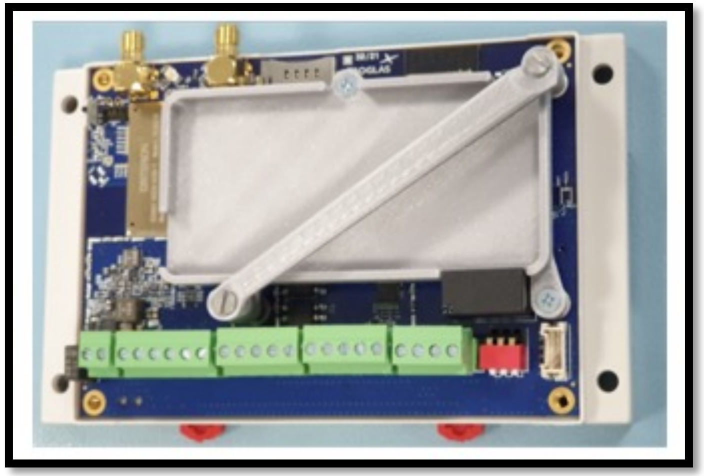
# Testing and Validation – Industrial Gateway

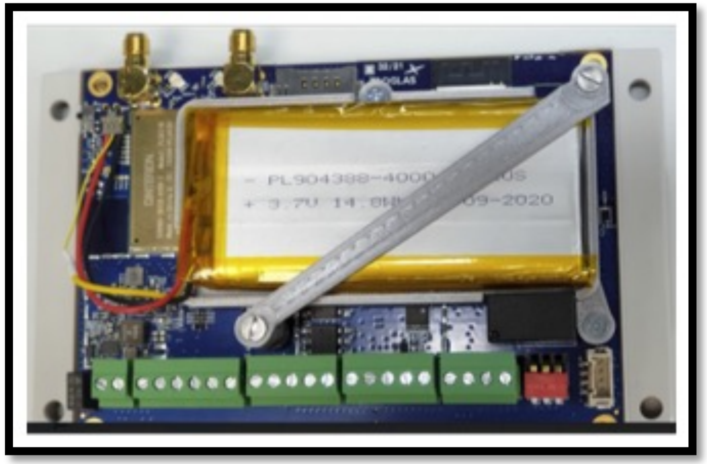
## Power Profiling Conclusion

From the power measurements obtained, we are able to infer the battery size required for a given user requirement.

To support this, the mechanical design of the housing includes a capability to support batteries of different sizes and capacities.

The main PCB was fitted with soldered standoffs that hold a battery cradle. This cradle can be sized to fit a specific battery size. This is illustrated in the photo



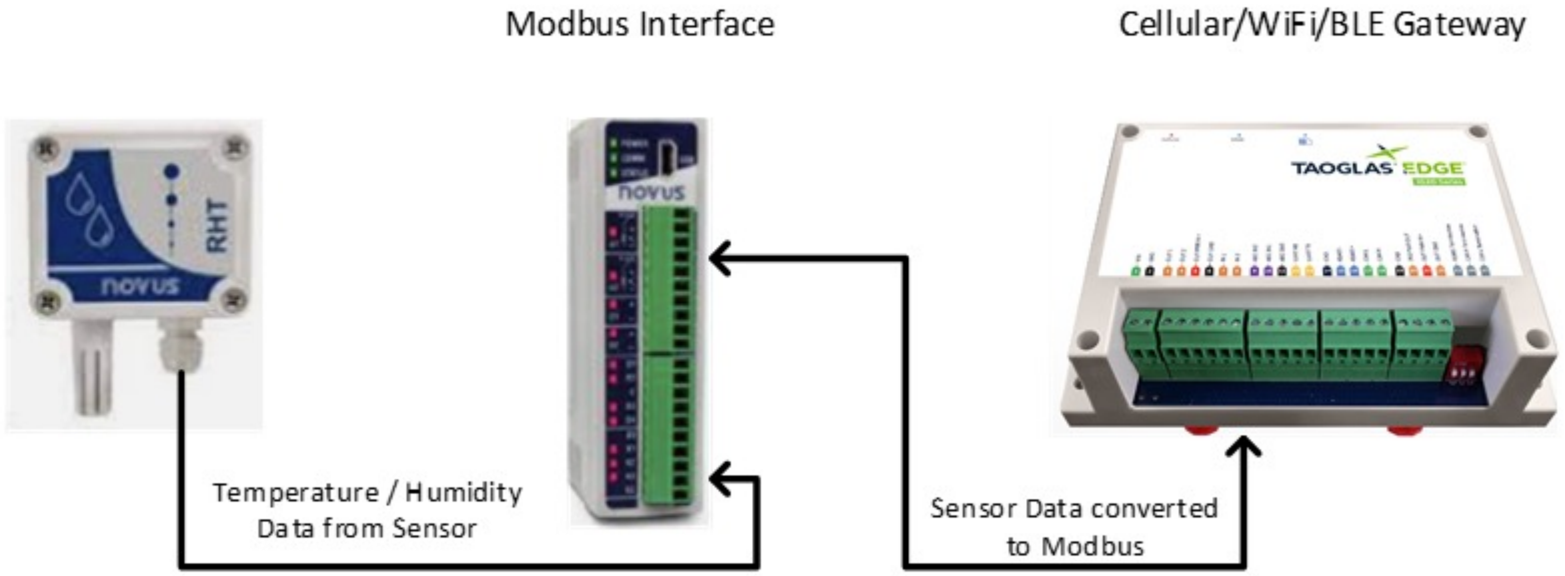


# Testing and Validation – Industrial Gateway

## Modbus Testing

Device was configured to read data from both Novus devices and send this data to the cloud.

The information from the Novus devices was Temperature and Humidity.



# Testing and Validation – Industrial Gateway

## Modbus Test #1

### Test conditions

1. The device was located ~3m from a window
2. Limited Sky View
3. Upload interval: Set to 85 minutes
4. Test Duration: 4.5 hours

| Modbus Data – Temperature Sensor (°C) | | |
|---|---|---|
| Timestamp | Digirail input 1 – temp (°C) | Interval (s) |
| 1.6391E+12 | 23 | 00:02:19.0 |
| 1.6391E+12 | 25 | 00:00:15.0 |
| 1.6391E+12 | 24 | 00:00:31.0 |
| 1.6391E+12 | 23 | 00:19:38.0 |
| 1.6391E+12 | 23 | 00:03:18.0 |
| 1.6391E+12 | 23 | 00:05:17.0 |
| 1.6391E+12 | 24 | 00:00:16.0 |
| 1.6391E+12 | 23 | 00:07:06.0 |
| 1.6391E+12 | 22 | 00:02:02.0 |
| 1.6391E+12 | 22 | 00:40:16.0 |
| 1.6391E+12 | 22 | 00:00:17.0 |
| 1.6391E+12 | 22 | 00:04:48.0 |
| 1.6391E+12 | 21 | 00:08:18.0 |
| 1.6391E+12 | 21 | 00:05:49.0 |
| 1.6391E+12 | 21 | 00:48:26.0 |
| 1.6391E+12 | 20 | |

| Modbus Data – Humidity Sensor (%) | | |
|---|---|---|
| Timestamp | Digirail input 2 – humidity (%) | Interval (s) |
| 1.6391E+12 | 45 | 00:00:32.0 |
| 1.6391E+12 | 47 | 00:00:15.0 |
| 1.6391E+12 | 48 | 00:00:16.0 |
| 1.6391E+12 | 45 | 00:01:00.0 |
| 1.6391E+12 | 46 | 00:00:16.0 |
| 1.6391E+12 | 94 | 00:00:15.0 |
| 1.6391E+12 | 95 | 00:00:16.0 |
| 1.6391E+12 | 94 | 00:00:15.0 |
| 1.6391E+12 | 87 | 00:00:16.0 |
| 1.6391E+12 | 66 | 00:00:15.0 |
| 1.6391E+12 | 54 | 00:00:16.0 |
| 1.6391E+12 | 51 | 00:00:15.0 |
| 1.6391E+12 | 49 | 00:00:31.0 |
| 1.6391E+12 | 48 | 00:00:16.0 |
| 1.6391E+12 | 47 | 00:00:15.0 |
| 1.6391E+12 | 46 | 00:00:16.0 |

# Testing and Validation – Industrial Gateway

## Modbus Conclusions

- Industrial Gateway can operate with the Novus Digirail Modbus interface and successfully transfer data to the cloud.

- We noted that there were drop outs of data and the sampling interval was not always met.

- However, during this testing we had the External Cellular Antenna mounted directly on the unit.

- As the use of an extension cable has been the normal configuration for all Gateways that we have sold to customers, we can offer this as standard with the product.

# Engineering Design

## Edge Micro SOM

# Testing and Validation – Edge Micro SOM

Carried out in Ireland and Poland with the following scenario's considered.

Static testing in 4 fixed locations, representing the use case of tracking an asset and general monitoring.

This also included testing of a new idea around the use of a Taoglas Patch Antenna connected into the dedicated GNSS Antenna input on the Edge Micro.

# Testing and Validation – Edge Micro SOM

## Roof Test

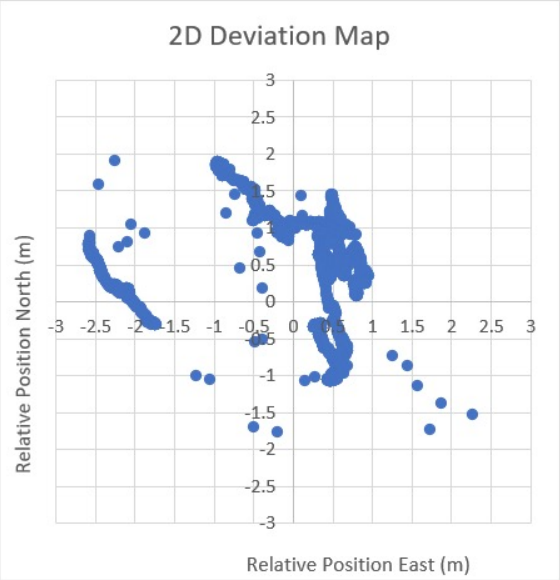
This test was carried out by the RF team with the device located on the roof of the Taoglas offices in DCU Alpha in Dublin.

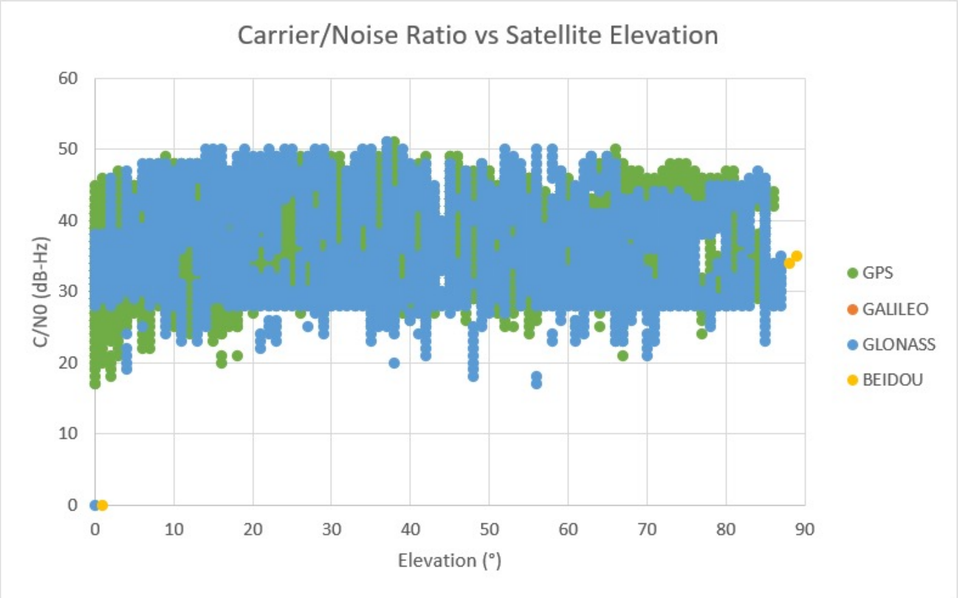
### Test Conditions

- Open sky conditions
- Sunny
- No corrections service
- 4h test

| Fix Mode | Time (TTFF) |
|---|---|
| A (Autonomous. Non-differential fix) | 49 s |

| CEP (50%) | DRMS (68%) | 2DRMS (95%) |
|---|---|---|
| 94.16 cm | 112.71 cm | 225.41 cm |



# Testing and Validation – Edge Micro SOM

## Static Test #1

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| 36 | 176.368 | 54.37464969 | 18.51759310 |

### Test conditions

1. Weather: Passing clouds, windy, foggy
2. Data polling interval: 3 minutes
3. Location: Shopping centre car park
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 1 hour

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| 16-12-2021 10:42 | 265.200012 | 2.400000 | 2 | 54.374937 | 18.516832 | 120 | 58,74255333 |
| 16-12-2021 10:45 | 205.600006 | 1.799999 | 3 | 54.374714 | 18.517145 | 64 | 29,8910536 |
| 16-12-2021 10:48 | 49.599998 | 1.799999 | 3 | 54.374892 | 18.518358 | 82 | 56,39460356 |
| 16-12-2021 10:56 | 47.700000 | 2.200000 | 3 | 54.374618 | 18.518257 | 72 | 43,14441128 |
| 16-12-2021 10:58 | 112.300003 | 2.200000 | 3 | 54.374785 | 18.517793 | 58 | 19,84942481 |
| 16-12-2021 11:03 | 106.800003 | 2.099999 | 3 | 54.375266 | 18.518212 | 100 | 79,39315857 |
| 16-12-2021 11:06 | 65.900001 | 2.000000 | 3 | 54.374762 | 18.517964 | 48 | 27,07487457 |
| 16-12-2021 11:09 | 194.800003 | 2.000000 | 3 | 54.375750 | 18.517796 | 85 | 123,0526269 |
| 16-12-2021 11:13 | 128.800003 | 1.700000 | 4 | 54.374759 | 18.517587 | 52 | 12,16135618 |
| 16-12-2021 11:13 | 131.399993 | 1.700000 | 4 | 54.374606 | 18.517750 | 39 | 11,26374404 |

# Testing and Validation – Edge Micro SOM

## Static Test #2

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| 38 | 108.262 | 54.34071840 | 18.58212519 |

### Test conditions

1. Weather: Passing clouds
2. Data polling interval: 3 minutes
3. Location: parking on the street with open sky, no buildings i.e.
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 50 minutes

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| 16-12-2021 12:49 | 60.500000 | 1.399999 | 6 | 54.340663 | 18.582165 | 46 | 6,67929027 |
| 16-12-2021 12:53 | 59.900001 | 1.399999 | 6 | 54.340684 | 18.582083 | 98 | 4,7019336 |
| 16-12-2021 12:57 | 61.000000 | 1.000000 | 6 | 54.340797 | 18.582107 | 52 | 8,81927969 |
| 16-12-2021 12:59 | 46.900001 | 1.200000 | 5 | 54.341081 | 18.581695 | 55 | 49,0232127 |
| 16-12-2021 13:03 | 108.400001 | 1.399999 | 6 | 54.340796 | 18.582513 | 56 | 26,5784927 |
| 16-12-2021 13:07 | 71.900001 | 1.200000 | 5 | 54.340748 | 18.582126 | 67 | 3,2913946 |
| 16-12-2021 13:11 | 82.800003 | 1.000000 | 6 | 54.340721 | 18.582200 | 52 | 4,8584246 |
| 16-12-2021 13:20 | 79.099998 | 1.299999 | 5 | 54.340820 | 18.582124 | 72 | 11,2976993 |
| 16-12-2021 13:24 | 81.699996 | 1.200000 | 5 | 54.340793 | 18.582124 | 56 | 8,2953027 |
| 16-12-2021 13:33 | 74.599998 | 1.399999 | 3 | 54.340663 | 18.582155 | 45 | 6,45629828 |

# Testing and Validation – Edge Micro SOM

## GNSS Testing Conclusion

| Requirement | Description | Conclusion |
|---|---|---|
| PR-05-01-01: Nav Update Rate: | Must support a navigation update of at least 1 Hz for real time asset theft monitoring. | Completed<br><br>Navigation update rates of 1Hz were used in testing. |
| PR-05-02-02: GNSS TTFF: | The GNSS TTFF must be < 45 seconds in open sky conditions (Roof test). | Completed<br><br>Referring to Tables we can see a Max of 155s and Min of 39s for TTFF in these conditions<br><br>We see a TTFF of 49s, just outside the specification<br><br>Note:<br><br>We understand there is an Efficiency issue with the Antenna choice on the Edge Micro, but notes that we measure 9s and 13s using a Patch Antenna |
| PR-05-01-03: GNSS Accuracy: | The GNSS accuracy must be < 5 metres under open sky conditions (Roof test). | Completed<br><br>In Static Tests 1 and 2 we noted that with 6 satellites acquired we can achieve <5m accuracy.<br><br>Referring to Table 10 we noted the 'Roof Test' achieved the best result of 0.168m with the Patch antenna and 0.225 with the PCB mounted Antenna<br><br>From Tables 4 & 6, we noted errors outside the specification with 3 satellites in view.<br><br>With 5+ Satellites we noted accuracy within the 5m requirement |
| NOTE on RTK Testing:<br><br>**When connected to the Edge Locate GNSS Module, the device is now effectively the Edge Rugged with RTK. So, results for this are included as part of the Edge Rugged section** | | |

# Engineering Design

## Edge Connect WSA

# Testing and Validation – Edge Connect WSA

## GNSS Testing

1. Static testing in 2 fixed locations, representing the use case of asset tracking and monitoring.

2. Static testing in open-sky conditions by the Taoglas RF team

# Testing and Validation – Edge Connect WSA

## Roof Test

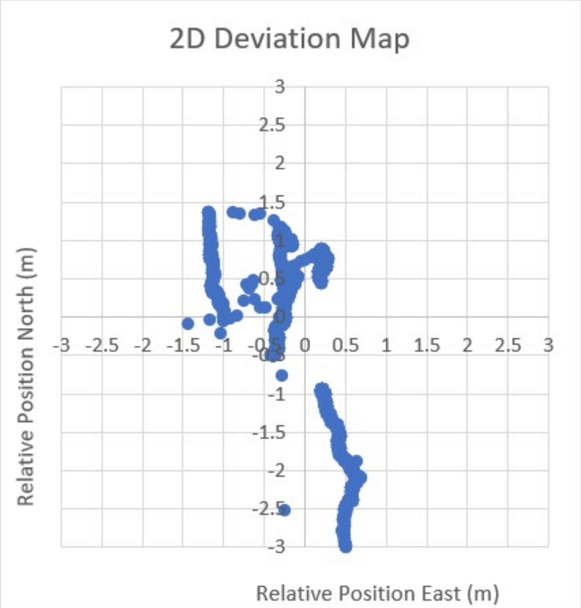
This test was carried out by the RF team with the device located on the roof of the Taoglas offices in DCU Alpha in Dublin.

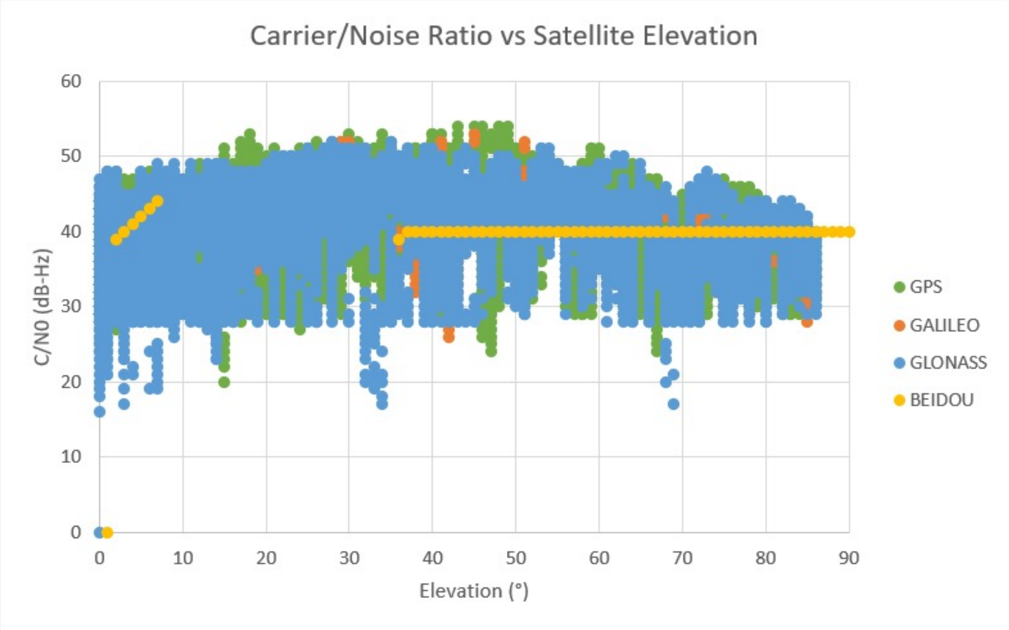
### Test Conditions

- Open sky conditions
- Sunny
- No corrections service
- 4h test

| Fix Mode | Time |
|---|---|
| A (Autonomous. Non-differential fix) | 13 s |

| CEP (50%) | DRMS (68%) | 2DRMS (95%) |
|---|---|---|
| 96.47 cm | 121.94 cm | 243.88 cm |



# Testing and Validation – Edge Connect WSA

## Static Test #1

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| 36 | 176.368 | 54.37464969 | 18.51759310 |

### Test conditions

1. Weather: Passing clouds, windy, foggy
2. Data polling interval: 3 minutes
3. Location: Shopping centre car park
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 1 hour

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| **16-12-2021 10:34** | -21.600000 | 1.600000 | 2 | 54.373877 | 18.517370 | 87 | 87,125832 |
| **16-12-2021 10:36** | 137.800003 | 1.299999 | 5 | 54.374591 | 18.517543 | 76 | 7,28779149 |
| **16-12-2021 10:39** | 119.400001 | 1.299999 | 5 | 54.374683 | 18.517567 | 65 | 4,07116386 |
| **16-12-2021 10:42** | 135.399993 | 1.200000 | 5 | 54.374642 | 18.517487 | 65 | 6,9244221 |
| **16-12-2021 10:45** | 109.000000 | 1.399999 | 4 | 54.374536 | 18.517383 | 65 | 18,5738672 |
| **16-12-2021 10:48** | 131.199996 | 2.099999 | 4 | 54.374681 | 18.517689 | 65 | 7,12078022 |
| **16-12-2021 10:51** | 163.600006 | 1.100000 | 4 | 54.374735 | 18.517531 | 67 | 10,3029951 |
| **16-12-2021 10:54** | 139.000000 | 1.299999 | 4 | 54.374601 | 18.517337 | 65 | 17,4484776 |
| **16-12-2021 10:57** | 161.399993 | 1.899999 | 4 | 54.374687 | 18.517633 | 65 | 4,88709358 |
| **16-12-2021 11:00** | 134.199996 | 1.200000 | 6 | 54.374556 | 18.517705 | 71 | 12,6911841 |

# Testing and Validation – Edge Connect WSA

## Static Test #2

| Satellites | Elevation (m) | Latitude (°) | Longitude (°) |
|---|---|---|---|
| 38 | 108.262 | 54.34071840 | 18.58212519 |

### Test conditions

1. Weather: Passing clouds
2. Data polling interval: 3 minutes
3. Location: parking on the street with open sky, no buildings i.e.
4. How many samples we used to get our ref point: The Emlid GNSS receiver was working on continuous mode, the coordinates noted after 15 minutes on the destinated area.
5. How long we remained at the location: 50 minutes

| Timestamp | Elevation [m] | HDOP | Satellites | Latitude [°] | Longitude [°] | TTFF [s] | Error [m] |
|---|---|---|---|---|---|---|---|
| **16-12-2021 12:49** | 60.500000 | 1.399999 | 6 | 54.340663 | 18.582165 | 46 | 6,67929027 |
| **16-12-2021 12:53** | 59.900001 | 1.399999 | 6 | 54.340684 | 18.582083 | 98 | 4,7019336 |
| **16-12-2021 12:57** | 61.000000 | 1.000000 | 6 | 54.340797 | 18.582107 | 52 | 8,81927969 |
| **16-12-2021 12:59** | 46.900001 | 1.200000 | 5 | 54.341081 | 18.581695 | 55 | 49,0232127 |
| **16-12-2021 13:03** | 108.400001 | 1.399999 | 6 | 54.340796 | 18.582513 | 56 | 26,5784927 |
| **16-12-2021 13:07** | 71.900001 | 1.200000 | 5 | 54.340748 | 18.582126 | 67 | 3,2913946 |
| **16-12-2021 13:11** | 82.800003 | 1.000000 | 6 | 54.340721 | 18.582200 | 52 | 4,8584246 |
| **16-12-2021 13:20** | 79.099998 | 1.299999 | 5 | 54.340820 | 18.582124 | 72 | 11,2976993 |
| **16-12-2021 13:24** | 81.699996 | 1.200000 | 5 | 54.340793 | 18.582124 | 56 | 8,2953027 |
| **16-12-2021 13:33** | 74.599998 | 1.399999 | 3 | 54.340663 | 18.582155 | 45 | 6,45629828 |

# Testing and Validation – Edge Connect WSA

## GNSS Testing Conclusion

| Requirement | Description | Conclusion |
|---|---|---|
| **PR-02-01-01: Antenna Switch Time:** | The firmware switch time must be < 5 milliseconds. | Completed<br>The Antenna switch time is limited by the propagation delay of the RF switch on the PCB. The devices datasheet states the switch time as being <1ms (215us) |
| **PR-02-01-02: GNSS TTFF:** | The GNSS TTFF must be < 45 seconds in open sky conditions (Roof test). | Completed<br>Referring to Tables we see that the TTFF was measured at 13s and meets the KPI.<br>Referring to Tables we noted that the TTFF ranged from a Min of 45s to a max of 98s |
| **PR-02-01-03: GNSS Accuracy:** | The GNSS accuracy must be < 5 metres under open sky conditions (Roof test). | Completed<br>In Static Tests 1 and 2 we noted that with 6 satellites acquired we can achieve <5m accuracy.<br>Referring to Tables we noted the 'Roof Test' achieved the best result of 0.248m |

# Testing and Validation – Edge Connect WSA

## Sensor upload Test #1

### Test conditions

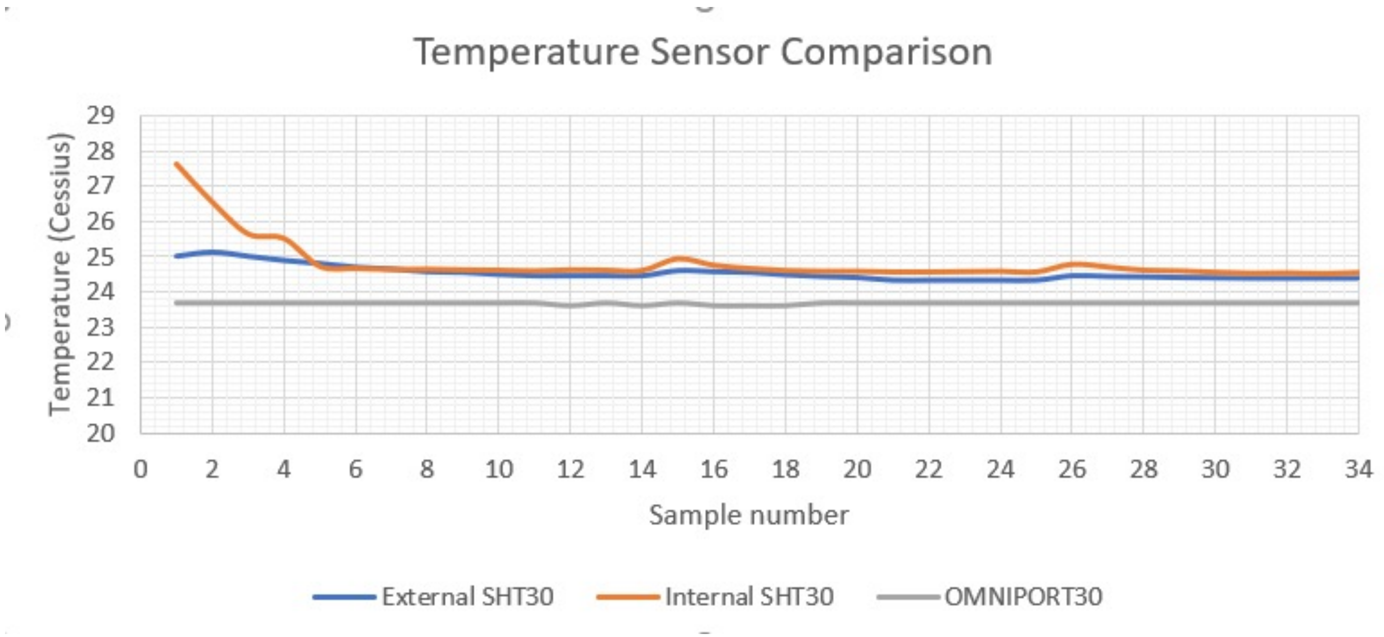
1. The device was located close (<2m) from a window and then further from the window (5m)
2. Partial Sky View and then limited sky view
3. Upload interval: Set to 15 minutes
4. Test Duration: 5 hours

| EDGE Connect WSA Sensor Polling (15 min interval) | | | | | |
|---|---|---|---|---|---|
| Timestamp | Humidity (%) | Sample Interval (s) | Timestamp | Temperature (F) | Sample Interval (s) |
| 1.639E+12 | 69.007 | 00:15:00 | 1.6385E+12 | 64.3622 | 00:15:01 |
| 1.639E+12 | 59.424 | 00:15:01 | 1.6385E+12 | 67.2368 | 00:15:00 |
| 1.639E+12 | 62.098 | 00:15:00 | 1.6385E+12 | 64.6178 | 00:15:01 |
| 1.639E+12 | 63.842 | 00:15:01 | 1.6385E+12 | 64.742 | 00:15:01 |
| 1.639E+12 | 65.247 | 00:15:01 | 1.6385E+12 | 62.969 | 00:15:00 |
| 1.639E+12 | 59.598 | 00:15:00 | 1.6385E+12 | 65.786 | 00:15:01 |
| 1.639E+12 | 50.109 | 00:15:01 | 1.6385E+12 | 72.8078 | 00:15:01 |
| 1.639E+12 | 56.252 | 00:15:01 | 1.6385E+12 | 57.1964 | 00:15:00 |
| 1.639E+12 | 68.099 | 00:15:00 | 1.6385E+12 | 51.1934 | 00:15:01 |
| 1.639E+12 | 66.434 | 00:15:01 | 1.6385E+12 | 51.8792 | 00:15:01 |
| 1.639E+12 | 62.615 | 00:10:33 | 1.6385E+12 | 54.6008 | 00:10:32 |
| 1.639E+12 | 69.692 | 00:15:00 | 1.6385E+12 | 51.548 | 00:15:00 |
| 1.639E+12 | 65.578 | 00:15:00 | 1.6385E+12 | 52.7216 | 00:15:01 |
| 1.639E+12 | 63.26 | | 1.6385E+12 | 54.4226 | |
| AVERAGE SAMPLE INTERVAL | | 00:14:40 | AVERAGE SAMPLE INTERVAL | | 00:14:40 |

# Testing and Validation – Edge Connect WSA

## Reference Temperature comparison testing

- Edge Connect WSA was fitted with its external sensor board
- Compare performance against the Omniport 30 reference thermometer

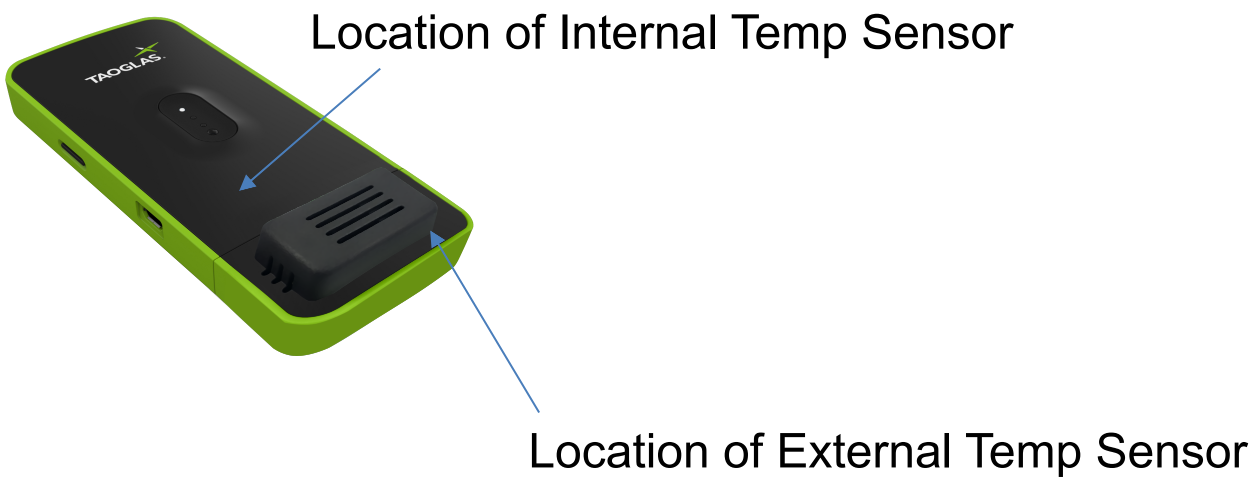


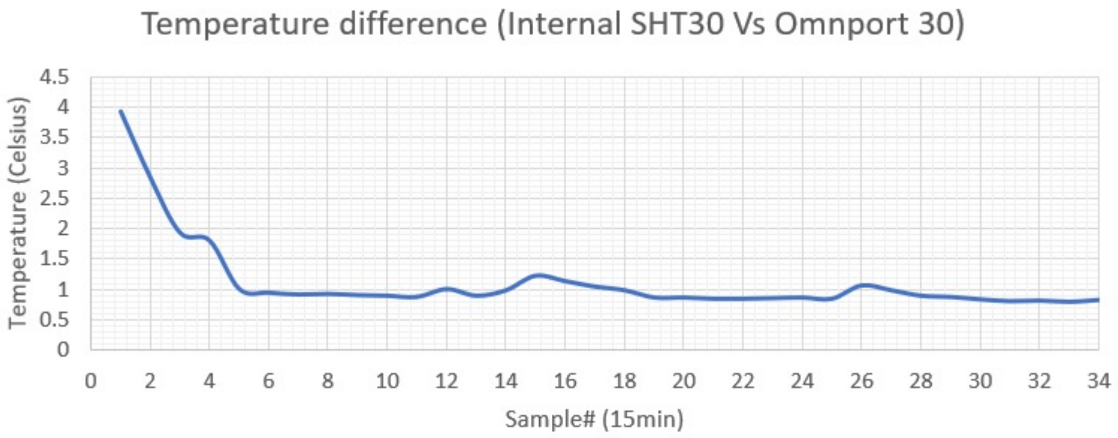

| Sample | External SHT30 | Internal SHT30 | OMNIPORT30 |
|---|---|---|---|
| 1 | 25.02 | 27.63 | 23.7 |
| 2 | 25.14 | 26.54 | 23.7 |
| 3 | 25.02 | 25.63 | 23.7 |
| 4 | 24.9 | 25.5 | 23.7 |
| 5 | 24.81 | 24.7 | 23.7 |
| 6 | 24.7 | 24.64 | 23.7 |
| 7 | 24.65 | 24.61 | 23.7 |
| 8 | 24.57 | 24.62 | 23.7 |
| 9 | 24.55 | 24.6 | 23.7 |
| 10 | 24.49 | 24.59 | 23.7 |
| 11 | 24.45 | 24.57 | 23.7 |
| 12 | 24.45 | 24.6 | 23.6 |
| 13 | 24.45 | 24.59 | 23.7 |
| 14 | 24.45 | 24.58 | 23.6 |
| 15 | 24.6 | 24.92 | 23.7 |
| 16 | 24.57 | 24.73 | 23.6 |
| 17 | 24.55 | 24.64 | 23.6 |
| 18 | 24.48 | 24.58 | 23.6 |
| 19 | 24.43 | 24.56 | 23.7 |
| 20 | 24.4 | 24.56 | 23.7 |
| 21 | 24.32 | 24.54 | 23.7 |
| 22 | 24.32 | 24.54 | 23.7 |
| 23 | 24.32 | 24.55 | 23.7 |
| 24 | 24.32 | 24.56 | 23.7 |
| 25 | 24.32 | 24.54 | 23.7 |
| 26 | 24.45 | 24.76 | 23.7 |
| 27 | 24.43 | 24.68 | 23.7 |
| 28 | 24.42 | 24.59 | 23.7 |
| 29 | 24.4 | 24.57 | 23.7 |
| 30 | 24.39 | 24.53 | 23.7 |
| 31 | 24.38 | 24.5 | 23.7 |
| 32 | 24.38 | 24.51 | 23.7 |
| 33 | 24.38 | 24.49 | 23.7 |
| 34 | 24.38 | 24.52 | 23.7 |

# Testing and Validation – Edge Connect WSA

## Reference Temperature test Conclusion

| | | |
|---|---|---|
| **PR-02-02-02: Sensor Impact by Onboard Electronics:** | The system temperature and humidity must be accurate to within 1 degree Celsius and 5% RH. This tolerance must not be exceeded regardless of thermal impact of onboard processors and radios. | Completed<br>Referring to Figure, we noted that the device does converge to an error of <1°C on the internal Temp sensor<br>We noted better performance from the External Sensor<br>Optimal upload interval is 15m for this use case with Temperature sampled every 90s.<br>Further testing showed capability to be within 0.1°C using modified bottom housing. (outside of scope) |



# Thank you for listening

Questions.?