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SEAL | SEAL Ex

Non-ATEx and ATEx Certified Wearable GPS Tracker

Technical Reference Manual

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SEAL without Safety Clip	T0008768
SEAL ATEx with Safety Clip	T0008767
SEAL ATEx without Safety Clip	T0008766

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Table of Contents

List of Tables

List of Figures

Acronyms and Glossary

ABP .... activation by personalization
ADR .... adaptive data rate
B .... byte
BeiDou . ... BeiDou Navigation Satellite System (BDS)
BD_ADDR .... Bluetooth Device Address
BLE .... Bluetooth Low Energy
DC .... data converter
DL .... downlink
DR .... data rate
DZ .... designated/danger zone
EAR .... EMERGENCY App Request
EB .... emergency button
EU .... European Union
flash .... a non-volatile memory, referring to either the MCU (internal) flash—containing application and configuration settings—or the GNSS receiver (external) flash memory—containing GNSS logs
FSM .... finite state machine
FW .... firmware
g .... gravity (unit of acceleration ≈ 9.8 m/s^2)
Galileo . ... EU GNSS
GLONASS .... GLObal NAvigation Satellite System
GNSS .... Global Navigation Satellite System
GPS .... Global Positioning System
ID .... identity/identifier
IoT .... Internet of Things
IP .... Ingress Protection
JSON .... JavaScript Object Notation
LAP .... lower address part
LED .... light-emitting diode
LID .... lithium-iron disulfide
LoRa .... a patented "long-range" IoT technology acquired by Semtech
LoRAMAC .... LoRaWAN MAC
LoRaWAN .... LoRa wide area network (a network protocol based on LoRa)
sLSb .... least significant bit
LSB .... least significant byte
MAC .... Medium Access Control
MB .... Mute Button
MCU .... microcontroller unit
min .... minute(s)
MSb .... most significant bit
MSB .... most significant byte
NA .... North America
NAR .... NORMAL App Request
NS .... network server
OTA .... over-the-air
OTAA ... . OTA activation
OUI .... organizationally unique identifier
POST .... power-on self-test
QZSS .... Quasi-Zenith Satellite System, Japanese SBAS for GPS
RF .... radio frequency
RFU .... reserved for future use
RO .... read-only
R/W .... read/write
RSSI .... received signal strength indicator
Rx .... receiver
SB .... sleep button
SBAS .... Satellite-Based Augmentation System
sec .... second(s)
SH .... safety hook
SHB...... ....safety hook button
SW .... software
transducer .... a sensing element in the SEAL, such as the accelerometer
TRM .... technical reference manual (this document)
Tx .... transmission

UL .... uplink

UTC .... Coordinated Universal Time

ver. .... Version

SEAL .... Wearable GPS Tracker

1 Introduction

This document provides technical details regarding the supported functionalities of both the non-ATEx and ATEx versions of the Tektelic Wearable GPS Tracker sensors, referred to as SEAL and SEAL Ex, respectively. It includes comprehensive descriptions of the LoRa IoT uplink and downlink payload structures, as well as user-accessible configuration settings. Prior familiarity with the hexadecimal number system, LoRaWAN network architecture, the Network Server (NS), and its command interfaces is assumed for effective comprehension of the content.

1.1 Overview

LoRaWAN, the LoRa wireless communications standard protocol, offers a solution for transmitting small data packets over long distances with low power consumption. This technology, designed with wireless sensing applications in mind, facilitates the gathering of telemetry data in various environments. The SEAL and SEAL Ex trackers support both LoRa and (G)FSK modulations in accordance with the LoRaWAN 1.0.4 Specification (LoRa Alliance, Feb 2017). Utilizing the 150 MHz-960 MHz ISM bands, the trackers cater to diverse application requirements across different regions, accommodating both standard and proprietary protocols.

The SEAL/SEAL Ex is a compact, lightweight, IP67-rated LoRaWAN sensor designed for tracking people or equipment, serving as a wearable device. It utilizes GNSS and BLE technologies for geolocation tracking, offering extended battery life and low operational and maintenance costs. With an operational temperature range of -20°C to +60°C, it is suitable for various environments.

The tracker is available in two variants: SEAL Ex, which is ATEX/IECEx certified for use in potentially hazardous and explosive atmospheres, and SEAL, a non-ATEX/IECEx unit. Both variants are offered with or without a safety clip harness. The safety clip harness includes a detection mechanism for a safety hook, triggering a local alarm if the hook is engaged, alerting the user.

1.2 Features and Functions

The SEAL/SEAL Ex is equipped with advanced hardware components tailored for its functionalities. It utilizes the Semtech SX1261 modem for LoRaWAN communication. The device features an STM32 MCU from STMicroelectronics, specifically designed for low-power IoT applications and featuring a built-in BLE module to facilitate Bluetooth communication.

The SEAL/SEAL Ex incorporates a high-sensitivity GNSS receiver, supporting GPS, Galileo, GLONASS, BeiDou, QZSS, and SBAS systems for geolocation tracking. Fixes obtained from this receiver are automatically logged and can be accessed at a later date. The device has the capacity to store up to 3000 log entries at a time. As new entries are logged, the oldest ones are deleted to make space for the new ones, ensuring continuous data recording. Additionally, the device features a low-power 3-axis MEMS accelerometer and a digital barometric air pressure sensor, further enhancing its sensing capabilities for comprehensive data collection and analysis.

The device is equipped with various user interface elements, including a push button serving as an emergency/SOS/panic button, and a buzzer for locally indicating emergency button (EB) presses or safety hook (SH) connections. A mute button (MB) is provided for manual muting or unmuting the buzzer, as well as for resetting the sensor. Additionally, there are two sets of LEDs: one set at the top featuring two high-intensity amber color LEDs, and another set at the front consisting of three high-intensity amber color LEDs. These LEDs are utilized to indicate various statuses such as emergency situations, low battery levels, and the system transitioning into or out of DEEP SLEEP mode, among other features.

The SEAL/SEAL Ex also incorporates additional sensing functions, including temperature monitoring, remaining battery lifetime, and remaining battery capacity. These metrics are calculated using current measurements by an onboard current sense amplifier (CSA). The remaining battery lifetime is expressed in terms of the number of days, while the remaining battery capacity is represented as a percentage. Users have the flexibility to define a low battery threshold either in days or as a percentage. When the reported battery level falls below the set threshold, this condition is visibly indicated to the user through distinct periodic LED flashes, providing clear feedback on the device's battery status.

In the event of unforeseen critical component or system failures, the SEAL/SEAL Ex is equipped with self-recovery capabilities designed to address the issue. These self-recovery mechanisms target the affected components with precision to restore operations. If these targeted recovery efforts are unsuccessful, the SEAL initiates a system reset. Following the reset, logs detailing the reset event and any associated failures are transmitted as the first uplink, providing administrators with information about the events leading to the reset.

Table 1-1 below summarizes all supported features and functions and the applicable variant.

Table 1-1: Supported functions and applicable variants

Features and Functions	Section #	SEAL	SEAL with Clip	SEAL Ex	SEAL Ex with Clip
GNSS Geolocation Positioning	7.1	✓	✓	✓	✓
GNSS Datalogging	7.3	✓	✓	✓	✓
GNSS Danger Zoning	7.2	✓	✓	✓	✓
BLE Geolocation Tracking	8.1	✓	✓	✓	✓
BLE Danger Zoning	8.2	✓	✓	✓	✓
Emergency Alarm	6.1	✓	✓	✓	✓
Fall Detection	6.3	✓	✓	✓	✓
Safety Hook Detection	6.2	✗	✓	✗	✓
Pressure/Elevation Alarm	6.7	✓	✓	✓	✓
Temperature Monitoring	10.2	✓	✓	✓	✓
Accelerometer Vector	9.2	✓	✓	✓	✓
Barometric Pressure	10.1	✓	✓	✓	✓
Battery Lifetime	4.3	✓	✓	✓	✓
Battery Capacity	4.3	✓	✓	✓	✓
Low Battery Alarm	4.3	✓	✓	✓	✓
GNSS Diagnostics	7.4	✓	✓	✓	✓

Features and Functions	Section #	SEAL	SEAL with Clip	SEAL Ex	SEAL Ex with Clip
System Diagnostics	11	✓	✓	✓	✓

1.3 Hardware Models, Data Streams, and Default Behavior

Table 1-2 and Table 1-3 below shows more information on the supported HW models and the supported data streams.

Table 1-2: SEAL and SEAL Ex HW Models

Part Number			Description
T0008766			SEAL Module, 2x AA-Cell (ATEX) With no Safety Clip
T0008767			SEAL Module, 2x AA-Cell (ATEX) With Safety Clip
T0008768			SEAL Module, 3x AA-Cell with Safety No Clip
T0008769			SEAL Module, 3x AA-Cell with Safety Clip
	T0007706		SEAL PCBA, non-ATEX
	T0008211		SEAL PCBA, ATEX
		T0008189	SEAL PCB

Table 1-3: SEAL Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port
Uplinks (SEAL/SEAL Ex to NS)	Systems Diagnostics Information • Component errors • System errors • Reset types and counts	**5**
	All Real-time sensing data • GNSS position fix (latitude, longitude, altitude) • Groundspeed • GNSS and BLE DZ status • Accelerometer vector report • Barometric pressure • Temperature • Battery life capacity • Battery life lifetime • Safety Status	**10**
	GNSS log Reports	**15**
	GNSS Diagnostics Reports	**16**
	Discovered BLE device Reports	**25**

Stream Direction	Data Type	Sent on LoRaWAN Port
	Response to read/write commands from the NS	**101**
Downlinks (NS to SEAL/SEAL Ex)	Query for sensor's diagnostics report	**5**
	Request safety status change	**10**
	Request GNSS logs	**15**
	Configuration and Control Commands	**100**

The default configuration on the SEAL/SEAL Ex for periodic reports is outlined in Table 1-4 below.

Table 1-4: SEAL/SEAL Ex Default Reporting Behavior

Report type	Occurrence
Remaining battery capacity in percentage	• Once every day in the NORMAL state • Once every min in the EMERGENCY state
Remaining battery lifetime in days	• Disabled by default
GNSS Position Fix Coordinates (latitude, longitude) GNSS Position Fix Altitude GNSS Position Fix Timestamp Groundspeed	• Every 15 mins in the NORMAL state • Every min in the EMERGENCY state
Emergency Alarm Status	• Every 15 mins in the NORMAL state • Every min in the EMERGENCY state • With any status change in EB, Fall, SH, EAR/NAR, or Pressure/Elevation alarm.
GNSS Danger Zone Status	• Disabled by default
BLE Danger Zone Status	• Disabled by default
Barometric Pressure	• Every 15 mins in the NORMAL state • Every min in the EMERGENCY state
Acceleration Vector	• Disabled by default
Ambient Temperature	• Disabled by default
GNSS Diagnostics	• Disabled by default
System Diagnostics	• First UL after a reset

1.4 Finite State Machine

The finite state machine (FSM) for the SEAL/SEAL Ex system provides a comprehensive overview of the system's behavior, outlining the transitions between various operational states and the associated behaviors for each state and transition. In this model, the system is capable of existing in only one state at any given time, and state transitions are triggered by external inputs or events, such as a button press.

Figure 1-3 illustrates the state machine of the SEAL/SEAL Ex, complemented by a glossary section to elucidate the behaviors of each state. Here's an in-depth explanation of each operational state:

1. DEEP SLEEP: In this state, the SEAL/SEAL Ex's MCU enters a deep sleep mode to minimize energy consumption. The device defaults to this state upon factory initialization. Applying the specific pattern[1] outlined below to the Mute Button (MB) wakes the SEAL/SEAL Ex into STARTUP. Repeating this button press pattern during network join returns the SEAL/SEAL Ex to DEEP SLEEP, while applying it in other states resets the device.

    i. Press and hold the mute button for 1 second, and release.
    ii. Press and hold the mute button again for at least 3 seconds but less than 10 seconds, then release.

Figure 1-1: Enclosure front view showing the Mute Button

See Section 5.1.2 for more information on the Mute Button pattern.

2. STARTUP: The STARTUP state marks the initial boot-up phase of the SEAL, where the device undergoes essential procedures such as Power-On Self Tests (POSTs) and other initialization tasks. These preparations are conducted to ensure the system is ready to commence the process of joining the LoRa network. The SEAL/SEAL Ex transitions into this state following a successful reset or wake-up from DEEP SLEEP mode following the Mute button press pattern.

3. JOIN: In the JOIN state, the SEAL/SEAL Ex endeavors to connect to a LoRa network. Initially, the top LEDs flash rapidly, signaling the initiation of this process, with this rapid flashing lasting for the first hour. Subsequently, the flashing rate slows down to conserve battery life. Throughout the entire joining process, the three front LEDs flash each time the SEAL/SEAL Ex sends a join request uplink, providing visual feedback of the ongoing network connection attempt.

4. NORMAL: Upon successfully completing the JOIN process, the SEAL/SEAL Ex transitions to the NORMAL state. In this state, the device periodically sends reports containing GNSS position fixes, ground speed, and Safety Status information. This includes updates on the status of various features such as the Emergency Button (EB), Fall detection, Safety Hook (SH), Emergency App request (EAR), and Pressure/Elevation alarm.

[1] The button press should be done in quick succession

Additionally, the device monitors motion in this state, and if no activity exceeding a predefined acceleration threshold is detected for a specified period (set to a default of 15 minutes), the device transitions to SLEEP mode to conserve energy. See Section 9.4 for more information on the inactivity sleep function.

5. EMERGENCY: Transitioning to the EMERGENCY state occurs when specific events are detected, such as pressing the Emergency Button (EB) or safety hook, detecting a human fall, entering a designated danger zone, triggering a Pressure/Elevation Alarm, or receiving an EMERGENCY App Request (EAR) command. It is possible for the SEAL/SEAL Ex to enter multiple EMERGENCY states simultaneously. For instance, both the Emergency Button and Fall alarms can be active concurrently if the device detects a fall while the button is pressed. This capability ensures that the SEAL/SEAL Ex can accurately capture and respond to multiple emergency situations simultaneously, providing comprehensive support in critical scenarios.

   Upon entering this state, the following actions occur:

   a. A Safety Status report is immediately transmitted to the cloud application.
   b. The buzzer emits a local acknowledgment sound to alert both the wearer and nearby individuals. The frequency of the buzz is determined by the type of emergency triggered. For example, a safety hook alarm has a periodic buzz pattern, while there is no buzzer activity for a designated/danger zone alarm. This tailored feedback ensures that the alert system effectively communicates the nature of the emergency to the user.
   c. All LEDs flash rapidly and periodically, providing a visual indication of the emergency.
   d. All transducer data and enabled geolocation data are reported at an increased rate to provide comprehensive information.

   The transition back to the NORMAL state occurs once all emergency situations are resolved. Additionally, if the device resets or restarts while in an active emergency state, the emergency button state remains active upon rejoining the network. This prevents the loss of an active emergency and ensures continued monitoring and response to critical situations.

   It's important to note that there is no direct transition from the EMERGENCY state to SLEEP mode. See Section 6 for more information on all supported Emergency states.

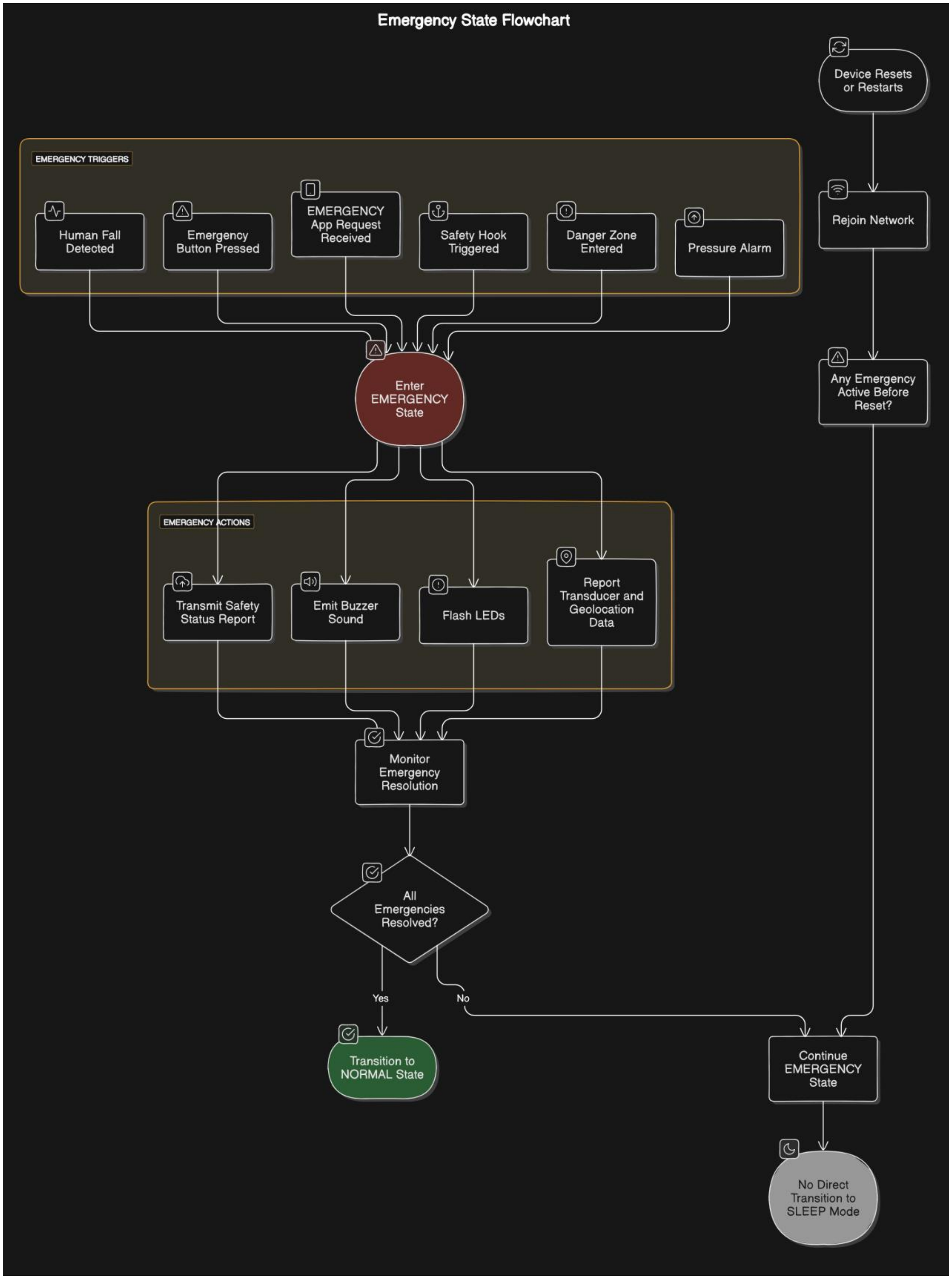


Figure 1-2: Emergency State Flowchart

6. SLEEP: The SEAL/SEAL Ex enters the SLEEP mode to conserve battery power when it remains motionless in the NORMAL state for the default duration of fifteen minutes. During this mode, all transducers, except the accelerometer, are minimized to their lowest energy states to reduce power consumption. If motion exceeding the sleep threshold acceleration is detected, the device wakes up, transitioning back to the NORMAL state to resume regular operation.

The finite state machine is illustrated in

Figure 1-3 below.

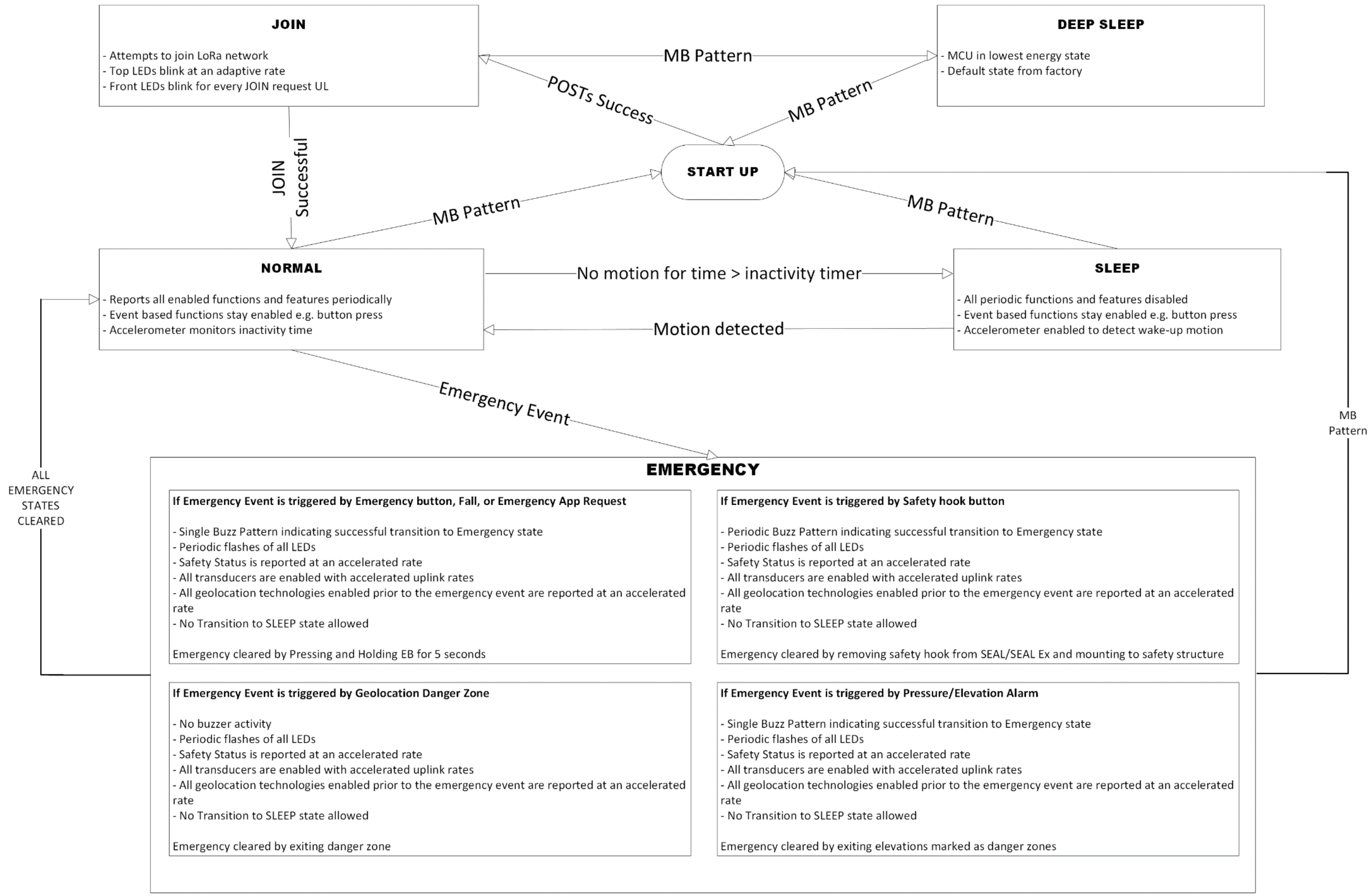


Figure 1-3: The SEAL/SEAL Ex Finite State Machine.

2 Sensor Activation and Management

This section outlines the steps required to set up the SEAL/SEAL Ex tracker and manage the sensor thereafter.

2.1 Unpacking

The following items are included with every SEAL/SEAL Ex package:

- One SEAL/SEAL Ex Wearable GPS Tracker module with Lithium Iron Disulfide AA batteries installed
- A Quick Start Guide

When unpacking the package, please follow these precautions:

- Inspect the shipping carton and report any significant damage to TEKTELIC.
- Conduct unpacking in a clean and dry location.
- Store the package box in a safe and dry location after unpacking. This will be required for returns if the need arises.

2.2 Commissioning

Each SEAL/SEAL Ex package box contains a sticker with the necessary commissioning values for registering the sensor on a network server. The commissioning keys provided for each sensor include the following:

- Sensor T-code, Revision Number, and Serial Number: These unique identifiers ensure accurate tracking and maintenance of the specific sensor unit.
- DEVEUI (Device EUI): A globally unique 16-byte identifier for the device, used in the network server to identify the device.
- APPEUI (Application EUI): 16-byte key that Identifies the owner or the application provider of the device, ensuring it connects to the correct application.
- APPKEY (Application Key): A 32-byte security key used to authenticate the device during the join process with the network server.

Ensure to keep this information secure and accessible for future reference and troubleshooting.

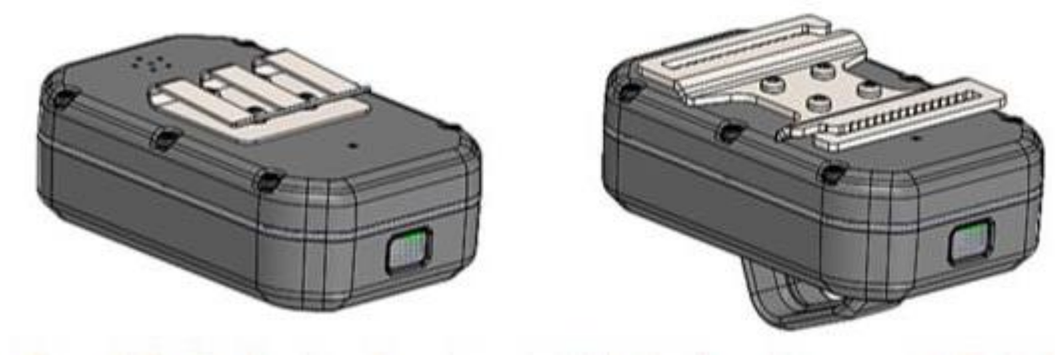
2.3 Activation

The SEAL/SEAL Ex is shipped in a sealed enclosure with batteries installed and engaged, but the device is in a state of DEEP SLEEP. For detailed instructions on how to wake the device from DEEP SLEEP, please refer to section 1.4.

2.4 Mounting

On the battery side of the enclosure, there are four clip holes designed for attaching the SEAL/SEAL Ex Tracker to a belt or harness clip, as shown in Figure 2-1 below. The recommended screws for this purpose are M3 5mm stainless steel screws. Please note that the SEAL package does not include separate mounting screws.

Figure 2-1: Belt clip (L) and Harness Clip (R)



2.5 Battery Replacement

The SEAL module requires three (3) Energizer L91 AA size Lithium Iron Disulfide "Ultimate Lithium" batteries, while the SEAL Ex requires two (2). Always replace all batteries together as a set, ensuring the correct polarity according to the markings.

Follow these steps to replace the batteries in the SEAL/SEAL Ex sensor:

1. Ensure the SEAL/SEAL Ex sensor is powered down before starting the battery replacement process.
2. Locate the battery compartment at the back of the SEAL/SEAL Ex module and use a 1.5mm internal hex screwdriver to carefully open the battery compartment. Keep the screws in a safe place.
3. Remove the existing batteries from the compartment and dispose in accordance with local regulations.
4. Insert the required number of new Energizer L91 AA size Lithium Iron Disulfide "Ultimate Lithium" batteries.
5. Ensure the correct polarity by aligning the batteries with the polarity markings inside the compartment.
6. Carefully close the battery compartment, tightening each screw to 2.5 lbs-in (30 N-cm). This is required to prevent moisture or debris from entering.
7. Power up the SEAL/SEAL Ex sensor to verify that it operates correctly with the new batteries.

Remember to handle batteries with care and avoid mixing old and new batteries or different types of batteries, as this can affect device performance and battery life.

3 General Sensor and LoRaWAN Communication Information

The SEAL/SEAL Ex devices communicate with the Network Server (NS) using LoRaWAN packets. When the tracker sends data to the NS, it's referred to as an UPLINK, whereas communication from the NS to the tracker is termed a DOWNLINK. By default, LoRaWAN communications for SEAL/SEAL Ex devices are Class A or one-way, implying that the tracker is either transmitting data to the NS or receiving data from it, but not both simultaneously. However, these and other sensor behaviors can be configured differently to suit various types of applications.

The subsequent sub-sections outline the general format of uplinks and downlinks, communication streams, and packet formats supported by SEAL/SEAL Ex devices. For comprehensive packet codec functionality, an online application called KONA ATLAS is available (Tektelic, n.d.). This tool supports the encoding of Downlink (DL) payloads and decoding of Uplink (UL) payloads specifically for SEAL/SEAL Ex devices.

3.1 Uplink Payloads

Uplinks are LoRaWAN packets sent from the SEAL/SEAL Ex to the NS. Each uplink from the SEAL/SEAL Ex is encoded in a frame shown below. Note that a big-endian format (MSb/MSB first) is always followed.

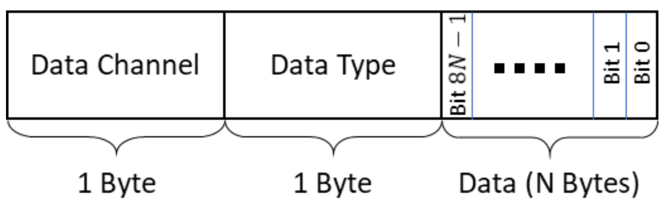


Figure 3-1: Uplink Payload Format

A SEAL/SEAL Ex uplink payload can include multiple blocks of uplinks from the same port and can be arranged in any order. Uplink payloads are generally categorized into the following.

1. Informational data uplinks: These uplinks convey information from the sensor to the NS regarding specific requests, actions, or sensor status updates. Unlike sensor data uplinks, informational data uplinks do not require transducer measurements. An example is the system diagnostics uplink, which contains information such as reset/restart counters, communication bus failures, component failures, and more.
2. Sensor data uplinks: These uplinks consist of measurement reports obtained from onboard transducers such as the GNSS receiver, barometer, accelerometer, etc.

For each of the uplink category above, there are two further sub-divisions based on the event or action that triggers the report. This sub-categorization helps in organizing and understanding the nature of the data being transmitted.

1. Periodic: uplink reports are sent at regular intervals defined by a system time period known as a “tick”.

2. Event based reporting: uplink is triggered by specific actions or events, such as a press of a button.

Table 3-1 below tabulates the supported uplink streams for SEAL/SEAL Ex trackers, their uplink types, and their corresponding port numbers.

Table 3-1: SEAL/SEAL Ex Uplink Streams

Uplink Heading	Information/Sensor Data	Periodic/Event-based	Port
System diagnostics • Reset counters • Most recent reset type • Components health status	Information	Event-based (second uplink on successful network JOIN) and after a query DL	5
All real-time sensing data • GNSS location fix • Accelerometer vector report • Barometric pressure report • Temperature report • Battery life information report	Sensor Data	Periodic (15 minutes interval by default)	10
Periodic Safety Status • Emergency Button Status • Safety hook button status • Fall Detection Status • Emergency app request status • Pressure/Elevation status	Information	• Periodic (15 minutes interval by default) • Event-based (on any status change)	10
Danger Zone Status • GNSS danger zone status • BLE danger zone status	Information	• Periodic (disabled by default) • Event-based (on any status change)	10
Datalogger reports • Log entry coordinates • Log entry timestamp • Log request	Information	Event-based	15
GNSS Fix Diagnostics Information • Number of satellites • Average Satellite SNR • Most recent log entry number • GNSS fix type • Time-to-fix • Fix accuracy • Groundspeed accuracy • Number of fixes per scan	Sensor Data	Periodic (disabled by default)	16
Scanned BLE devices	Sensor Data	Periodic (disabled by default)	25
Response to downlink commands	Information	Event-based (on any read/write downlink command)	100 (read), 101 (write)

Refer to appendix 0 for a comprehensive table of all supported uplinks.

3.2 Downlink Payloads

Downlinks, which are LoRaWAN packets transmitted from the Network Server (NS) to the sensor, play a vital role in communicating instructions or requests to the SEAL/SEAL Ex device. These downlinks can be categorized as follows:

1. Application Request Downlinks: These downlinks are directed to the sensor to solicit information regarding system status or to induce changes in system behavior. Notably, these downlink registers are read-only.

    a. Request system diagnostics status on **port 5** (Refer to section 11)

    b. Request for Emergency status change on **port 10** (Refer to section 6.4)

    c. Request for logged entries from flash memory on **port 15** (Refer to section 7.3)

2. Configuration and Control Downlinks (port 100 downlinks): These downlinks are dispatched to the sensor to either read, write, or execute other configuration-related actions.

    a. Request to read the current value of a configuration register (R)

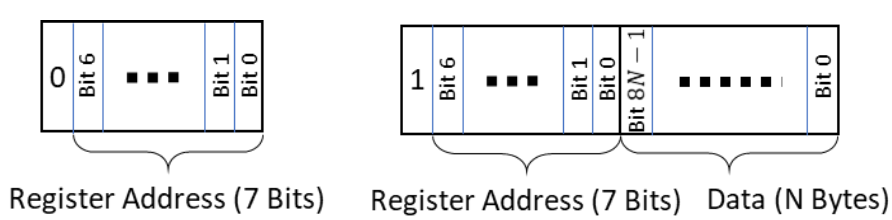
    b. Request to write a value to a configuration register (W)

    c. Request for the sensor to execute a specific operation, such as resetting to factory defaults (Refer to section 4.4)

    A single DL configuration and control message can contain multiple command blocks, with a possible mix of read and write commands. Each message block is formatted as shown in Figure 3-2. A big-endian format (MSB first) is always followed.

    The Register Address is used to access various configuration parameters. These addresses are bound between 0x00 and 0x7F.

    Bit 7 of the first byte determines whether a read or write action is being performed, as shown in Figure 3-2. All read commands are one-byte long. Data following a read access command will be interpreted as a new command block. Read commands are processed last. For example, in a single DL message, if there is a read command from a register and a write command to the same register, the write command is executed first.



(a) The read command block (b) The write command block.

Figure 3-2: Format of a DL configuration and control message block.

All DL configuration and control commands are sent on ***LoRaWAN port 100***.

NOTE: When forming DL payloads with more than 1 command block, sometimes the order of the commands will affect how the sensor responds overall to the whole payload. Refer to section 3.3 for a description of how the sensor processes, executes, and responds to configuration and control commands.

3.3 Response to Downlink Payloads

When the SEAL/SEAL Ex receives a downlink containing a request for an action, such as reading the value of a downlink register or writing to a downlink register, it responds with an acknowledgement to the network server. This acknowledgement indicates whether the read or write operation was successful or failed.

Commands received in a downlink (DL) payload are processed sequentially, one at a time, from Most Significant Bit (MSB) to Least Significant Bit (LSB). However, they are typically not executed immediately upon processing. Write commands, if deemed valid, are executed promptly upon processing. Conversely, other types of commands are queued for execution later.

<u>If all commands were processed successfully</u>, the following happens in order:

1. Any queued Command-and-Control (C&C) operations[2] are executed in the following order.
    a. Save configuration settings to flash.
    b. Reset configuration settings to factory default.
    c. Restart sensor.
2. If any read commands were queued, they are executed, and a ***LoRaWAN port 100* read response** is sent.
3. If any write commands were executed, a ***LoRaWAN port 101* write response** is sent.

<u>As soon as an invalid command[3] is processed</u>, the following happens in order:

1. No further command blocks are processed.
2. If any read commands were queued, they are executed, and a ***LoRaWAN port 100* read response** is sent.
3. A ***LoRaWAN port 101* write/error response** is sent.

Read Response: In the case of a valid read command block, a UL payload is sent back on ***LoRaWAN port 100*** containing the addresses and values of each of the registers under query. The bit indexing scheme as shown in Figure 3-3 below

[2] C&C operations are defined as commands accessing register 0x 70 or 0x 72 with bit 7 set to 1 (i.e. if a command block begins with 0x F0 or 0x F2). Refer to section 4.4 for more details.

[3] An invalid command is one that either tries to access a register designated as RFU or write an invalid value to an accessible register.

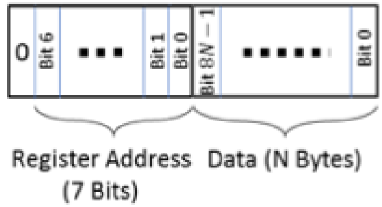


Figure 3-3: Bit Indexing Scheme for Configuration Registers

If the sensor receives a read command trying to access a register that is designated as RFU, the address is included in the error response as described below.

Write/Error Response: A message UL is sent on ***LoRaWAN port 101*** with the frame format as shown in Figure 3-4.

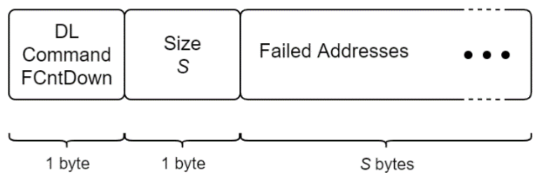


Figure 3-4: The *LoRaWAN port 101* Write/Error Response UL Frame Format

The contents of the frame include:

- *DL Command FCntDown*: the last byte (LSB) of the LoRaWAN frame count down number of the DL payload which contained the command block that elicited this response (LoRa Alliance, Inc., 2016).
- *Size*: the number of registers, *S*, that were <u>NOT</u> successfully written to, and therefore the size of the rest of the payload. *S* can range from 0 to 255.
- *Failed Addresses*: the address(es) of the register(s) where the command(s) failed.

If all commands were successful, *S* = 0x 00 and no failed addresses are included. This includes if a redundant write command was issued (i.e., the value of that register did not change).

As soon as the sensor encounters an invalid command block (read or write), the address of that command block is added to the ***LoRaWAN port 101*** response and no further command blocks are processed.

NOTES:

- If anti-bricking is activated, this is considered an unsuccessful command and register address 0x 21 will be added to the ***LoRaWAN port 101*** response. See section 4.2.1.1 for more details about anti-bricking.
- If there were any C&C operations queued to be executed but 1 or more command blocks in the payload were unsuccessful, the C&C commands are not executed, and their addresses are added to the ***LoRaWAN port 101*** response.
- If the DL payload had a mix of read and write command blocks, the read responses are sent separately on ***LoRaWAN port 100*** as described above. In this case, the read responses are sent first and the write/error responses after.

3.3.1 Example of Response to DL Command Payloads

- ***LoRaWAN port 101:*** **0x 0F 00**
  - 0x 0F → Response to write command in DL with FCntDown ending in 15
  - 0x 00 → Size = 0; no failed write commands

- ***LoRaWAN port 101:*** **0x 03 04 15 16 17 18**
  - 0x 03 → Response to write command in DL with FCntDown ending in 3
  - 0x 04 → Size = 4; 4 failed write commands
  - 0x 15 16 17 18 → The write commands attempting to overwrite registers 0x 15, 0x 16, 0x 17, and 0x 18 all failed.

4 Basic Operation Configuration

The basic functionality of the SEAL/SEAL Ex can be broken down into the following categories:

- **LoRaMAC Options**: LoRaWAN general parameters and behaviour as defined by the LoRaWAN Specifications (LoRa Alliance, July 2016).
- **Periodic Report Scheduling**: Scheme for scheduling regular sensor data reports.
- **Battery Management**: Keeping track of consumed battery charge.
- **General Command and Control Operations**: Reading SW metadata, saving configuration settings, resetting to factory default, and sensor restart.

In the following subsections, the operational descriptions, report formats, and configurable settings for each category are explained.

4.1 LoRaMAC Configuration

The LoRaMAC options manage specific LoRaWAN-specified MAC configuration parameters that the sensor initializes on start-up and utilizes during run-time. The definitions for these parameters are outlined in the LoRaWAN Specifications and Regional Parameters (LoRa Alliance, Feb 2017), (LoRa Alliance, July 2016). For detailed descriptions of these parameters and their expected behavior, please refer to these sources, as they are beyond the scope of this Technical Reference Manual (TRM).

4.1.1 Configuration Settings

Table 4-1 shows the MAC configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Table 4-1: LoRaMAC Options Configuration Registers

Address	Name	Size	Access	Description	JSON Variable	Default
0x 10	Join Mode	2 B	R/W	• Bits 0-14: RFU • Bit 14: ABP/OTAA mode	*loramac_join_mode: <value> (unsigned/no unit)*	OTAA mode

Address	Name	Size	Access	Description	JSON Variable	Default
0x 11	Options	2 B	See description	• Bits 0 (Read/Write): 0: Unconfirmed 1: Confirmed • Bit 1 (Read Only): 1 0: Private Sync Word 1: Public Sync Word • Bit 2 (Read/Write): 0: Duty Cycle Disabled 1: Duty Cycle Enabled • Bit 3 (Read/Write): 0: ADR Disabled 1: ADR Enabled • Bits 4-15: RFU	*loramac_opts: {* *confirm_mode: <value>, (unsigned/no unit)* *sync_word: <value>, (unsigned/no unit)* *duty_cycle: <value>, (unsigned/no unit)* *adr: <value> (unsigned/no unit)* *}*	*Unconfirmed UL* *Public Sync Word* *Duty Cycle Enabled*[4] *ADR Enabled*
0x 12	DR and Tx Power[5]	2 B	R/W	• Bits 0-3: Default Tx power • Bits 4-7: RFU • Bits 8-11: Default DR number • Bits 12-15: RFU	*loramac_dr_tx: {* *dr_number: <value>, (unsigned/no unit)* *tx_power_number: <value> (unsigned/no unit)* *}*	*DR4* *Tx Power 0 (as per* Table 4-2*)*
0x 13	Rx2 Window	5 B	R/W	• Bits 0-7: DR for Rx2 • Bits 8-39: Channel frequency in Hz for Rx2	*loramac_rx2: {* *frequency: <value>, (unsigned/Hz)* *dr_number: <value> (unsigned/no unit)* *}*	*As per* Table 4-2

[4] **WARNING**: Disabling the duty cycle in certain regions makes the sensor non-compliant with the LoRaWAN Specifications [4]. It is recommended that the duty cycle remains enabled. In the LoRa RF regions where there is no duty cycle limitation, the "enabled duty cycle" configuration is ignored.

[5] Tx power number m translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [5].

Table 4-2: Default Max Tx Power, Rx2 Channel Frequency, and Rx 2 DR Number by Regions

RF Region	Max Tx EIRP[6] [dBm]	Channel Frequency for Rx2 Window [Hz]	DR Number for Rx2 Window
EU868	16	869525000	0
US915	30	923300000	8
AS923	16	923200000	2
AU915	30	923300000	8
IN865	30	866550000	2
KR920	14	921900000	0
RU864	16	869100000	0

Note: Modifying these LoRaMAC settings only changes them in the sensor; LoRaMAC setting in the NS may also need to be changed depending on the desired use case and to ensure a sensor is not stranded without being able to communicate with the network. Modifying configuration parameters in the NS is outside the scope of this document.

4.1.2 LoRaMAC Config Examples

- Switch Device to ABP Mode:
  - DL payload: **0x 90 00 00**
    - Register 0x 10 with bit 7 set to 1 = 0x 90
    - Desired option: register value with bit 15 set to 0 = 0x 00 00

- Disable ADR, keep Duty Cycle enabled, and use confirmed ULs:
  - DL payload: **0x 91 00 07**
    - Register 0x 11 with bit 7 set to 1 = 0x 91
    - Desired options: register value with bit 3 set to 0, bit 2 set to 1, bit 1 set to 1, and bit 0 set to 1 = 0x 00 07

- Set default DR number to 3, default Tx power number to 4, and read the current Rx2 settings:
  - DL payload: **0x 92 03 04 13**
    - Register 0x 12 with bit 7 set to 0 = 0x 92
    - DR3 = 0x 03
    - Tx 4 = 0x 04
    - Register 0x 13 with bit 7 set to 0 = 0x 13

[6] These are Tx power *setpoints* and are the maximum allowable by the LoRaWAN regional parameters specification [5]. The actual Tx power of the sensor is limited by the radio transceiver, which is 15 dBm. Therefore, a setpoint greater than 15 dBm will be equivalent to a setpoint of 15 dBm or the Max Tx EIRP for the region, whichever is lower.

4.2 Periodic Reporting Scheduling

4.2.1 Operation Description

All periodic reporting of sensor data is synchronized around ticks. The *core tick* is simply a user-configurable time base unit that is used to schedule sensor measurements. For each transducer or subsystem in the sensor, the number of elapsed ticks between data transmissions is configurable. These reporting periods are defined by the following equation:

<Data Type> *Reporting Period* = *Seconds per Core Tick* × *Ticks per* <Data Type>

The available options for periodically reported data types are listed below. That is, <Data Type> can be:

- **Battery**: Remaining capacity [%], remaining lifetime [days], or both. See section 4.3 for battery management details.
- **Geolocation Update:** The results from a geolocation scan cycle**.** The results sent depend on which scan technologies are enabled and can include
    - GNSS position fix information
        - Latitude
        - Longitude
        - Altitude
        - Groundspeed
    - GNSS diagnostics information
        - Position accuracies (vertical and horizontal)
        - Datalogging information
        - GNSS signal information such as SNR
    - Discovered BLE device MAC addresses and RSSIs.

  2 different update periods can be defined; 1 that is used when the sensor is in the NORMAL state and the other when in EMERGENCY state. See section 4.3 for more information on these states
- **Accelerometer**: Acceleration vector [*g*] in three axes. See section 9 for accelerometer operation details.
- **Ambient Temperature**: Temperature of the ambient environment [°C]. See section 10 for environment sensing details.

NOTES: *Seconds per Core Tick* cannot be set to 0; periodic transmissions cannot be globally disabled.

If <Data Type> *Reporting Period* equals 0, it means that periodic reporting is disabled for that data type. Since *Seconds per Core Tick* cannot be set to 0, the above equation can only equal 0 when *Ticks per* <Data Type> is equal to 0. Therefore, to disable the periodic reporting of a specific data type, set its *Ticks per* <Data Type> to 0.

Additionally, no periodic uplinks are sent when the SEAL/SEAL Ex is in inactivity sleep.

The default reporting behaviour is:

- 1 battery report per day.
- 1 geolocation update every 15 minutes.
- 1 status update every 15 minutes

These settings only control the scheduling of reporting data, not *what* is reported; the format and/or content of the reported payloads may depend on other configuration settings. Additionally, the periodic report scheduling settings only affect *periodic* reporting behaviour and do not affect *event-based* reporting behaviour. To configure behaviour not related to the scheduling of reports, refer to the relevant sections for the subsystem or transducer being used.

It is not recommended to set the geolocation update reporting periods to less than 3.5 min.

The first periodic report for every enabled report type occurs right after the sensor successfully joins the network. That is, tick 1 occurs right after successful join. A consequence of this is that, using the default battery reporting configuration as an example, the first battery report will occur immediately after join, but the next one will occur 23 hours later (everyone thereafter will occur at the expected 24-hour intervals).

4.2.1.1 Anti-bricking Strategy

As a Class-A LoRaWAN end-device, the SEAL/SEAL Ex sensor can only be receptable to a DL in the short period after sending an UL. Therefore, if the sensor is configured to send periodic ULs very infrequently or not at all, it could become impossible to send a DL command. A sensor in a “stranded” state like this is referred to as *bricked*.

SEAL/SEAL Ex can manually force a UL by pressing the emergency button which cannot be disabled, so it is impossible to *completely* brick the sensor. However, there are use cases in which using the emergency button to trigger the sensor may not be a convenient option, e.g., due to special application integration that is in place in case of emergency. In this use-case, a strategy to avoid bricking the sensor is beneficial and therefore included as a SW feature.

The anti-bricking strategy is summarized by the following statement:

The Battery Reporting Period cannot be set to a value greater than 1 day.

Consequently, it is impossible to completely disable periodic reporting. This is accomplished by restricting acceptable values of the tick registers. Specifically:

1. Register 0x 20: S*econds per Core Tick* cannot be set to 0.

   This ensures that all periodic reporting cannot be disabled at once.

2. The equation in below must be nonzero and less than or equal to 1 day (86 400 s) for the battery report. This ensures that at a minimum, the sensor will send a battery report UL once per day. That is, the following must be true:

$$\textit{Battery Reporting Period} = \textit{Seconds per Core Tick} \times \textit{Ticks per Battery}$$

$$0 < \textit{Battery Reporting Period} \leq 1 \text{ day}$$

$$0 < \textit{Battery Reporting Period} \leq 86\,400 \text{ s}$$

If the SW detects that a configuration has been set which does not satisfy the above condition, the *Ticks per Battery* is automatically set to $\left\lfloor \frac{86\,400 \text{ s}}{\textit{Seconds per Core Tick}} \right\rfloor$.

4.2.2 Configuration Settings

Table 4-3 lists the registers used to configure the periodic reporting periods. *Seconds per Core Tick* is configured using register 0x 20, and the *Ticks per* <Data Type> are configured using registers 0x 21 through 0x 27. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in section 3.1.

Table 4-3: Periodic Report Scheduling Configuration Registers

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x21	Ticks per Battery	R/W	2 B	• Ticks between battery reports • Acceptable values: 1,2…65535 • 0, Other values: Invalid	*ticks_battery: <value> (number/no unit)*	1440 ticks = 1 day period **0x 05 A0**
0x22	Ticks in NORMAL State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in NORMAL state. • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic reports in NORMAL state • Other values: Invalid	*ticks_normal_state: <value> (number/no unit)*	15 ticks = 15 mins period **0x 00 0F**

Address	Name	Access	Size	Description	JSON Variable	Default
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in EMERGENCY state. • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state • Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min period **0x 00 01**
0x24	Ticks per Accelerometer	R/W	2 B	• Ticks between accelerometer reports • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic accelerometer reports • Other values: Invalid	*ticks_accelerometer: <value> (number/no unit)*	0 tick = disabled **0x 00 00**
0x25	Ticks per Temperature	R/W	2 B	• Ticks between temperature reports • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic temperature reports • Other values: Invalid	*ticks_temperature: <value> (number/no unit)*	0 tick = disabled **0x 00 00**
0x26	Ticks for Safety Status in NORMAL State	R/W	2 B	• Ticks between Safety Status reports in NORMAL state • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic Safety Status reports in NORMAL state • Other values: Invalid	*ticks_safety_status_normal: <value> (number/no unit)*	5 ticks = 5 mins **0x 00 05**
0x27	Tick per Pressure report (either uncalibrated or calibrated)	R/W	2 B	• Bits 0 – 7: Period between consecutive pressure reports • Acceptable values: 0,1,2…65535 • 0: Disables periodic pressure reports • Other values: Invalid	*ticks_pressure: <value> (unsigned/number/no unit)*	0 tick = disabled **0x 00 00**

4.2.2.1 *Example DL Payloads*

- Change core tick to 1 hour:
    - DL payload: **0x A0 00 00 0E 10**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - Seconds per Core Tick = 3 600 = 0x 00 00 0E 10

- Read current value of Seconds per Core Tick:
    - DL payload: **0x 20**
        - Register 0x 20 with bit 7 set to 0 = 0x 20

- Change settings to update the geolocation every 5 mins in NORMAL state
    - DL payload: **0x A0 00 00 00 3C A2 00 05**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - Seconds per core tick = 60 s = 0x 00 00 00 3C
        - Register 0x 22 with bit 7 set to 1 = 0x A3
        - Ticks in NORMAL state = 5 ticks = 0x 00 05

4.3 Battery Management

The SEAL/SEAL Ex has a battery management system that monitors battery energy depletion and presents the remaining energy in user friendly ways.

4.3.1 Operation Description

The remaining battery capacity is the percentage of battery energy still available to the sensor relative to a fully charged battery. The SW always keeps track of this value, which gradually drops throughout normal operation and rapidly drops in EMERGENCY operation. The rate at which the capacity drop depends on configuration; for example, a sensor configured to send a UL report every 15 mins will have a larger energy consumption rate than one that is configured to send a UL report every 60 mins.

The remaining battery lifetime is the estimated number of days remaining before the battery dies. The SW estimates this value, which may fluctuate up and down throughout the normal operation of the sensor. Variations occur because some operations, such as GNSS scans, have variable durations depending on environmental conditions. For instance, an outdoor scan with a clear sky view completes faster than an indoor scan with poor visibility. Additionally, configuration settings can be changed at any time during normal operation, affecting the energy consumption rate.

4.3.1.1 *Resets and Battery Replacement*

The battery management system bases calculations on the average nominal battery capacity of a new battery. When the battery is replaced, the remaining battery capacity and lifetime values are automatically reset to reflect a fully charged battery. Any hard reset (i.e., any complete loss of power to the battery contacts) will result in the battery management system resetting.

Battery management data will not reset when a soft reset occurs (i.e., when a magnet reset, reset button press, OTA reset command, or Tracker/Beacon Mode switch occurs).

4.3.1.2 Battery Passivation

Due to the chemistry of the batteries, a *passivation layer* can build up internally during periods when the battery has little to no charge flowing out (e.g. when sensor is in DEEP SLEEP). This layer can prevent high pulse current draws for a few minutes at the time of first use (Jauch Marketing Team, 2020). As the sensor begins drawing current from the battery, the passivation begins to break down. The longer the dormant state of the battery, the longer it takes to break the passivation layer down.

At the user-level, passivation means that the first time a sensor is woken up or powered on with a new battery, it is possible that there is some ramp-up time required before it can complete the join procedure. Until the device detects that it can get enough current from the battery, it will constantly reset in attempt to break the passivation layer down. If this occurs, the LEDs will go through the normal power-on patterns and begin the join pattern for about 1s before a reset occurs.

Some example circumstances which may lead to battery passivation include:

- The battery is replaced with a new one, including new devices from the factory, where the battery may have been unused for more than a month.
- The sensor was in DEEP SLEEP for longer than a month, such as while being in long-term storage or warehouse stock.

4.3.2 UL Report Frame Formats

Battery reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the battery report frame formats are listed in Table 4-4. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 4-4: Battery Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Remaining Battery Capacity	0x 00	0x D3	1 B	Percentage	• 1% / LSb (unsigned)	*rem_batt_capacity: <value> (unsigned/%)*
Remaining Battery Lifetime	0x 00	0x BD	2 B	Days	• 1 day / LSb	*rem_batt_days: <value> (unsigned/days)*

4.3.2.1 Example UL Payloads

- **0x 00 D3 32 00 BD 01 E6**
  - Channel ID = 0x 00, Type ID = 0x D3 → remaining battery capacity data report
  - 0x 32 = 50 × 1% = 50%
  - Channel ID = 0x 00, Type ID = 0x BD → remaining battery lifetime data report
  - 0x 01 E6 = 486 × 1 day = 486 days

4.3.3 Configuration Settings

All configuration registers that control battery management behaviour are listed in Table 4-5. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Size	Access	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x21	Ticks per Battery	2 B	R/W	• Ticks between battery reports • Acceptable values: 1,2…65535 • 0, Other values: Invalid	*ticks_battery: <value> (number/no unit)*	1440 ticks = 1 day period **0x 05 A0**
0x68	Battery Report Options	1 B	R/W	• Bits 0, 3-7: 0, otherwise invalid • Bit 1: 0/1 = Remaining battery capacity [%] not reported/reported • Bit 2: Remaining battery lifetime [days] not reported/reported • Bits 1-2 all set to 0: Invalid	*battery_options{* *battery_lifetime_dys_report: <value> (string/no unit)* *battery_lifetime_pct_report: <value> (string/no unit)* *}*	Only battery lifetime report in percentage enabled **0x 02**

Address	Name	Size	Access	Description	JSON Variable	Default
0x69	Low Battery Threshold	2 B	R/W	• Bits 0-13: Low battery threshold value in case of percentage: 1%/LSB in case of days: 1 day/LSB • Bits 14-15: Threshold type 1: Threshold on capacity in percentage 2: Threshold on remaining lifetime in days • Bit 0,3: 0, otherwise invalid.	*battery_threshold* *{* *low_battery_threshold_value: <value> (number/%-days)* *low_battery_threshold_type: <value> (string/no unit)* *}*	Threshold = 10% Threshold type = threshold on battery capacity in percentage **0x 40 0A**

Table 4-5: Battery Management Configuration Registers

4.3.3.1 *Example DL Payloads*

- Schedule battery reports every 48 hours:
  - DL payload: **0x A0 00 00 0E 10 A1 00 30**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 3600 s/core tick = 0x 00 00 0E 10
    - Register 0x 21 with bit 7 set to 1 = 0x A1
    - Report every 48 ticks = 0x 00 30

- Include remaining battery capacity and battery life in battery reports:
  - DL payload: **0x E8 06**
    - Register 0x 68 with bit 7 set to 1 = 0x E8
    - Value bits 1 and 2 set to 1 = 0x 06

- Set a low battery threshold of 30 days
  - DL payload: E9 80 1E
    - Register 0x 69 with bit 7 set to 1 = 0x E9
    - 80 = Bit 15 set to 1 hence remaining battery lifetime selected
    - 1E = 30 days threshold value

4.4 General Command-and-Control Operations

The general command and control operations supported by the SEAL/SEAL Ex are:

- Saving the current configuration settings to flash memory.
- Restarting the sensor (soft reset).
- Reading FW metadata (SW version numbers).
- Factory reset of configuration settings.

To perform a command-and-control operation, the appropriate register must be accessed. Table 4-6 lists the details of the command-and-control registers. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in the following subsections and in section 3.2.

Table 4-6: Command & Control Register Details

Address	Access	Name	Size	Description and Options	JSON Variable (Type/Unit)
0x 70	X	Flash Write Command	2 B	• Bit 14: 0/1 = Do not write/Write LoRaMAC Configuration • Bit 13: 0/1 = Do not write/Write App Configuration • Bit 0: 0/1 = Do not restart/Restart Sensor • Bits 1-12, 15: Ignored	*write_to_flash {* *app_config: <value>, (unsigned/no unit)* *lora_config: <value>, (unsigned/no unit)* *restart_sensor: <value> (unsigned/no unit)* *}*

Address	Access	Name	Size	Description and Options	JSON Variable (Type/Unit)
0x 71	RO	FW Metadata	7 B	• Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRa Basics modem version major • Bits 16-23: LoRa Basics modem version minor • Bits 8-15: LoRa Basics modem version revision • Bits 0-7: LoRaMAC region number[7]	*metadata {* *app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value>, (unsigned/no unit)* *app_ver_revision: <value>, (unsigned/no unit)* *modem_ver_major: <value>, (unsigned/no unit)* *modem_ver_minor: <value>, (unsigned/no unit)* *modem_ver_revision: <value>, (unsigned/no unit)* *loramac_region: <value> (unsigned/no unit)* *}*
0x 72	X	Reset Configuration to Factory Defaults	1 B	• 0x 0A: Reset app configuration • 0x B0: Reset LoRaMAC configuration • 0x BA: Reset both App and LoRaMAC configurations • Any other value: Invalid	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*

4.4.1 Save Current Configuration Settings

Configuration changes are not retained after a power cycle (soft or hard reset) unless they are saved in the non-volatile flash memory. To do so, the *Flash Write Command* register, 0x 70, must be accessed to execute the save-to-flash operation. The DL payload structure is as shown in Figure 3-2. That is, with the first byte being the register address with bit 7 set to 1 (i.e., 0x F0) and the data indicating which options are selected of those listed in Table 4-6. Specifically, the payloads for the different save options (without restarting the sensor) are:

- **0x F0 20 00**: Save current configuration settings of all FW application registers (0x 20 through 0x 6F) to flash.

[7] Defined by Table 4-7.

- **0x F0 40 00**: Save current configuration settings of all FW LoRaMAC Option registers (0x 11 and 0x 12) to flash.
- **0x F0 60 00**: Save current configuration settings of both FW application and LoRaMAC Options registers to flash.

The save-to-flash command can be sent in a separate DL at any time or be included in the same payload as other read and write command blocks. In the latter case, all other command blocks are always executed first, so that settings can be changed and saved in a single payload.

Register 0x 70 also supports a reset option, described in section 4.4.2. When this option is not selected, the sensor will send a write response (as described in section 3.3) after receiving the flash write command.

4.4.2 Sensor Restart

The *Flash Write Command* register, 0x 70, is used to restart the device via soft reset.

This is done by setting bit 0 to 1. This can be used alone or in conjunction with any of the save-to-flash operation options listed in section 4.4.1 above. In the former case, the explicit payload is **0x F0 00 01**.

Immediately after receiving the reset command in a DL, the sensor will reset.

NOTE: Do not send the reset command as a confirmed DL. The reset command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[8].

4.4.3 Read FW Metadata

The *FW Metadata* register, 0x 71, can be accessed to read the *application version number*, *LoRa Basics modem version number*, and *LoRaMAC region number*. The read metadata command is formulated as a regular read command. Explicitly, the command blocks in the payload would be **0x 71** for FW.

After receiving one of these commands, the sensor will respond with a UL message containing the following:

- For FW metadata:
    - The fist byte is the register address: 0x 71.
    - Bits 32 to 55 of the value contain the application revision numbers which define the FW version. The FW version is reported in the format as shown in Figure 4-1, which is shown using the example FW v1.0.15 (value 0x 01 00 0F).

[8] Some network servers, including TEKTELIC's KONA Core, have an optional setting to clear the DL queue upon receiving a JOIN REQUEST for a new session. This is an alternative solution if confirmed DLs are required.

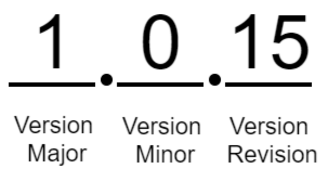


Figure 4-1: Example FW Version Format

- Bits 8 to 31 of the value contain the LoRa Basics modem version numbers. The format is the same as shown in Figure 4-1. This number is not to be confused with the LoRaWAN specification version according to the LoRa Alliance standards. The LoRaMAC version number is the version of the FW used by the LR1110.
- The last byte contains the LoRaMAC region number. Current LoRaMAC regions and corresponding region numbers for the sensor are listed in Table 4-7.

Table 4-7: Available LoRaMAC Regions and Channel Plan IDs

LoRaMAC Region	Channel Plan ID
EU868	1
US915	2
AU915	5
AS923-1	7
AS923-2	8
AS923-3	9
KR920	10
IN865	11
RU864	12
AS923-4	13

4.4.4 Factory Reset

The *Reset Configuration to Factory Defaults* register, 0x 72, is used to reset all the configuration register values (0x 10 to 0x 6F) back to the default settings.

The DL payload structure is as shown in Figure 3-3. That is, with the first byte being the register address with bit 7 set to 1 (i.e., 0x F2) and the data indicating which options are selected of those listed in Table 4-6. Specifically, the payloads for the different factory reset options are:

- **0x F2 0A**: Restore configuration settings of all FW application registers (0x 20 to 0x 5C) to factory default values.
- **0x F2 B0**: Restore configuration settings of all FW LoRaMAC Options registers (0x 10 to 0x 13) to factory default values.
- **0x F2 BA**: Restore configuration settings of both FW application and LoRaMAC Options registers to factory default values.

The factory command can be sent in a separate DL at any time or be included in the same payload as the other read and write command blocks. In the latter case, only the factory command block is executed while all other commands are discarded.

After receiving the factory reset command, the sensor always restarts immediately.

NOTE: Do not send the factory reset command as a confirmed DL. The command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[9].

[9] Some network servers, including TEKTELIC's KONA Core, have an optional setting to clear the DL queue upon receiving a JOIN REQUEST for a new session. This is an alternative solution if confirmed DLs are required.

5 External User Interfaces

The SEAL/SEAL Ex sensor features five LEDs, with two on the top and three on the front, and a buzzer. The non-clip variant has two buttons, while the clip variant has three buttons, with the additional button being the safety hook button. Figure 5-1 and Figure 5-2 below show different perspectives of the SEAL/SEAL Ex with and without a clip, respectively.

Figure 5-1: SEAL/SEAL Ex Clip Variant

Figure 5-2: SEAL/SEAL Ex Non-Clip Variant

Figure 5-3 below shows the location of the user-accessible external interfaces for the clip variant. The non-clip variant has all the same external interfaces, except for the safety hook button.

Figure 5-3: External User Interfaces on SEAL/SEAL Ex Clip variant

5.1 Buttons

The SEAL/SEAL Ex is outfitted with buttons designed to initiate actions or modify the system's behavior. The number of buttons differs between the non-clip and clip variants, with two buttons on the former and three buttons on the latter. These buttons include:

1. Emergency button
2. Mute button
3. Safety hook button (Clip variants ONLY)

5.1.1 Emergency Button (EB)

All variants of the SEAL/SEAL Ex feature a side orange color button known as the Emergency Button (EB). This button is strategically positioned to minimize the likelihood of false or unintended presses, while remaining easily accessible for effortless operation even with gloves.

5.1.1.1 Operation Description

The button serves two purposes related to the activation and deactivation of the emergency button alarm, outlined as follows:

1. Emergency Button Alarm Activation: Pressing and holding the EB for 1s transitions the SEAL/SEAL Ex into an active Emergency Button Alarm State if it's not already in that state. If the SEAL/SEAL Ex is already in the Emergency State, pressing the EB for a second has no effect. Refer to section 6 for more information on emergency alarms.
2. Emergency Button Alarm Deactivation: Pressing and holding the EB for at least 5s when the SEAL/SEAL Ex is in an Active Emergency state triggers a state change back to NORMAL state, if all other EMERGENCY states are cleared, as explained in section 6.

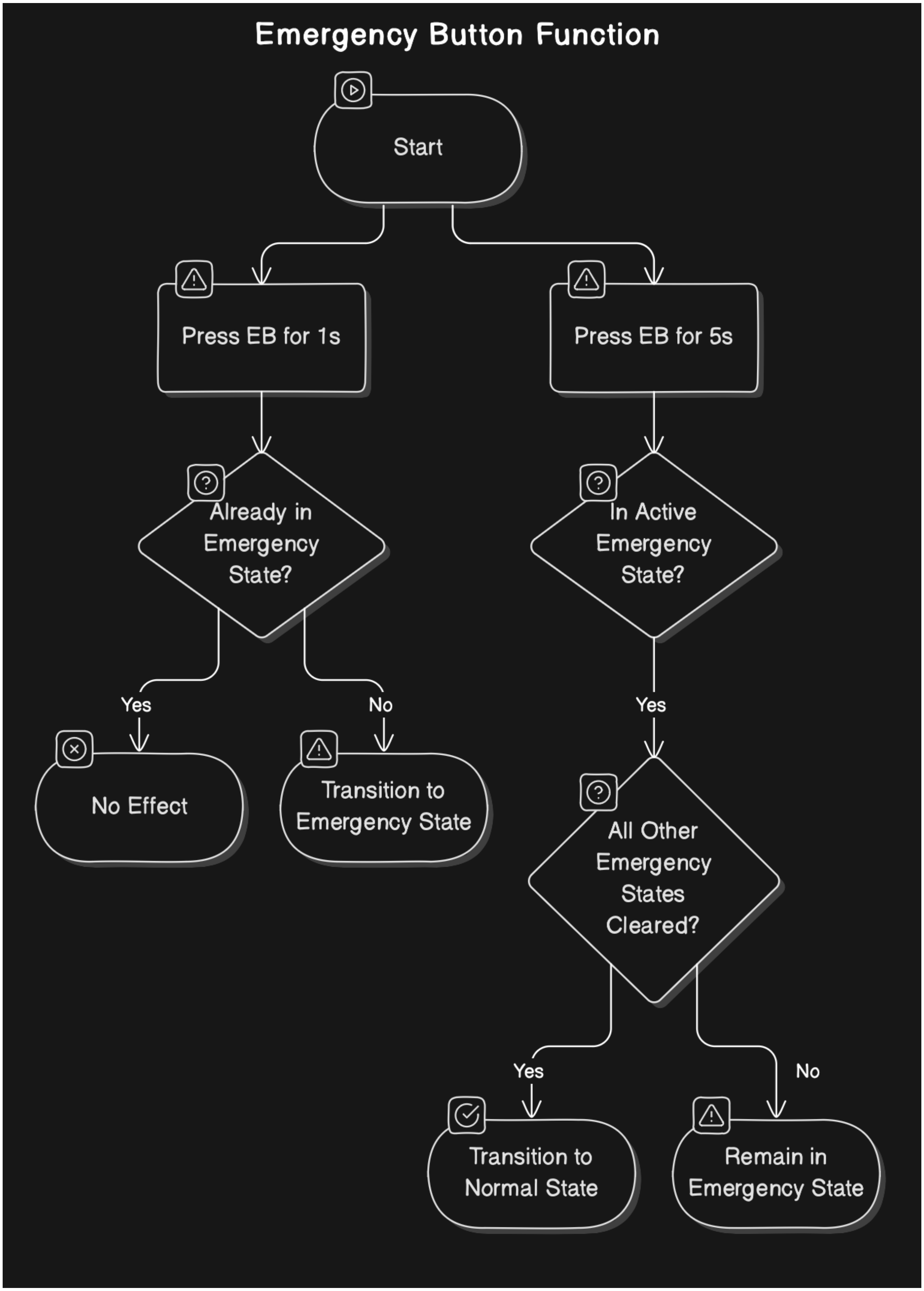


Figure 5-4: Activating and Deactivating Emergency State by Emergency Button (EB)

5.1.2 Mute Button (MB)

All variants of SEAL/SEAL Ex include a blue color button at the base of the sensor referred to as the Mute Button.

5.1.2.1 Operation Description

The mute button serves as both a buzzer mute/disable function and a reset button for the SEAL/SEAL Ex. The following details these uses of the mute button:

1. Mute and unmute the buzzer: Pressing the mute button for 1s mutes the buzzer for a configurable duration referred to as the "buzzer disable timeout" (see section 5.1.2.2). Once this timeout elapses, the system automatically re-enables the buzzer. Conversely, if the buzzer is already disabled, pressing the mute button for 1s re-enables it.

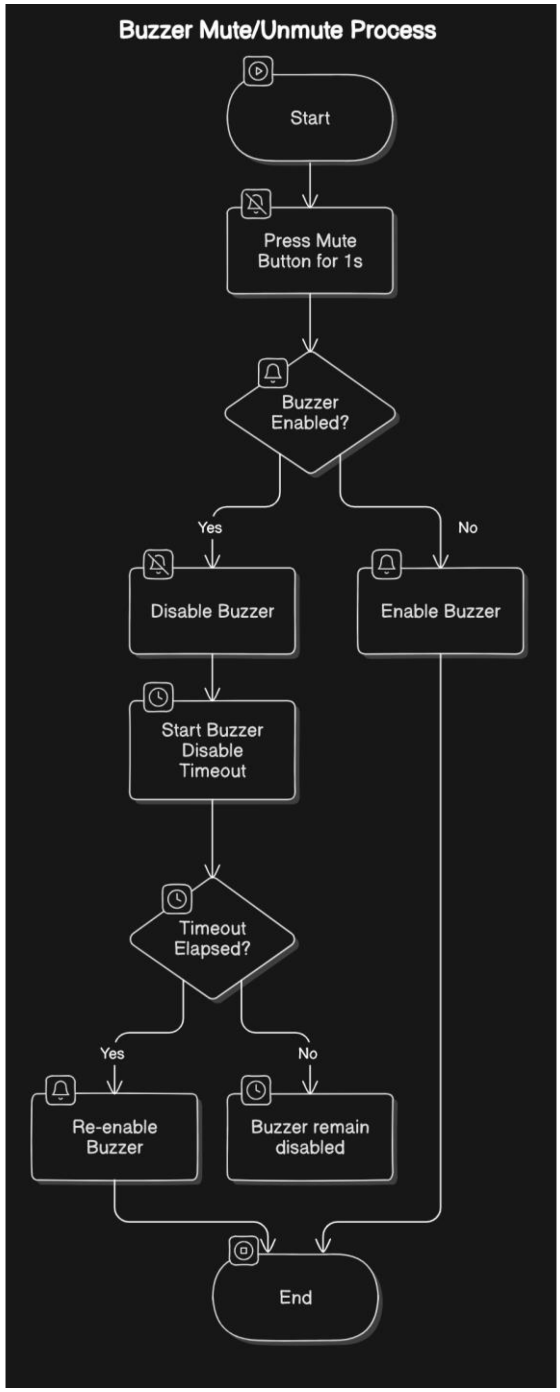


Figure 5-5: Muting and Unmuting the Buzzer

2. Reset the SEAL/SEAL Ex: When the press pattern depicted in Figure 5-6 is applied to the mute button during operation (i.e. after a successful Network Join), the SEAL/SEAL Ex initiates a reset.
3. Put the SEAL/SEAL Ex in and out of deep sleep: When the press pattern shown in Figure 5-6 is applied to the mute button during the Join operation, the SEAL/SEAL Ex enters deep sleep mode. Applying the same pattern while in deep sleep mode wakes the SEAL/SEAL Ex up.

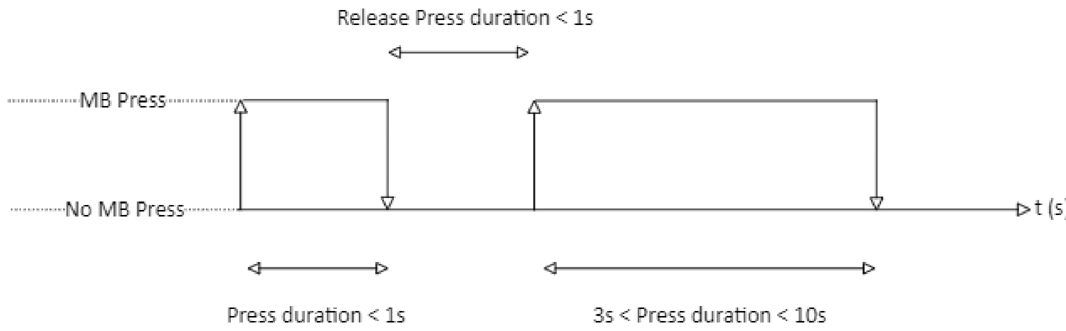


Figure 5-6: Mute Button Press Pattern for Reset and Deep Sleep

5.1.2.2 Configuration Settings

All configuration registers that control mute button behaviour are listed in Table 5-1. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Size	Access	Description	JSON Variable	Default
0x6C	Buzzer Disable Timeout	R/W	1 B	• Buzzer disable timeout in mins • Acceptable values: 1, 2, 3, …, 255 • 0, other values: Invalid	*buzzer_disable_timeout: <value> (number/min)*	60 mins **0x 3C**

Table 5-1: Mute Button Configuration Register

5.1.2.2.1 Example DL Payloads

- Set buzzer disable timeout to 10 mins:
  - DL payload: **0x EC 0A**
    - Register 0x 6C with bit 7 set to 1 = 0x EC
    - Set timeout to 10 mins = 0x 0A

5.1.3 Safety Hook Button (SHB)

NOTE: This only applies to SEAL/SEAL Ex with Clip variants.

Clip variants of the SEAL/SEAL Ex feature a gray color button positioned beneath the "hook" on the front panel, known as the Safety Hook Button (SHB).

5.1.3.1 Operation Description

The safety hook button serves to detect the presence of a safety harness clip. The following outlines the usage of the safety hook button:

1. Safety Hook Alarm Activation: When the user secures their safety harness clip to the hook on the front panel of the SEAL/SEAL Ex for a user configurable period (see section 5.1.3.2), the weight of the hook presses the button, triggering a safety hook alarm. This alarm is activated because the SEAL/SEAL Ex assumes that both ends of the safety harness are attached to the user's body and not latched to a support structure, posing a potential hazard. Additional conditions, such as checking if the SEAL/SEAL Ex is in a danger zone, can also contribute to the activation criteria. Refer to section 6.2 for more details on the safety hook alarm.
2. Safety Hook Alarm Deactivation: The safety hook alarm is deactivated when the safety harness is released from the front panel of the SEAL/SEAL Ex causing the safety hook button to be released, and all applicable conditions, such as being outside a danger zone, are met.

5.1.3.2 Configuration Settings

All configuration registers that control safety hook button behaviour are listed in Table 5-2. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x2C	Safety Hook Debounce Interval	R/W	1 B	• SHB debounce period in seconds • Acceptable values: 0,1, 2, 3, …, 255 • 0: disables debounce • other values: Invalid	*sh_debounce_interval: <value> (number/sec)*	10 s **0x 0A**

Table 5-2: Safety Hook Button Configuration Register

5.1.3.2.1 Example DL Payloads

- Set safety hook button debounce period to 0 s:
  - DL payload: **0x AC 00**
    - Register 0x 6C with bit 7 set to 1 = 0x EC
    - Set timeout to 0s = 0x 00
- Set safety hook button debounce period to 15 s:
  - DL payload: **0x AC 0F**
    - Register 0x 6C with bit 7 set to 1 = 0x EC
    - Set timeout to 15s = 0x 0F

5.2 Buzzer

The SEAL/SEAL Ex comes with a built-in buzzer, which is enabled by default but can be toggled on or off using the mute button (refer to Section 5.1.2). This buzzer serves as user feedback/acknowledgment for the activation and deactivation of all emergency alarms, including the Emergency Button (EB), Safety Hook (SH), Emergency Application Request (EAR), Human Fall detection, and Pressure/Elevation alarms. However, each alarm triggers a distinct buzz pattern tailored to its specific application as described below, enhancing user comprehension and responsiveness.

The general buzzer pattern is depicted in Figure 5-7 below

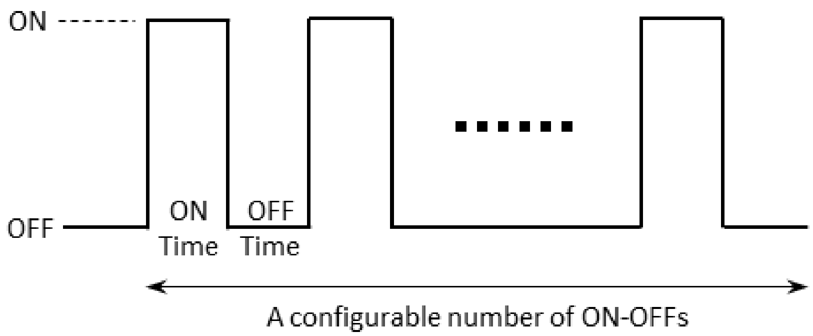


Figure 5-7: Supported Buzzer Pattern

5.2.1 EB, Fall, EAR, and Pressure/Elevation Alarms Buzzer pattern

All emergency states share a common buzz pattern for activation and deactivation, except for the Safety Hook alarm (See section 5.2.2). This section discusses this common pattern and the supported configuration registers.

5.2.1.1 Operation Description

When any combination of the Emergency Button (EB), Fall, Emergency Application Request (EAR), and Pressure/Elevation alarms are activated on the SEAL/SEAL Ex, the buzzer emits the following pattern:

1. The buzzer emits three (3) consecutive buzzes, each lasting 500 milliseconds, with a delay of 1 second between each buzz.
2. Once this pattern completes, normal system operation resumes without any further buzzer activity.

Conversely, when all of the EB, Fall, EAR, and Pressure/Elevation alarms are de-activated, the buzzer emits a different pattern:

1. The buzzer emits three (3) consecutive buzzes, each lasting 200 milliseconds, with a delay of 200 milliseconds between each buzz.
2. After this pattern concludes, normal system operation resumes without additional buzzer activity.

5.2.1.2 Configuration Settings Format

All configuration registers that control safety hook button behaviour are listed in Table 5-3. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Table 5-3: Buzzer Config Registers for EB, Fall, EAR, and Pressure/Elevation

Address	Name	Access	Size	Description	JSON Variable	Default
0x 28	Active Emergency Buzzer Config	R/W	3 B	• Bits 0-7: Emergency Active Buzz Pattern Period 0: Invalid • Bits 8-15: Emergency Active Buzz OFF time in milliseconds (0.1 sec/LSB) 0: Invalid • Bits 16-23: Emergency Active Buzz ON time in milliseconds (0.1 sec/LSB) 0: Invalid	*active_emerg_buzz_config{* *emerg_buzz_active_num_on_offs: <value> (number/no unit)* *emerg_buzz_active_off_time: <value> (number/sec)* *emerg_buzz_active_on_time: <value> (number/sec)* *}*	ON/OFF: 3 OFF: 1s ON: 500ms **0x 05 0A 03**
0x 29	Inactive Emergency Buzzer Config	R/W	3 B	• Bits 0-7: Emergency Inactive Buzz Pattern Period 0: Invalid • Bits 8-15: Emergency inactive Buzz OFF time in milliseconds (0.1 sec/LSB) 0: Invalid • Bits 16-23: Emergency Inactive Buzz ON time in milliseconds (0.1 sec/LSB) 0: Invalid	*inactive_emerg_buzz_config{* *emerg_buzz_inactive_num_on_offs: <value> (number/no unit)* *emerg_buzz_inactive_off_time : <value> (number/sec)* *emerg_buzz_inactive_on_time : <value> (number/sec)* *}*	ON/OFF: 3 OFF: 200ms ON: 200ms **0x 02 02 03**

5.2.1.2.1 Example DL Payloads

- Set active emergency buzzer config to ON for 1s, OFF for 2s, and number of ON/OFF cycle to 10:
    - DL payload: **0x A8 0A 14 0A**
        - Register 0x 28 with bit 7 set to 1 = 0x A8
        - Set ON period to 1s = 0x 0A
        - Set OFF to 2s = 0x 14
        - Set number of ON/OFF cycle to 10 = 0x 0A
- Set inactive emergency buzzer config to ON for 1s, OFF for 1s, and number of ON/OFF cycle to 5:
    - DL payload: **0x A9 0A 0A 05**
        - Register 0x 29 with bit 7 set to 1 = 0x A9
        - Set ON to 1s = 0x 0A
        - Set OFF to 1s = 0x 0A
        - Set number of ON/OFF cycle to 5 = 0x 05

5.2.2 Safety Hook Alarm Buzzer Pattern

The safety hook alarm has a distinct buzzer pattern, compared to the other emergency states discussed in section 5.2.1. This section discusses this pattern and the supported configuration registers.

5.2.2.1 *Operation Description*

When the Safety Hook Alarm is active, the buzzer emits the following pattern by default:

1. The buzzer emits two (2) consecutive buzzes, each lasting 400 milliseconds, with a delay of 100 millisecond between each buzz.
2. Next, there is a 10-second delay before step 1 is repeated. It's important to note that this delay timer begins counting from the start of the sequence. As step 1 takes about 1 second to complete a cycle, the observable delay is 9 seconds. This process continues until the safety hook emergency is resolved.

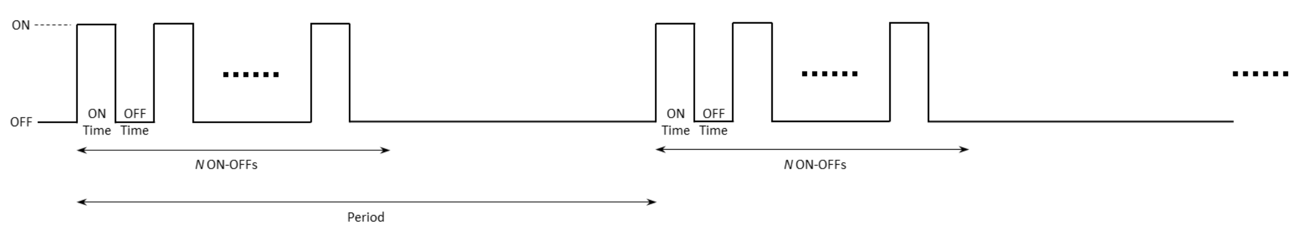


Figure 5-8: Safety Hook Alarm Buzz Pattern

This pattern is user configurable as seen in section 5.2.2.2.

The buzzer can be configured to emit the configured safety hook buzzer pattern in specific conditions such as:

- ALWAYS: the buzzer is triggered every time the safety hook button is pressed for a duration longer than the safety hook button debounce period (as described in section 5.1.3).

- In GNSS Danger Zones Only: The buzzer is activated only when the safety hook button is pressed for a duration longer than the safety hook button debounce period within designated GNSS danger zones (see section 7.2).
- In BLE Danger Zones Only: The buzzer is activated only when the safety hook button is pressed for a duration longer than the safety hook button debounce period within designated BLE danger zones (see section 8.2).
- In GNSS and BLE Danger Zones: The buzzer is activated only when the safety hook button is pressed for a duration longer than the safety hook button debounce period within either GNSS or BLE danger zones.

Conversely, when an active Safety Hook Alarm is resolved, normal system operation resumes without additional buzzer activity.

5.2.2.2 *Configuration Settings Format*

All configuration registers that control safety hook button behaviour are listed in Table 5-4. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Table 5-4: Buzzer Config Registers for Safety Hook Alarm

Address	Name	Access	Size	Description	JSON Variable	Default
0x 2D	Safety Hook Alarm Buzzer Config	R/W	5 B	• Bits 0-7: SH Buzz period (0.1s/LSB) 0: Invalid • Bits 8-15: Buzz ON/OFF cycle (1/LSB) 0: Invalid • Bits 16-23: SH Buzz OFF time (0.1s/LSB) 0: Invalid • Bits 24-31: SH Buzz ON time (0.1s/LSB) 0: Invalid • Bits 32-33: SH Alarm trigger 0: Always 1: IN GNSS DZ ONLY 2: IN BLE DZ ONLY	*safety_hook_buzz_config {* *sh_buzz_period: <value> (number/sec)* *sh_buzz_num_on_offs: <value> (number/no unit)* *sh_buzz_ off_time: <value> (number/sec)* *sh_buzz_ on_time: <value> (number/sec)* *sh_buzz_ trigger_type: <value> (string/no unit)* *}*	Period: 10s ON/OFF: 2 times OFF: 100ms ON: 400ms Trigger: ANY DZ **0x 03 04 01 02 64**

Address	Name	Access	Size	Description	JSON Variable	Default
				3: IN ANY DZ • Bits 34-39: 0, otherwise invalid		

5.2.2.2.1 Example DL Payloads

- Set active emergency buzzer config to always buzz, ON time of 500ms, OFF time of 200ms, 5 number of ON/OFFs, and 5s between each buzz cycle
  - DL payload: **0x AD 00 05 02 05 32**
    - Register 0x 2D with bit 7 set to 1 = 0x AD
    - Set trigger type to “always” = 00
    - Set ON period to 500 ms = 0x 05 = 5 x 0.1s = 500ms
    - Set OFF period to 200 ms = 0x 02 = 2 x 0.1s = 200ms
    - Set number of ON/OFF cycle to 5 = 0x 05 = 5 x 1 = 5 times
    - Set period between buzz pattern cycle to 5s = 0x 32 = 50 x 0.1s = 5s

5.3 LEDs

The SEAL/SEAL Ex is outfitted with two sets of amber-colored LEDs: the Top-Set LEDs (TS) comprising two LEDs and the Front-Set LEDs (FS) comprising three LEDs. Each set of LEDs functions collectively, meaning that the LEDs within each set blink in unison.

The subsections below present a breakdown of LED behaviors programmed for the SEAL/SEAL Ex for different states. It's important to note that each LED set runs only one LED pattern at a time. Also, only the Emergency and Low battery warnings are user configurable.

5.3.1 Power-On and Network Join LED Patterns

Note: The LED patterns described in this section are NOT user-configurable

When the sensor is woken up from DEEP SLEEP or reset:

1. Both **TS** and **FS** are OFF for approximately 0.5 s after any reset occurs.
2. Upon startup, the SW conducts its POST[10]. Both **TS** and **FS** are turned on when the POST begins.
3. When the POST ends (about 2 s), both **TS** and **FS** are turned off. Immediately following, the sensor will do 1 of 2 things, depending on the POST result:
   a. If the POST passes, **TS** is toggled ON and OFF 3 times: every 100 ms for 0.6 s, as shown in Figure 5-9. In this case, the LED pattern proceeds to step 4.

[10] POSTs, short for Power-On Self Tests, are a series of initialization tests performed by the SEAL/SEAL Ex immediately after powering on.

b. If the POST fails, **FS** is toggled ON and OFF 3 times: every 100 ms for 0.6 s, as shown in Figure 5-9. In this case, the device restarts and the LED pattern begins again at step 1 after approximately 4 s

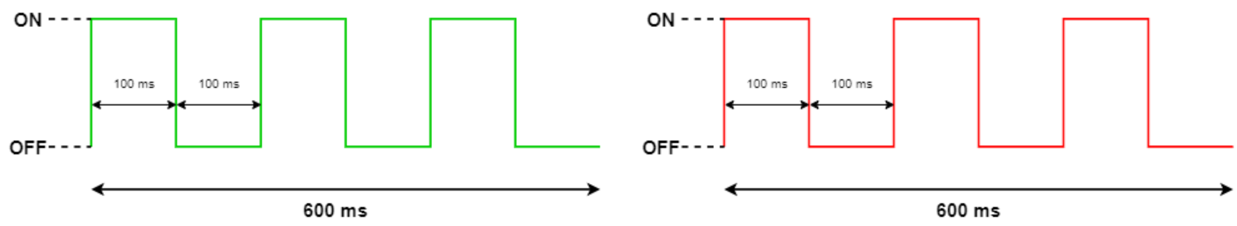


Figure 5-9: The TS POST Pass (left) and FS POST Failure (right) LED Patterns

4. After a successful POST, both **TS** and **FS** are turned off. Immediately following this, the sensor will enter JOIN mode and begin attempting to join the network with the LED pattern shown in
5. Figure 5-10.. For the first hour:
   a. **TS** is toggled ON and OFF every 50 ms for the first hour.
   b. **FS** flashes just once:
      i. with a pulse duration of 25 ms right after transmitting a JOIN REQUEST. This occurs at approximately 10 s intervals at the beginning of the join process, but at decreasing regularity the longer the join process continues due to battery saving measures and possible duty-cycle limitations in certain regions (LoRa Alliance, Feb 2017)
      ii. with a pulse duration of 100 ms right after receiving a JOIN ACCEPT. This will occur once, after which, the device will have joined the network and normal operation begins.

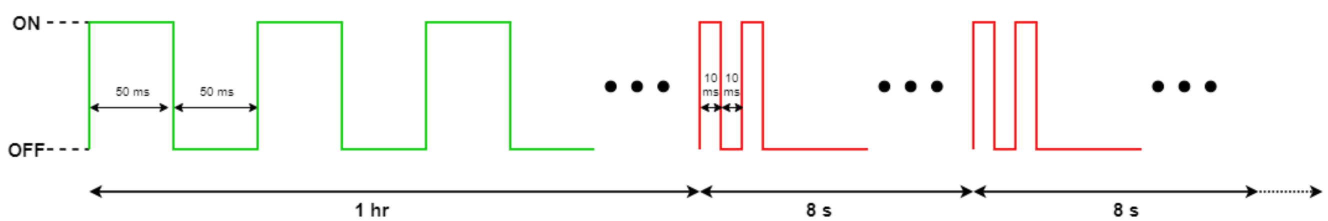


Figure 5-10: The LED Patterns During JOIN Mode

If the sensor has been unsuccessfully trying to join for more than an hour, it enters *join back-off mode* to conserve power. While the sensor still attempts to join, **TS** stops flashing and **FS** flashes twice (ON time: 10 ms, OFF time: 10 ms) every 8s.

5.3.2 Normal Operation LED Patterns

After the Sensor has joined the network:

b. **FS** flashes just once with a pulse duration of 25 ms right after transmitting an uplink.
c. **TS** flashes just once with a pulse duration of 100 ms right after receiving a downlink.
d. FS and TS flash with the configured durations in respective emergency and danger zone states, as discussed in section 5.3

5.3.3 DEEP SLEEP and Reset Pattern

Note: The LED patterns described in this section are NOT user-configurable

The sensor displays an LED indication when it is brought out of DEEP SLEEP or reset by applying the mute button pattern (see section 5.1.2).

If the mute button pattern was applied during operation (post successful join), the following LED pattern is observed:

1. There is a 1s to 3s pause with no LED activity while the device resets
2. Then, normal Power-On and Network Join LED patterns described in section 5.3.1 above occur.

If the mute button was applied during join, the following LED pattern is observed

1. There is a 1s to 3s pause with no LED activity while the device resets
2. Then, steps 1 to 3 of the Power-On and Network Join LED patterns described in section 5.3.1 above occur.
3. Immediately after that, **FS** is toggled ON and OFF 3 times: every 100 ms for 0.6 sec as shown in Figure 5-11. The device goes to DEEP SLEEP after this.

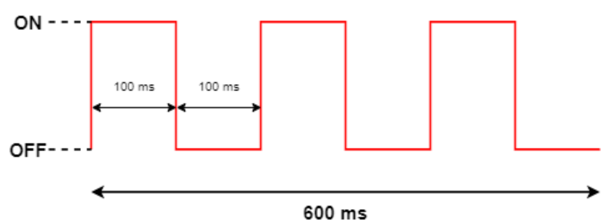


Figure 5-11: The RED LED Pattern Before Entering DEEP SLEEP

5.3.4 EB, Fall, EAR, and Pressure/Elevation Alarms LED Patterns

When the SEAL/SEAL Ex is in an EMERGENCY state and/or a danger zone, all LEDs flash periodically to visually indicate the danger. Most emergency types share the same LED flash patterns, with the safety hook being the only emergency type with a distinct LED pattern. All danger zones (BLE and GNSS) share the same LED patterns when active. This section discusses this common pattern and the supported configuration registers.

5.3.4.1 Operation Description

The following LED pattern is observed when any one or combination of EB, Fall, EAR, and pressure/elevation alarms is active.

1. TS and FS flashes three times with the following user configurable parameters:
    a. pulse duration of 500ms
    b. delay of 1s between pulses
2. Then, there is a delay of 6s before step 1 is repeated. This delay timer starts counting from the start of the sequence, so it's a 2.5s observable delay since step 1 takes 3.5s to complete. This goes on until all the emergencies with this pattern are cleared.
3. System continues with all normal operation patterns described in section 5.3.2, but with step 1 pulses above having higher priority over the normal operation patterns LED pulses. This means that if an uplink was sent during the execution of steps 1 pulses above, the alarm LED patterns in step 1 above are observed and not the uplink LED pattern described in section 5.3.2. However, if the uplink was sent during the delays in steps 1 and 2, then the uplink LED pattern is observed.

When <u>ALL</u> of the applicable emergencies are inactive, the following LED patterns apply.

1. TS and FS flashes three times with a pulse duration of 200ms and delay of 200ms between pulses
2. System continues with all normal operation patterns described in section 5.3.2

5.3.4.2 Configuration Settings Format

All configuration registers that control safety hook button behaviour are listed in Table 5-5. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Table 5-5: EB, EAR, Fall, Pressure/Elevation Alarm LED Config Registers

Address	Name	Access	Size	Description	JSON Variable	Default
0x 39	Active Emergency State LED Config	R/W	4 B	• Bits 0-7: Emergency Active LED period (1sec/LSB) 0: Invalid • Bits 8-15: Emergency Active LED number of ON-OFFs (1/LSB) 0: Invalid • Bits 16-23: Emergency Active LED OFF time (0.01s/LSB) 0: Invalid • Bits 24-31: Emergency Active LED ON time	*active_emerg_led_config {emerg_led_active_period: <value> (number/seconds)* *emerg_led_active_priodicity: <value> (number/no unit)* *emerg_led_active_off_time: <value> (number/sec)* *emerg_led_active_on_time: <value>*	Period: 500ms ON/OFF: 3 times OFF: 1s ON: 500ms 0x 03 39 32 64 03 06

Address	Name	Access	Size	Description	JSON Variable	Default
				(0.01s/LSB) 0: Invalid	*(number/sec)* }	

5.3.4.2.1 Example DL Payloads

- Set active emergency LED config to ON time of 200ms, OFF time of 500ms, 10 number of ON/OFFs, and 10s between each buzz cycle
  - DL payload: **0x B9 14 32 0A 0A**
    - Register 0x 39 with bit 7 set to 1 = 0x B9
    - Set ON period to 200 ms = 0x 14 = 20 x 0.01s = 200ms
    - Set OFF period to 500 ms = 0x 32 = 50 x 0.01s = 500ms
    - Set number of ON/OFF cycle to 10 = 0x 0A = 10 x 1 = 5 times
    - Set period between LED pattern cycle to 10s = 0x 0A = 10 x 1s = 10s

5.3.5 Safety Hook Alarm LED Pattern

Note: The LED patterns described in this section are NOT user-configurable

The following LED pattern is observed when the Safety hook alarm is active.

1. TS and FS flashes two (2) times with a pulse duration of 400ms and delay of 100ms between pulses
2. Then, there is a delay of 10s before step 1 is repeated. This delay timer starts counting from the start of the sequence, so it’s a 9s observable delay since step 1 takes 1s to complete a cycle. This goes on until safety hook emergency is cleared.
3. System continues with all normal operation patterns described in section 5.3.2, but with step 1 pulses above having higher priority over the normal operation patterns LED pulses. This means that if an uplink was sent during the execution of steps 1 pulses above, the alarm LED patterns in step 1 above are observed and not the uplink LED pattern described in section 5.3.2. However, if the uplink was sent during the delays in steps 1 and 2, then the uplink LED pattern is observed.

When the safety hook alarm is inactive, the following LED patterns apply.

1. All periodic LED flashes are stopped
2. System continues with all normal operation patterns described in section 5.3.2

Note: The LED pattern described in this section is NOT user-configurable

5.3.6 Active Danger Zone LED Pattern

Note: The LED patterns described in this section are NOT user-configurable

The following LED pattern is observed when one or more danger zones are active.

1. TS and FS flashes three times with a pulse duration of 500ms and delay of 1s between pulses

2. Then, there is a delay of 6s before step 1 is repeated. This delay timer starts counting from the start of the sequence, so it's a 2.5s observable delay since step 1 takes 3.5s to complete. This goes on until all the emergencies with this pattern are cleared.
3. System continues with all normal operation patterns described in section 5.3.2, but with step 1 pulses above having higher priority over the normal operation patterns LED pulses. This means that if an uplink was sent during the execution of steps 1 pulses above, the alarm LED patterns in step 1 above are observed and not the uplink LED pattern described in section 5.3.2. However, if the uplink was sent during the delays in steps 1 and 2, then the uplink LED pattern is observed.

When ALL active danger zones are inactive, the following LED patterns apply.

1. All periodic LED flashes are stopped
2. System continues with all normal operation patterns described in section 5.3.2

NOTE: Config register in Table 5-5 is also applicable to the danger zone LED pattern

5.3.7 Low Battery Warning LED Pattern

The SEAL/SEAL Ex has a mechanism in place to warn users of low battery using the top LEDs (TS). The low battery threshold that triggers this warning can be set as discussed in section 4.3.

5.3.7.1 Operation Description

The following LED pattern is observed when the battery life indicator goes below the defined battery threshold (refer to section 4.3)

1. TS and FS flashes ten (10) times with a pulse duration of 50ms and delay of 180ms between pulses
2. Then, there is a delay of 180s before step 1 is repeated. This delay timer starts counting from the start of the sequence, so it's a 177s observable delay since step 1 takes 3s to complete a cycle. This goes on until the battery dies or is changed.
3. System continues with all normal operation patterns described in section 5.3.2, but with step 1 pulses above having higher priority over the normal operation patterns LED pulses. This means that if an uplink was sent during the execution of steps 1 pulses above, the alarm LED patterns in step 1 above are observed and not the uplink LED pattern described in section 5.3.2. However, if the uplink was sent during the delays in steps 1 and 2, then the uplink LED pattern is observed.

To deactivate a low battery alarm, replace the battery with a new one. The supported config register for low battery LED patterns is shown in Table 5-6.

5.3.7.2 Configuration Settings Format

All configuration registers that control safety hook button behaviour are listed in Table 5-6. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Table 5-6: Low Battery Warning LED Config

Address	Name	Access	Size	Description	JSON Variable	Default
0x 6A	Low Battery LED Config	R/W	4 B	• Bits 0-7: Low Battery Active LED period (1sec/LSB) 0: Invalid • Bits 8-15: Low Battery Active LED count per ON/OFF (1/LSB) 0: Invalid • Bits 16-23: Low Battery Active LED OFF time (0.01s/LSB) 0: Invalid • Bits 24-31: Low Battery Active LED ON time (0.01s/LSB) 0: Invalid	*low_battety_led_config* *{* *low_battery_led_active_period:* *<value>* *(number/seconds)* *low_battery_led_active_priodicity:* *<value>* *(number/no unit)* *low_battery_led_active_off_time:* *<value>* *(number/sec)* *low_battery_led_active_on_time:* *<value>* *(number/sec)* *}*	Period: 180s ON/OFF: 10 times OFF: 180ms ON: 50ms **0x 05 12 0A B4**

5.3.7.2.1 Example DL Payloads

- Set active emergency LED config to ON time of 90ms, OFF time of 20ms, 3 number of ON/OFFs, and 5s between each buzz cycle
    - DL payload: **0x EA 09 02 03 05**
        - Register 0x 6A with bit 7 set to 1 = 0x EA
        - Set ON period to 90 ms = 0x 09 = 9 x 0.01s = 90ms
        - Set OFF period to 20 ms = 0x 02 = 2 x 0.01s = 20ms
        - Set number of ON/OFF cycle to 3 = 0x 03 = 3 x 1 = 3 times
        - Set period between LED pattern cycle to 5s = 0x 05 = 5 x 1s = 5s

6 Emergency States

The SEAL/SEAL Ex serves as a robust worker safety device, featuring five distinct alarm types aimed at ensuring comprehensive safety measures:

1. Emergency button alarm
2. Safety hook alarm
3. Human fall detection alarm
4. Emergency Application Request (EAR) alarm
5. Pressure/elevation alarm

Each of these emergency states triggers a specific response from the system, tailored to the nature of the alarm. While the system response remains consistent across all alarm types, the feedback mechanisms, such as LED indicators and buzzer activities, vary accordingly (see sections 5.2 and 5.3).

When ANY of the alarm types is ACTIVE, the system response follows a specific order:

1. SEAL/SEAL Ex enables all transducer measurements and reports (Barometer, Accelerometer, Temperature, and Battery life) and utilizes the "Emergency Alarm Tick" to periodically report them.

2. The enabled geolocation technology before the alarm activation is scanned and reported using the "Emergency Alarm Tick" period.

In the subsequent chapters, we will explore the specifics of each emergency type, providing a comprehensive overview of their activation criteria, system response/behavior, supported configurations, and deactivation processes.

6.1 Emergency Button Alarm

The emergency button alarm is triggered when the user presses the designated emergency button on the SEAL/SEAL Ex device. This button is strategically placed for easy access in case of an urgent situation. When activated, the device immediately sends instant and periodic alerts to the application, indicating that the user requires immediate assistance. The buzzer will emit a sound pattern, and the LEDs will flash in a distinct pattern to acknowledge the button press and attract attention. This alarm ensures that help can be dispatched quickly, enhancing the user's safety in emergency situations.

6.1.1 Operation Description

The emergency button alarm is activated and de-activated as described below:

1. Emergency Button Alarm Activation: Pressing and holding the EB for 1s transitions the SEAL/SEAL Ex into an active Emergency Button Alarm State if it's not already in that state. If the SEAL/SEAL Ex is already in Emergency State, pressing the EB for 1s does nothing. The following system events occur upon a successful transition to an Active Emergency Button Alarm State:
    - Activation of the emergency active buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
    - Periodic flashing of all LEDs as detailed in section 5.3.4.1

- Transmission of a Safety Status Report with the EB Alarm bit set to “1” (Refer to section 6.6)
- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2

2. Emergency Button Alarm Deactivation: Pressing and holding the EB for at least 5 seconds when the SEAL/SEAL Ex is in an Active Emergency Button Alarm state triggers the following actions:
    - Activation of the emergency inactive buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
    - Termination of the periodic LED flashes
    - Transmission of a Safety Status report with the EB Alarm bit set to “0” (Refer to section 6.6)
    - System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

6.2 Safety Hook Alarm

The safety hook alarm is activated when the safety hook button is pressed for a duration longer than the debounce period and the device is in a defined danger or designated zone, which is detailed in section 5.1.3. This feature is particularly useful in hazardous environments where the user might need to secure the device to a support structure to prevent falls or accidents. When the safety hook alarm is triggered, the buzzer emits a specific pattern periodically, and the LEDs flash in a similar periodic manner to indicate that the safety harness is still attached to the SEAL/SEAL Ex and not a support structure. This mechanism serves as a precautionary measure, ensuring that the user remains safe, and the device is properly secured.

6.2.1 Operation Description

The safety hook emergency alarm is activated and de-activated as described below:

1. Safety Hook Button Alarm Activation: Pressing and holding the SHB with one end of a safety rope for a duration longer than the debounce interval transitions the SEAL/SEAL Ex into an active Safety Hook Alarm State if it's not already in that state. The following system events occur upon a successful transition to an Active Safety Hook Emergency Alarm State:
    - Activation of the periodic safety hook emergency active buzz pattern as detailed in section 5.2.2.1, if the buzzer is enabled.
    - Periodic flashing of all LEDs as detailed in section 5.3.4.1
    - Transmission of a Safety Status Report with the SH Alarm bit set to “1” (Refer to section 6.6)

- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2

2. Emergency Button Alarm Deactivation: Releasing the SHB when the SEAL/SEAL Ex is in an Active Safety Hook Emergency Alarm state triggers the following actions instantly:
    - Termination of the periodic LED flashes and buzzer sounds
    - Transmission of a Safety Status report with the SH Alarm bit set to “0” (Refer to section 6.6)
    - System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

6.3 Human Fall Detection Alarm

The human fall detection alarm is designed to detect when the user has experienced a fall. The SEAL/SEAL Ex is equipped with sensors that monitor the user's movements and can identify sudden changes in motion or orientation that are characteristic of a human fall. Upon detecting a fall, the device sends an alert to the monitoring system and activates the buzzer and LEDs. This immediate response allows for rapid intervention, which is crucial in preventing further injury and providing timely medical assistance. The fall detection algorithm is calibrated to minimize false alarms while ensuring prompt detection of genuine falls.

6.3.1 Operation Description

The human fall emergency alarm is activated and de-activated as described below:

1. Human Fall Detection Alarm is activated when specific acceleration magnitude conditions are met within a defined time frame. When SEAL/SEAL Ex detects these conditions, it triggers the fall detection alarm. The detailed criteria for these acceleration and time conditions, including the configuration and expected behavior, are explained in section 9.3.

   The following system events occur upon a successful transition to an Active Fall Alarm State:
    - Activation of the emergency active buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
    - Periodic flashing of all LEDs as detailed in section 5.3.4.1
    - Transmission of a Safety Status Report with the EB Alarm bit set to “1” (Refer to section 6.6)
    - Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2

2. Human Fall Detection Alarm Deactivation: Pressing and holding the EB for at least 5 seconds when the SEAL/SEAL Ex is in an Active Fall Detection Alarm state triggers the following actions:
   - Activation of the emergency inactive buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
   - Termination of the periodic LED flashes
   - Transmission of a Safety Status report with the Fall Alarm bit set to “0” (Refer to section 6.6)
   - System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

6.4 Emergency Application Request (EAR) Alarm

The application can request the SEAL/SEAL Ex to change from Normal state to Emergency state and vice versa by sending the EMERGENCY App Request (EAR) and Normal App Request (NAR) DL commands respectively on **LoRaWAN port 10**. If the SEAL/SEAL Ex is already in Normal state, the NAR command does not trigger a state change since the device is already in Normal state. However, if the device is in any type of EMERGENCY state other than one triggered by an EAR command, an EAR DL command will activate the Emergency by EAR. In other words, the Emergency state triggered by EAR DL command is independent of all other Emergency triggers (EB, SH, and Fall) and can only cleared by a NAR DL command.

6.4.1 Operation Description

The Emergency Application Request Alarm is activated and de-activated as described below:

1. Emergency Application Request (EAR): Sending a **0x 00 01 FF** downlink on **port 10** transitions the SEAL/SEAL Ex into the EAR alarm, if it’s not already in this alarm. If the SEAL/SEAL Ex is already in EAR alarm state, sending the downlink does nothing. The following system events occur upon a successful transition to an Active EAR Alarm State:
   - Activation of the emergency active buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
   - Periodic flashing of all LEDs as detailed in section 5.3.4.1
   - Transmission of a Safety Status Report with the EAR Alarm bit set to “1” (Refer to section 6.6)
   - Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2
2. Normal Application Request (NAR): Sending a **0x 00 01 00** downlink on **port 10** transitions the SEAL/SEAL Ex into the Normal state from EAR emergency state, if it’s not already in Normal state. If the SEAL/SEAL Ex is already in normal state, sending the downlink does nothing. The

following system events occur upon a successful transition to a Normal State from EAR Alarm state:

- Activation of the emergency inactive buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
- Termination of the periodic LED flashes
- Transmission of a Safety Status report with the EAR Alarm bit set to "0" (Refer to section 6.6)
- System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

Request on Port 10	Expected SEAL/SEAL Ex Action
0x 00 01 00 (called NORMAL App Request or NAR)	Go to, or stay in NORMAL
0x 00 01 FF (called EMERGENCY App Request or EAR)	Go to, or stay in EMERGENCY

Table 6-1: Emergency and Normal Application Requests

6.5 Pressure/Elevation Alarm

The pressure/elevation alarm is triggered when the SEAL/SEAL Ex experiences significant changes in atmospheric pressure measured by the onboard barometer, which could indicate that the user has entered a potentially dangerous environment, such as high altitudes or underground areas. The SEAL/SEAL Ex device continuously monitors these parameters and sends an alert if the pressure or elevation exceeds safe thresholds. The alarm activates the buzzer and LEDs to warn the user and notify the cloud application of the change. This feature is especially useful for users working in varied terrains or high-risk areas, providing an additional layer of safety by ensuring they are aware of environmental changes that could impact their health or safety.

6.5.1 Operation Description

The pressure/elevation alarm is activated and de-activated as described below:

1. Pressure/Elevation Alarm is activated when the system pressure measurement falls within a defined pressure range, indicating the SEAL/SEAL Ex is in an elevation designated as a danger or unauthorized zone. The detailed criteria for these pressure thresholds, including the configuration and expected behavior, are explained in section 10.1.2.

   The following system events occur upon a successful transition to an Active Pressure/Elevation Alarm State:

   - Activation of the emergency active buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
   - Periodic flashing of all LEDs as detailed in section 5.3.4.1

- Transmission of a Safety Status Report with the Pressure/Elevation Alarm bit set to "1" (Refer to section 6.6)
- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using "Tick in Emergency State" as described in section 4.2

2. Human Fall Detection Alarm Deactivation: Moving the SEAL/SEAL Ex away from the defined pressure levels deactivates the pressure alarm and triggers the following actions:
    - Activation of the emergency inactive buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
    - Termination of the periodic LED flashes
    - Transmission of a Safety Status report with the Pressure/Elevation Alarm bit set to "0" (Refer to section 6.6)
    - System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

6.6 EB, SH, Fall, Pressure/Elevation Alarm UL Report Frame Formats

Safety reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in Table 6-2. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 6-2: Safety Status Reports

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Safety Status	0x 02	0x 95	1 B	Bitmap Input	• Bit 0: 0/1 = EB Inactive/Active • Bit 1: 0/1 = Fall Cleared/Active • Bit 2: 0/1 = SH OFF/ON Always = 0 for non-clip variants • Bit 3: 0/1 = EAR Alert Inactive/Active • Bit 4: 0/1 = Pressure Alarm Inactive/Active Bits 5-7: 0, otherwise invalid	*safety_status {* *safety_status_eb: <value> (string/no unit)* *safety_status_fall: <value> (string/no unit)* *safety_status_sh: <value> (string/no unit)* *safety_status_ear: <value> (string/no unit)* *safety_status_pressure <value> (string/no unit)* *}*

6.6.1 Example UL Payloads

- **0x 02 95 04**
  - Channel ID = 0x 02, Type ID = 0x 95 → safety status report
  - 0x 01 = EB Active

6.7 EB, SH, Fall, Pressure/Elevation Alarm Configuration Settings

All user-configurable registers for safety status and Emergency/Normal tick management are listed in Table 6-3. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x22	Ticks in NORMAL State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in NORMAL state. • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic reports in NORMAL state • Other values: Invalid	*ticks_normal_state: <value> (number/no unit)*	15 ticks = 15 mins period **0x 00 0F**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in EMERGENCY state. • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min period **0x 00 01**
0x26	Ticks for Safety Status in NORMAL State	R/W	2 B	• Ticks between Safety Status reports in NORMAL state • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic Safety Status reports in NORMAL state Other values: Invalid	*ticks_safety_status_normal: <value> (number/no unit)*	5 ticks = 5 mins **0x 00 05**

Table 6-3: Safety Status Configuration Registers

Note: In Emergency state, the safety status is sent every "Ticks in EMERGENCY State," and in Normal state, it is sent every "Ticks for Safety Status in NORMAL State".

6.7.1 Example DL Payloads

- Change settings to update the geolocation every 5 mins in NORMAL state and 2 mins in EMERGENCY state
    - DL payload: **0x A0 00 00 00 3C A2 00 05 A3 00 02 A6 00 0F**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - Seconds per core tick = 60 s = 0x 00 00 00 3C
        - Register 0x 22 with bit 7 set to 1 = 0x A2
        - Ticks in NORMAL state = 5 ticks = 0x 00 05
        - Register 0x 23 with bit 7 set to 1 = 0x A3
        - Ticks in EMERGENCY state = 5 ticks = 0x 00 02
        - Register 0x 26 with bit 7 set to 1 = 0x A6
        - Ticks for Safety Status in NORMAL State = 15 ticks = 0x 00 0F

7 GNSS Operation

The SEAL/SEAL Ex includes an onboard receiver for GNSS localization and other GNSS-related features such as GNSS danger zone and GNSS datalogging. Users can also enable additional diagnostic information on the GNSS localization attempts.

These features are discussed in detail in the following subsections.

7.1 GNSS Position fixes

The onboard GNSS receiver is a low-power, high-precision module that supports concurrent receptions from up to four GNSS constellations (GPS, GLONASS, Galileo, and BeiDou). The high number of visible satellites enables the receiver to select the best signals, maximizing position availability, particularly under challenging conditions such as deep urban canyons.

GNSS scans are enabled and are initiated every 15 minutes by default.

The specifications of the GNSS receiver on the SEAL/SEAL Ex are listed below.

1. Position accuracy (50% CEP): 2.5m[11]

   The accuracy of the position is measured by the Circular Error Probable (CEP), which indicates that 50% of the position readings will fall within a 2.5-meter radius of the true location. This metric helps in understanding the reliability of the position data provided by the GNSS receiver.

2. Time to first fix:

   a. Cold start: 1 min

      The time required for the GNSS receiver to acquire satellite signals and calculate a position fix when the device is powered on without any prior knowledge of its location, time, or satellite constellation. For the SEAL/SEAL Ex, a cold start typically takes 1 minute.

   b. Hot start: 5s

      The time required for the GNSS receiver to acquire a position fix when the device is powered on with prior knowledge of its location, time, and satellite constellation. This is much quicker than a cold start, typically taking around 5 seconds.

7.1.1 Operation Description

GNSS scans can be enabled or disabled, depending on the use-case the SEAL/SEAL Ex is being used in. For indoor use-cases, tracking with BLE presents the more suitable option, and disabling the GNSS scans could save battery life.

[11] Calculated from 6 hours of continuous multi-constellation fixes in static open and clear sky.

When GNSS scans are enabled, the SEAL/SEAL Ex performs multiple scans until a suitable position fix is acquired, with each scan lasting a non-configurable duration of four (4) seconds. These scans can last for a maximum non-configurable period of 210s per period before the SEAL/SEAL Ex reports “Invalid scan” via an uplink on port 10. If a suitable position fix is acquired before the 210s timeout, then the scan results are sent to the application.

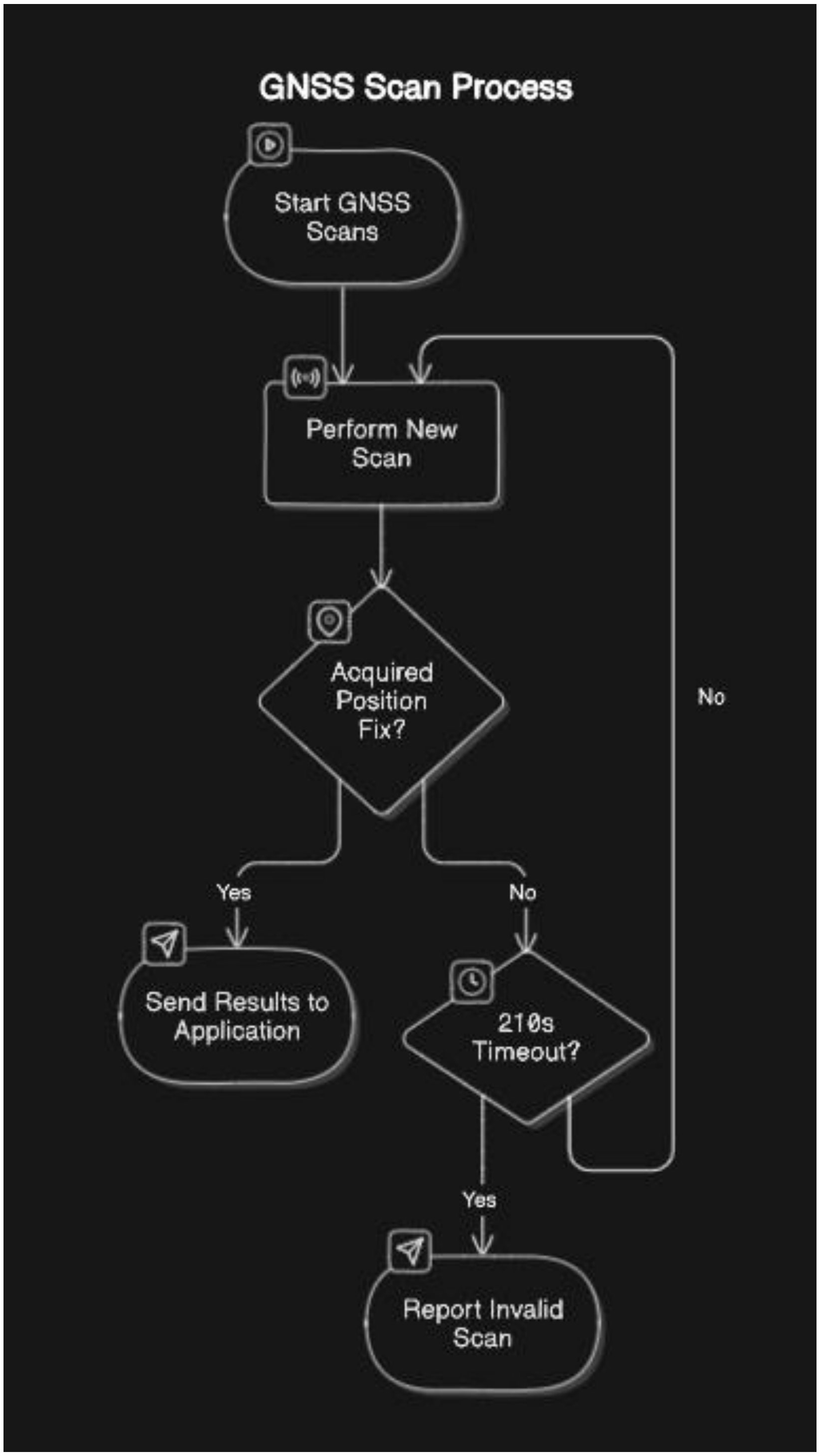


Figure 7-1: GNSS Scan Process

Following a successful GNSS scan, the SEAL/SEAL Ex provides the following information:

1. Position Fix Coordinates, if enabled
    a. Latitude: The geographic coordinate that specifies the north–south position of a point on the Earth's surface. Latitude values range from -90.0 to +90.0 degrees.
    b. Longitude: The geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude values range from -180.0 to +180.0 degrees.
    c. Altitude: the elevation above sea level, measured in meters.

2. Position Fix Timestamp (in UTC), if enabled
    a. Year: The year the position fix was acquired.
    b. Month: The month the position fix was acquired.
    c. Day: The day the position fix was acquired.
    d. Hour: The hour (in 24-hour format the position fix was acquired.
    e. Minute: The minute the position fix was acquired.
    f. Second: The second the position fix was acquired.

3. Groundspeed, if enabled: the speed of the SEAL/SEAL Ex device relative to the ground, measured in meters per second

4. Scan diagnostics information, if enabled: this includes additional details about the GNSS scan process, such as the number of satellites used, signal strength, and other relevant metrics. For more information, refer to section 7.4

Note: Position fix coordinates and the timestamp are jointly enabled or disabled. This means that when position fix coordinates are enabled, the timestamp will also be enabled automatically, and vice versa.

7.1.2 UL Report Frame Format

GNSS position fix reports are sent on *LoRaWAN port 10* and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in Table 7-1. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
UTC Timestamp	0x00	0x85	4 B	Timestamp	• Bits 0-5: Second [0-60][12] • Bits 6-11: Minute [0-59] • Bits 12-16: Hour [0-23] • Bits 17-21: Day [1-31] • Bits 22-25: Month [1-12] • Bits 26-31: [Year]−2020	*utc_timestamp {* *year: <value> (number/202(<value>))* *month: <value> (number/year)* *day: <value> (number/day)* *hour: <value> (number/hour)* *minute: <value> (number/min)* *second: <value> (number/s)* *}*
Position Coordinates	0x00	0x88	8 B	Coordinates	• Bits 40-63: Latitude (signed, $\frac{90^\circ}{2^{23}}$/LSB) • Bits 16-39: Longitude (signed, $\frac{180^\circ}{2^{23}}$/LSB) • Bits 0-15: [Altitude] + 500m (unsigned, $\frac{9500}{2^{16}}$ m/LSB)	*coordinates {* *latitude: <value> (number/°)* *longitude: <value> (number/°)* *altitude: <value> (number/m)* *}*
Ground Speed	0x00	0x92	1 B	Speed	0.27778 m/s/LSB	*ground_speed: <value> (number/m/s)*

[12] The maximum possible value for "second" is 60 to allow for leap seconds.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
No GNSS position fix	0x00	0x00	1B	Bitmap Input	• 0x 00: invalid GNSS fix	*gnss_fix: invalid <value> (string/no unit)*

Table 7-1: GNSS Position Fix UL Report Formats

7.1.2.1 UL Payload Examples

- Report "No GNSS position fix" after Scan timeout of 210s is exceeded
  - **0x 00 85 0D C3 5A 85 00 92 04**
    - Channel ID = 0x 00, Type ID = 0x 85 → UTC Timestamp
    - 0x 0D C3 5A 85 = Position fix UTC timestamp
      - year: 3, so 2020 + 3 = 2023
      - month: 7
      - day: 1
      - hour: 21
      - minute: 42
      - second: 5
    - Channel ID = 0x 00, Type ID = 0x 92 → Ground speed report
    - 0x 04 = 4 x 0.27778m/s = 1.1 m/s
- Report coordinates after successful scan
  - **0x 00 88 48 C4 C7 AE DE 6B 2B E5**
    - Channel ID = 0x 00, Type ID = 0x 88 → Position Fix Coordinates
    - 0x 48 C4 C7 = Latitude = 51.1654651
    - 0x AE DE 6B = Longitude = -114.0907216
    - 0x 2B E5 = Altitude – 500 = 1129m
- Report "No GNSS position fix" after Scan timeout of 210s is exceeded
  - **0x 00 00 00**
    - Channel ID = 0x 00, Type ID = 0x 00 → No GNSS position fix
    - 0x 00 = No GNSS position fix

7.1.3 Configuration Settings

All user-configurable registers for GNSS position fix report are listed on Table 7-2. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events Acceptable values: 15, 16, 17, …, 86400 Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x22	Ticks in NORMAL State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in NORMAL state. Acceptable values: 0, 1, 2, …, 65535 0: Disables periodic reports in NORMAL state Other values: Invalid	*ticks_normal_state: <value> (number/no unit)*	15 ticks = 15 mins period **0x 00 0F**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in EMERGENCY state Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min period **0x 00 01**
0x30	GNSS Mode	R/W	1 B	• Bits 0-6: 0, otherwise invalid • Bit 7: 0/1 = GNSS receiver disabled/enabled	*gnss_receiver: <value> (string/no unit)*	GNSS receiver enabled **0x 80**

Address	Name	Access	Size	Description	JSON Variable	Default
0x31	GNSS Report Options	R/W	1 B	• Bit 0: 0/1 = UTC and Position Coordinates report disabled/enabled • Bit 1: 0/1 = Ground Speed report disabled/enabled • Bit 2: 0/1 = GNSS DZ Status report disabled/enabled • Bits 0-2 = 0: invalid • Bits 3-7: 0, otherwise invalid	*gnss_report_option {* *gnss_dz_status_report: <value> (string/no unit)* *gnss_ground_speed_report: <value> (string/no unit)* *gnss_utc_coordinates_report: <value> (string/no unit)* *}*	UTC and position reports enabled Groundspeed reports enabled GNSS dangerzone status reports enabled **0x 07**

Table 7-2: GNSS Position Fix Configuration Settings

7.1.3.1 Example DL Payloads

- Enable GNSS scans every 1 hour in NORMAL state and every 5 minutes in EMERGENCY state:
  - DL payload: **0x A0 00 00 00 3C A2 00 3C A3 00 05**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 0x 00 00 00 3C = 60s core tick
    - Register 0x 22 with bit 7 set to 1 = 0x A2
    - 0x 00 3C = 60 ticks in NORMAL state
    - Register 0x 23 with bit 7 set to 1 = 0x A3
    - 0x 00 05 = 5 ticks in EMERGENCY state

- Disable GNSS receiver
  - DL payload: **0x B0 00**
    - Register 0x 30 with bit 7 set to 1 = 0x B0
    - Value bit 7 set to 0 = 0

- Disable all GNSS-related reports
  - DL payload: **0x B1 00**
    - Register 0x 31 with bit 7 set to 1 = 0x B1
    - All bits set to 0 = All reports disabled

7.2 GNSS Danger zones

The SEAL/SEAL Ex supports the definition of four (4) circular 2-D GNSS danger zones using user-configurable center coordinates (Latitude, Longitude) and radius length for each danger zone circle.

The following subsections detail the GNSS danger zone scheme, uplink formats, and supported configuration options with examples.

7.2.1 Operation Description

The SEAL/SEAL Ex can define up to four circular GNSS danger zones by providing the center coordinates and the radius for each zone. After a successful scan, as detailed in section 7.1, SEAL/SEAL Ex compares the acquired fix with the defined circular zones to determine if it falls within any of them. If it does, danger zone alarm(s) are triggered for the affected zone(s). If not, no action is taken. A GNSS danger zone (DZ) status update can be enabled to be sent to the cloud application periodically to inform the application of the status.

Note 1: EMERGENCY and Danger Zone alarms are mutually exclusive. This means that the SEAL/SEAL Ex cannot simultaneously trigger both an EMERGENCY alarm and a Danger Zone alarm. Each type of alarm is designed to address different scenarios

Note 2: Each danger zone operates independently, allowing zones to overlap one or more other zones if desired.

Note 3: By default, all GNSS DZs are disabled.

The following system behaviors are triggered when any of the four GNSS danger zones are activated:

- Periodic flashing of all LEDs as detailed in section 5.3.4.1
- Transmission of a GNSS Danger Zone (DZ) Status Report with the corresponding activated GNSS DZ bit set to “1” (Refer to section 0)
- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2

A transition back to NORMAL state is made when the SEAL/SEAL Ex acquires a GNSS position fix outside all the defined zones. When all GNSS danger zone (DZ) alarms are cleared, the following system behaviors occur:

- Termination of the periodic LED flashes
- Transmission of a GNSS Danger Zone (DZ) Status Report with the corresponding activated GNSS DZ bit set to “0” (Refer to section 0)
- System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

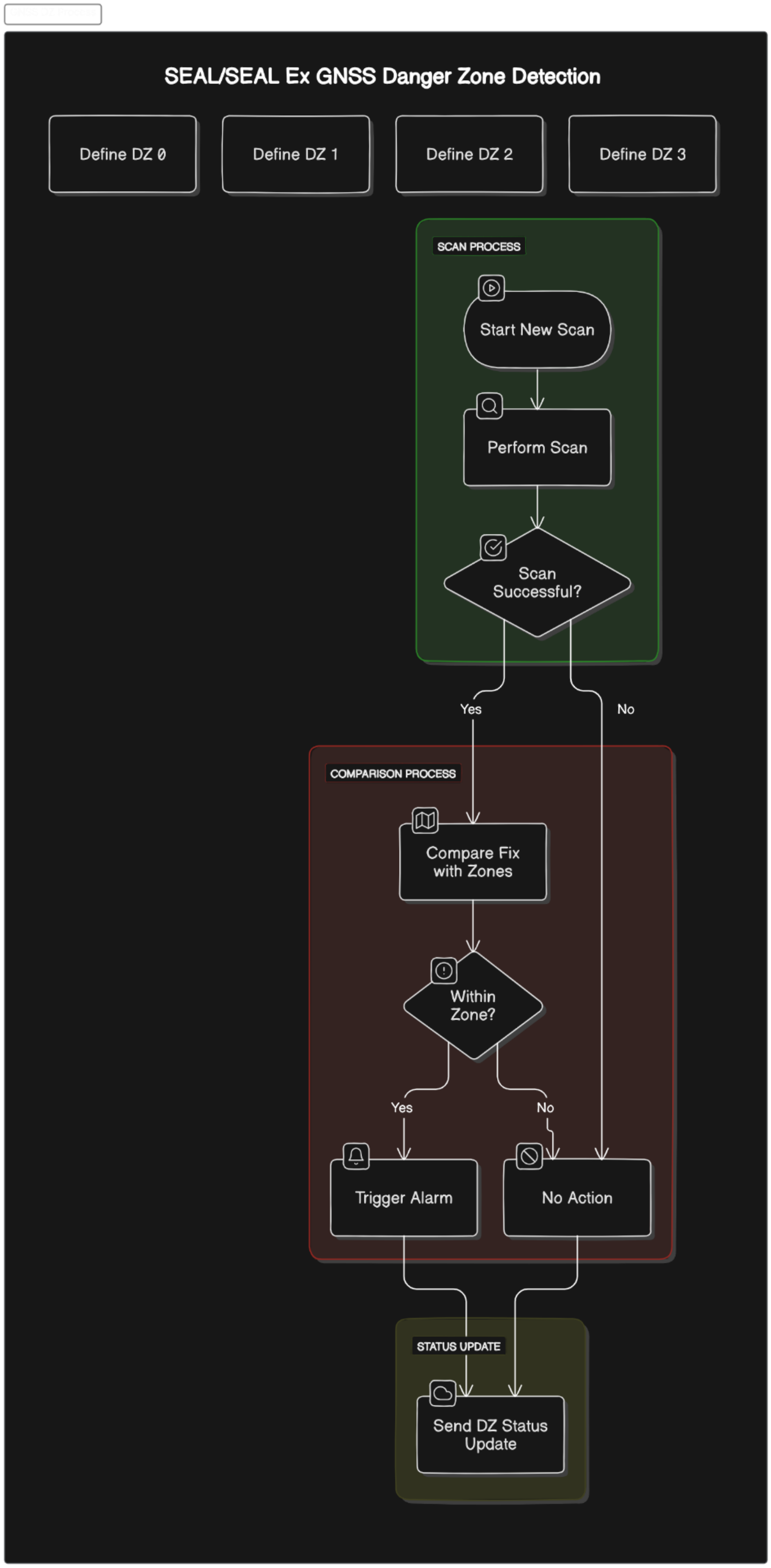


Figure 7-2: GNSS DZ Operation Flow

There are three (3) possible GNSS danger zone status explained below:

- The SEAL/SEAL Ex is inside a danger zone if the acquired position fix falls within the defined circle (center coordinates and radius) of the danger zone.
- The SEAL/SEAL Ex is outside a danger zone if the acquired position fix falls outside the defined circle of the danger zone.
- If any of the four GNSS danger zones are not set or are set incorrectly, the SEAL/SEAL Ex reports the status of that danger zone as unknown.

7.2.2 UL Frame Report Formats

GNSS DZ status reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in Table 7-3. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 7-3: GNSS DZ Status Reports

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
GNSS DZ Status	0x 00	0x 95	1 B	Bitmap Input	• Bit 0-1: DZ0 0 = Unknown 1 = Inside 2 = Outside • Bit 2-3: DZ1 0 = Unknown 1 = Inside 2 = Outside • Bit 4-5: DZ2 0 = Unknown 1 = Inside 2 = Outside • Bit 6-7: DZ3 0 = Unknown 1 = Inside 2 = Outside	*gnss_dz_status {* *gnss_status_dz0:* *<value>* *(string/no unit)* *gnss_status_dz1:* *<value>* *(string/no unit)* *gnss_status_dz2:* *<value>* *(string/no unit)* *gnss_status_dz3:* *<value>* *(string/no unit)* *}*

7.2.2.1 Example UL Payloads

- **0x 00 95 01**
  - 0x 00 (channel ID), 0x 95 (type ID) → GNSS DZ Status

- 0x 01 → Inside DZ0, all other DZs unknown

- **0x 00 95 09**
  - 0x 00 (channel ID), 0x 95 (type ID) → GNSS DZ Status
  - 0x 09 → Inside DZ0, Outside DZ1, all other DZ unknown

- **0x 00 95 55**
  - 0x 00 (channel ID), 0x 95 (type ID) → GNSS DZ Status
  - 0x 55 → Inside all DZs

7.2.3 Configuration Settings

All user-configurable registers for GNSS DZ are listed on Table 7-4. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x32	GNSS DZ 0 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^{\circ}}{2^{23}}$/LSB)	*gnss_dz0 {* *gnss_dz0_latitude: <value> (number/°)* *gnss_dz0_longitude : <value> (number/°)* *gnss_dz0_radius: <value> (number/m)* *}*	GNSS DZ 0 Undefined 0x00 00 00 00 00 00 00 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x33	GNSS DZ 1 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^{\circ}}{2^{23}}$/LSB)	*gnss_dz1 {* *gnss_dz1_latitude: <value> (number/°)* *gnss_dz1_longitude : <value> (number/°)* *gnss_dz1_radius: <value> (number/m)* *}*	GNSS DZ 1 Undefined 0x00 00 00 00 00 00 00 00
0x34	GNSS DZ 2 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^{\circ}}{2^{23}}$/LSB)	*gnss_dz2 {* *gnss_dz2_latitude: <value> (number/°)* *gnss_dz2_longitude : <value> (number/°)* *gnss_dz2_radius: <value> (number/m)* *}*	GNSS DZ 2 Undefined 0x00 00 00 00 00 00 00 00
0x35	GNSS DZ 3 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^{\circ}}{2^{23}}$/LSB)	*gnss_dz3 {* *gnss_dz3_latitude: <value> (number/°)* *gnss_dz3_longitude : <value> (number/°)* *gnss_dz3_radius: <value> (number/m)* *}*	GNSS DZ 3 Undefined 0x00 00 00 00 00 00 00 00

Table 7-4: Configuration Settings for GNSS Danger Zones

7.2.3.1 Example DL Payload

- Set GNSS DZ0 to the following
  - Latitude: 51.1654651,
  - Longitude: -114.0907216,
  - Radius: 100m
  - DL payload: **0x B2 48 C4 C7 AE DE 6B 00 0A**
    - Register 0x 32 with bit 7 set to 1 = 0x B2
    - 0x 48 C4 C7 = 51.1654651
    - 0x AE DE 6B = -114.0907216
    - 0x 00 0A = 10 x 10m = 100m

7.3 GNSS Datalogging

SEAL/SEAL Ex features the automatic logging of vital information from successful GNSS scans such as the coordinates (latitude, longitude, altitude) and UTC timestamp.

The following subsections detail the GNSS datalogging feature, uplink formats, and supported query options with examples

7.3.1 Operation Description

Position fixes and their respective timestamps (UTC) are logged in the SEAL/SEAL Ex, with the flash memory capable of storing up to 3000 entries at a time. When the flash memory reaches capacity, a batch containing a fraction of the oldest log entries is deleted to make space for new logs. This batching process reduces the number of flash-delete-then-write operations, thereby extending the life of the flash memory.

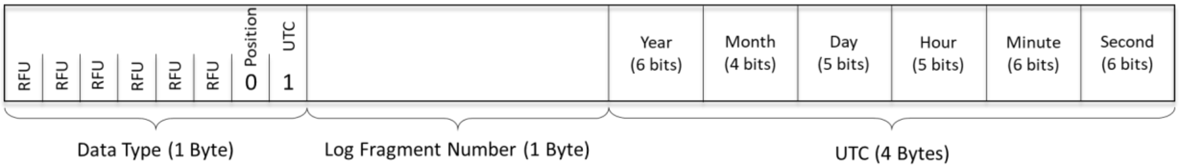
These fixes can later be retrieved from the flash memory and reported over-the-air (OTA) on LoRaWAN port 15 using the retrieval methods defined in section 7.3.3. The GNSS log(s) to be reported may consist of a single log entry or a combination of several log entries. Each log entry consists of a corresponding UTC timestamp and position coordinates.

If a timestamp that is not in the datalogger is requested from the SEAL/SEAL Ex by the application, a payload consisting of only 0x00 is transmitted on port 15 to indicate there is no log entry available to report. This applies to invalid timestamps, past timestamps (older than the oldest log entry), and future timestamps (more recent than the latest log entry).

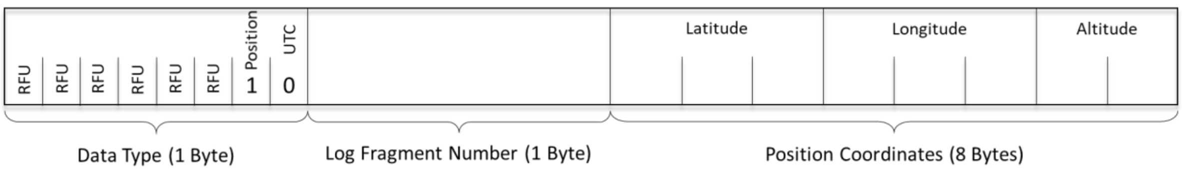
7.3.2 UL Frame Report Formats

The payloads to report these log entries are sent on port 15, and are available in one of two formats, as shown in Figure 7-3 and Figure 7-4.

In format A, a single log entry containing a set of position coordinates and its corresponding UTC timestamp is fragmented into two payloads. The corresponding timestamps and position coordinates payloads have the same log fragment number for reconstruction at the application side. This format is especially useful when the device is operating in a low data rate state.



(a)



(b)

Figure 7-3: UL Format A showing the Position coordinate (a) and UTC timestamp (b) Payload Blocks

For example, consider the following sequence of payloads to report two log entries:

1. Log entry 1: 0x T1 T2 T3 T4 C1 C2 C3 C4 C5 C6 C7 C8

    a. Payload 1 => "0x01 00 T1 T2 T3 T4" on port 15
        i. where 0x01 represents the data type for UTC timestamp
        ii. 00 is the fragment number
        iii. T1 T2 T3 T4 is the 4-byte timestamp information for log entry 1

    b. Payload 2 => "0x02 00 C1 C2 C3 C4 C5 C6 C7 C8"
        i. where 0x02 represents the data type for position coordinates,
        ii. 00 is the fragment number,
        iii. C1 C2 C3 C4 C5 C6 C7 C8 is coordinate information for log entry 1

2. Log entry 2: 0x TA TB TC TD CA CB CC CD CE CF CG CH

    a. Payload 1 => "0x01 01 TA TB TC TD" on port 15
        i. where 0x01 represents the data type for UTC timestamp
        ii. 01 is the fragment number
        iii. TA TB TC TD is the 4-byte timestamp information for log entry 2

    b. Payload 2 => "0x02 01 CA CB CC CD CE CF CG CH"
        i. where 0x02 represents the data type for position coordinates,
        ii. 01 is the fragment number,

iii. CA CB CC CD CE CF CG CH is coordinate information for log entry 2

Here, "T" denotes UTC timestamps, and "C" denote position coordinates. The fragment numbers (00, 01, 02) ensure that the application can accurately pair each timestamp with its corresponding position coordinates.

Format B is suitable for instances where the data rate allows uplinks of payloads containing one or more log entries. In this instance, a single payload sis used to report the entire log entry, with no need for a second payload. Fragment numbers are used as counters in this format.

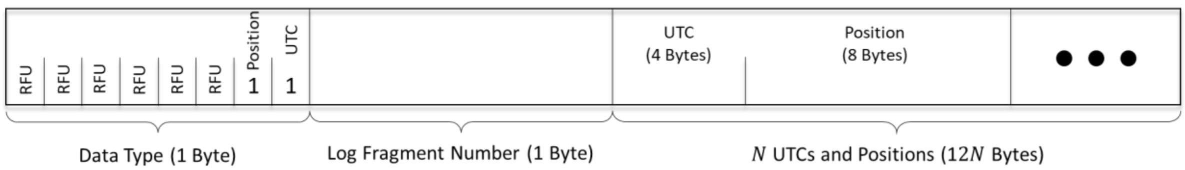


Figure 7-4: UL Format B Format

Using the same example as Format A above, the same two log entries would require just a single payload if the SEAL/SEAL Ex is operating in a higher DR that allows enough payload size.

Log entry 1: 0x T1 T2 T3 T4 C1 C2 C3 C4 C5 C6 C7 C8

Log entry 2: 0x TA TB TC TD CA CB CC CD CE CF CG CH

Payload using format B => 0x 03 00 T1 T2 T3 T4 C1 C2 C3 C4 C5 C6 C7 C8 01 T1 T2 T3 T4 C1 C2 C3 C4 C5 C6 C7 C8

Where:

- 0x03 represents data type for Format B
- 00, 01 are the incrementing counters
- "T" denotes timestamp and "C" denote coordinate

7.3.2.1 Example UL Payloads

- **0x 01 01 0D C3 5A 85**
  - 0x 01 (Data type) → Format A, UTC timestamp
  - 0x 01 → Fragment 1
  - 0x 0D C3 5A 85
    - Year: 3, so 2020 + 3 = 2023
    - Month: 7
    - Day: 1
    - Hour: 21
    - Minute: 42
    - Second: 5
- **0x 02 01 48 C4 C7 AE DE 6B 2B E5**
  - 0x 02 (Data type) → Format A, Coordinates

    - 0x 01 → Fragment 1
    - 0x **48 C4 C7 AE DE 6B 2B E5**
        - Latitude: 51.1654651
        - Longitude: -114.0907216
        - Altitude: 1129 m

- **0x 03 01 0D C3 5A 85 48 C4 C7 AE DE 6B 2B E5**
    - 0x 03 (Data type) → Format B, UTC timestamp + Coordinates
    - 0x 01 → Counter 1
    - 0x 0D C3 5A 85
        - Year: 3, so 2020 + 3 = 2023
        - Month: 7
        - Day: 1
        - Hour: 21
        - Minute: 42
        - Second: 5
    - 0x **48 C4 C7 AE DE 6B 2B E5**
        - Latitude: 51.1654651
        - Longitude: -114.0907216
        - Altitude: 1129 m

7.3.3 Datalogging Retriever Format

The request from the cloud application to receive the GNSS log is sent on **LoRaWAN port 15**. This request can be sent in two types, Type A and Type B, as shown in Figure 7-5 and Figure 7-6. The first byte in each payload indicates the request type (i.e., 0x0A for Type A or 0x0B for Type B).

In a Type A request, a UTC timestamp (t) and a number (n), where 1 ≤ n ≤ 255, are provided to the SEAL/SEAL Ex. The UTC timestamp follows the format specified in Table 7-1. By sending this request, the cloud application is asking for the last (most recent) n GNSS log entries (including position fixes, altitude, and timestamp) up to and including the specified timestamp (t). Essentially, the SEAL/SEAL Ex counts backward 'n' steps from the provided timestamp and returns the log entries within that range.

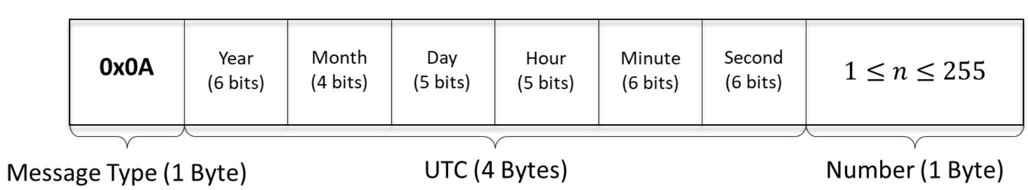


Figure 7-5: Type A Datalogging Request Format

This method is useful for historical data analysis where specific time-bound logs are needed. For instance, if a user needs to analyze the GNSS logs around a particular event that occurred at a specific time.

In a Type B request, only a number (n), where 1 ≤ n ≤ 255, is provided to the SEAL/SEAL Ex. By sending this request, the cloud application is asking for the last (most recent) n GNSS log entries (including position fixes, altitude, and time). Upon receiving a GNSS log request, the SEAL/SEAL Ex responds with the requested GNSS log on port 15, as explained in Section 7.3.2. If there is no log matching the request, the SEAL/SEAL Ex uplinks a one-byte 0x00 payload on port 15.

This method is ideal for retrieving the most recent logs, such as monitoring current activities or getting the latest position data of the device.

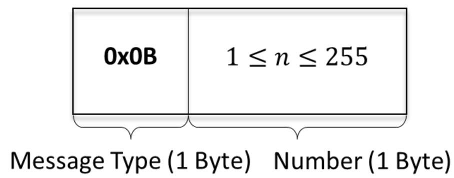


Figure 7-6: Type B Datalogging Request Format

7.3.3.1 Example DL Payloads

- Request the last 2 log entries from 01/07/2023 21:43:02
  - DL Payload: **0x 0A 0D C3 5A C2 02**
    - Register type 0x 0A = Request type A
    - 0x 0D C3 5A C2:
      - Year: 3, so 2020 + 3 = 2023,
      - Month: 7,
      - Day: 1,
      - Hour: 21
      - Minute: 43
      - Second: 2
    - 0x 02 = 2 entries

- Request the last 10 log entries
  - DL Payload: **0x 0B 0A**
    - Register type 0x 0B = Request type B
    - 0x 0A = 10 entries

7.4 GNSS Diagnostics Information

After completing a GNSS scan, SEAL/SEAL Ex users may enable different supported GNSS diagnostic information to be reported in a LoRaWAN uplink on port 10.

7.4.1 Operation Description

If any of the supported GNSS diagnostic reports are enabled, an additional uplink containing the enabled diagnostics is sent after each scan, regardless of whether the scan was successful or not. This diagnostics report is transmitted after the scan results are sent to the application cloud. The next scan, if scheduled, will only commence after the current diagnostics report has been sent.

Available diagnostics value options to report are:

- *Number of visible satellites:* total number of satellites detected during the GNSS scan.
- *Average satellite SNR*: the average signal-to-noise ratio of all signals detected during the GNSS scan, measured in dB. If no satellites were visible, a value of 0 is transmitted.
- *Most recent log entry number*: The ID number of the scan result in the flash memory. If the scan is unsuccessful, no scan result is logged, so the most recent log entry number is sent.
- *GNSS fix type*: The type of fix acquired by the receiver during the scan. Possible options are:
    - *0*: No fix available
    - *2*: 2D fix acquired - 2D fix is obtained when the receiver has only sufficient signal from detected satellites to allow determination of the receiver's latitude and longitude (horizontal position) but not altitude (vertical position) accurately.
    - *3*: 3D fix acquired - A 3D fix is obtained when the receiver has sufficient signal detected satellites for the determination of the receiver's latitude, longitude, and altitude (horizontal and vertical position). A 3D fix provides a more complete and accurate representation of the receiver's location, including its elevation.
- *Time-to-fix:* The total time that the GNSS receiver spent scanning for an acceptable fix
- *GNSS fix accuracy:* The receiver's estimation of how accurate the acquired fix is, broken down into horizontal and vertical accuracy.
- *Groundspeed Accuracy:* This is the receiver's estimation of how accurate the acquired groundspeed is.
- *Number of fixes per scan:* The number of fixes acquired in the scan before an acceptable fix was acquired.

7.4.2 UL Report Formats

GNSS Diagnostics reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in

Table 7-5. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Number of Visible Satellites	0x0D	0x3C	1 B	Integer	Bits 0-7: Number of satellites used to calculate the GNSS fix. If no fix was obtained, this value is the total number of visible satellites (unsigned, 1/LSB)	*num_satellites: <value> (unsigned/no unit)*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Average Satellite SNR	0x0D	0x64	2 B	Generic	• Bits 0-15: Average SNR of all satellites used in getting the GNSS fix (signed, 0.1 dB/LSB) • 0x 00 00 = No satellites visible for calculating average	*avg_satellite_snr: <value> (signed/dB)*
Most recent log entry number	0x0D	0x0F	2 B	Integer	Bits 0-15: Most recent log entry number (unsigned, 1/LSB)	*log_num: <value> (unsigned/ no unit)*
GNSS Fix Type	0x0D	0x95	1 B	Bitmap Input	• Bits 0-1: The type of fix acquired by the receiver (unsigned) Possible types are: 0 = No fix available 2 = 2D fix 3 = 3D fix • Bits 2-7: 0, otherwise, invalid	*fix_type: <value> (unsigned/ no unit)*
GNSS Time-to-fix	0x0D	Ox96	2 B	Stopwatch	Bits 0-15: The total time the GNSS receiver spent scanning for an acceptable fix (Unsigned, 1s/LSB)	*time_to_fix: <value> (unsigned/s)*
GNSS Fix Accuracy	0x0D	0x97	4 B	Fix Accuracy	• Bit 0-15: Horizontal fix accuracy (unsigned, 1m/LSB) • Bits 16-31: Vertical fix accuracy (unsigned, 1m/LSB)	*gnss_fix_accuracy {* *gnss_horizontal_accuracy : <value> (unsigned/m)* *gnss_vertical_accuracy: <value> (unsigned/m)* *}*
Ground Speed Accuracy	0x0D	0x98	4 B	Speed Accuracy	Bits 0-31: Ground speed accuracy (unsigned, 0.001m/s/LSB)	*ground_speed_accuracy: <value> (unsigned/m/s)*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Number of fixes per scan	0x0D	0x99	1 B	Integer (unsigned)	Bits 0-7: Number of fixes per scan (unsigned, 1/LSB)	*num_of_fixes: <value> (unsigned/no unit)*

Table 7-5: GNSS Diagnostics UL Formats

7.4.2.1 Example UL Payloads

- **0x 0D 3C 0F**
  - 0x 0D (channel ID), 0x 3C (type ID) → number of visible satellites
  - 0x 0F → 15 satellites

- **0x 0D 64 FE 79**
  - 0x 0D (channel ID), 0x 64 (type ID) → average satellite SNR
  - 0x FE 79 = -391 × 0.1 dB = -39.1 dB

7.4.3 Configuration Settings

All user-configurable registers for GNSS diagnostics report are listed in Table 7-6. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x22	Ticks in NORMAL State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in NORMAL state. • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic reports in NORMAL state • Other values: Invalid	*ticks_normal_state: <value> (number/no unit)*	15 ticks = 15 mins period **0x 00 0F**

Address	Name	Access	Size	Description	JSON Variable	Default
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in EMERGENCY state. • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state Other values: Invalid	*ticks_emergency_state: <value>* *(number/no unit)*	1 tick = 1 min period **0x 00 01**
0x36	GNSS Diagnostics Report Options	R/W	1 B	• Bit 0: 0/1 = Number of Visible Satellites report disabled/enabled • Bit 1: 0/1 = Average Satellite SNR report disabled/enabled • Bit 2: 0/1 = Fix Type report disabled/enabled • Bit 3: 0/1 = Time-To-Fix report disabled/enabled • Bit 4: 0/1 = Most Recent Log Entry # report disabled/enabled • Bit 5: 0/1 = GNSS fix accuracy, groundspeed accuracy, and number of fixes report disabled/enabled	*gnss_diagnostics_tx* *{* *num_of_sats: <value>, (unsigned/no unit)* *avg_sat_snr: <value>, (unsigned/no unit)* *reported_fix_type: <value>, (unsigned/no unit)* *time_to_reported_fix: <value> (unsigned/no unit)* *fix_log_num: <value> (unsigned/no unit)* *fix_acc_and_num_fixes_report: <value> (unsigned/no unit)* *}*	No diagnostics report enabled **0x 00**

Table 7-6: GNSS Diagnostics Configuration Settings

Note: When any GNSS diagnostic report is enabled, it is transmitted at every "Tick in Normal state" while the SEAL/SEAL Ex is in the NORMAL state, and at every "Tick in EMERGENCY state" while the SEAL/SEAL Ex is in the EMERGENCY state.

7.4.3.1 Example DL Payloads

- Enable all GNSS diagnostics to be reported after every GNSS scan:
    - DL payload: **0x B2 43**
        - Register 0x 32 with bit 7 set to 1 = 0x B2
        - Value bits 0, 1, and 6 set to 1 = 0x 43

- Enable only number of visible satellites to be reported after every GNSS scan:
    - DL payload: **0x B2 01**
        - Register 0x 32 with bit 7 set to 1 = 0x B2
        - Value bit 1 set to 1 = 0x 01

8 BLE Operation

The SEAL/SEAL Ex's MCU is an ultra-low power IoT targeted module with in-built support for Bluetooth low energy SIG 5.2 technology. The SEAL/SEAL Ex ONLY supports the use of this technology as a TRACKER. This means that the SEAL/SEAL Ex can track and discover BLE devices nearby, but it can't be discovered by other BLE trackers. By default, the BLE scanning functionality of the SEAL/SEAL Ex is disabled. However, this can easily be changed by sending a simple OTA command to enable the BLE mode.

8.1 BLE Scans

If BLE scans are enabled and defined, scans will occur periodically according to the rules defined in section 4.2

- In Normal state, SEAL/SEAL Ex scans for devices using the "Tick in Normal State" period
- In Emergency mode, SEAL/SEAL Ex scans for devices using the "Tick in emergency state" period

During each scan, other advertising BLE devices can be discovered. Each discovered device has its data (MAC address and the RSSI of the advertisement packet) saved by the SEAL/SEAL Ex to then be reported in a LoRa UL. This UL is normally reported immediately after the scan concludes but may be delayed due to duty cycle limitations (LoRa Alliance, Feb 2017). If a new BLE scan occurs before the results of the previous scan have been sent, the old scan results will be discarded.

The following subsections detail the scanning scheme, data preprocessing options, and device filtering options.

8.1.1 Scanning Scheme

A single BLE scan lasts for a configurable *scan duration*.

As illustrated in Figure 8-1, each scan duration is divided into regular *scan intervals*. The beginning of each scan interval marks the beginning of scanning on a different BLE channel frequency. The channels are cycled through in order; during the first scan interval the tracker receives on channel 37, the second on channel 38, the third on channel 39, the fourth on channel 37, and so on. The scan interval is configurable.

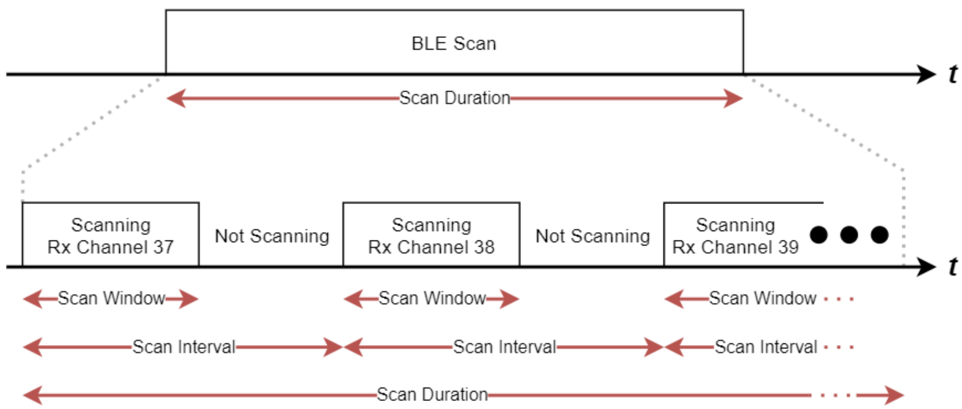


Figure 8-1: The BLE Scan Scheme

Also illustrated in Figure 8-1, the actual BLE scanning only occurs during the *scan window* portion of the scan interval. The scan window is configurable, which allows for the *scan duty cycle* to be implemented:

$$\text{scan duty cycle} = \frac{\text{scan window}}{\text{scan interval}} \times 100\%$$

A scan window equal to the scan interval represents a scan duty cycle of 100% (a continuous scan) over each scan duration. This is the default behavior as it maximizes the chance of "discovering" nearby BLE advertisement packets for a given scan duration. Reducing the duty cycle below 100% has the advantage of decreasing power consumption at the expense of possibly missing some beacon signals. The BLE scan can be disabled entirely and re-enabled at any time in tracker mode.

The BLE scan is *passive*. This means the tracker listens to surrounding beacons but does not transmit to them to request additional information.

8.1.2 Pre-processing Discovered BLE Device Data (Averaging Mode)

During each scan, if a BLE advertisement is received by the tracker, the BLE device from which that advertisement originated is referred to as a *discovered device*. For each individual advertisement packet received, the SW records:

- The 6-byte *BLE Device MAC address*, BD_{ADDR}, of the advertising device, and
- The 1-byte *Received Signal Strength Indicator* (*RSSI*), in [dBm], of the packet.

The tracker reports up to *N* MAC address + RSSI pairs following each scan, which is configurable via register 0x 50 (see section 0)

During a single scan, it is possible to detect more than one advertisement from a single discovered device if that device is advertising with a period less than the tracker's scan duration. Because of this, the tracker supports the ability to report either the complete, "raw," discovered device data, or apply some pre-processing before reporting. In both cases, a maximum of *N* MAC address + RSSI data pairs are reported:

- **Raw Data:** No pre-processing is done on the packets received during each scan before reporting via UL; the *N* last discovered devices are sent. This means it is possible to have repeated devices in the same UL (one for each received advertisement).
- **Averaging Mode:** The RSSIs from each unique discovered device are averaged over all packets received from that device to get a single value. Then the devices are sorted in order from strongest average RSSI to weakest. The top *N* devices are sent in the UL report. Averaging mode is enabled by default.

8.1.3 Filtering Discovered BLE Devices

The tracker supports inclusion filtering of discovered devices based on BD_{ADDR}.

Each 6-byte BD_{ADDR} consists of an *Organizationally Unique Identifier* (*OUI*) comprising the 3 MSBs followed by a *Lower Address Part* (*LAP*) comprising the 3 LSBs in the form:

$$BD_{ADDR} = OUI:LAP$$

The *OUI* is unique for a batch of devices; most commonly this means that all devices manufactured by the same company will share the same *OUI*[13]. The *LAP* is unique for each device.

The tracker can filter by single BD_{ADDR} or, more generally, by a range of BD_{ADDR}s if a common *OUI* is shared. This keeps undesired devices out of the OTA report, thus reducing OTA time and saving battery life. An example application is for an indoor BLE beacon network; only the beacon signals are of interest and not those from other devices like smartphones.

Up to 4 separate filter ranges can be defined and used at the same time. The user must specify the start and end bounds of each range. That is, if a discovered device has a BD_{ADDR} which falls inside the range $OUI{:}LAP_{start}$ to $OUI{:}LAP_{end}$ its data is kept. If not, its data is discarded immediately. The range is inclusive, meaning that a BD_{ADDR} equivalent to the start or end bounds is considered in-range. Each range is defined in the following 9-byte format:

$$BD_{ADDR}\, range = OUI|LAP_{start}|LAP_{end}$$

The following rules describe the behaviour of the filter ranges and reporting:

1. A range set to all 0s is an *inactive range*. Otherwise, an *active range*. All ranges are inactive by default.

2. All 4 ranges inactive means **basic reporting** is enabled. Following each scan, any and all discovered devices (up to a maximum *N*) are reported. Otherwise, **filtered reporting** is enabled. Basic reporting is the default behaviour.

[13] TEKTELIC's OUI is 64:7F:DA

3. Following any BLE scan, there will be at least 1 report corresponding to each active range. Each report is sent in a separate UL. Even if no devices from a certain range are discovered, an empty list is always sent for that range. See §8.1.4 for more details on reporting.

4. If a range is defined with $LAP_{start} > LAP_{end}$, the range is active but empty. I.e., an empty list is always reported for that range.

5. If an active range is defined with $LAP_{start} = LAP_{end}$, the range has only one BD_{ADDR} in it. This is *single device filtering*.

6. Ranges are allowed to overlap. A BD_{ADDR} that falls into more than one active range will be reported in each of those ranges.

NOTE: Averaging/raw modes and basic/filtered reporting are mutually compatible; that is, any combination of the four options is acceptable. Filtering always occurs during the scan, and averaging always occurs after.

8.1.4 UL Report Frame Formats

Discovered BLE devices are reported on ***LoRaWAN port 25***. As described in section 8.1.4, either basic or filtered reporting can be done.

NOTE 1: 0, 1, or more devices can be reported in a single message, depending on the number of devices available to report and payload size limitation as determined by LoRaWAN regional parameters (LoRa Alliance, Feb 2017). For all BLE reporting described below, if the discovered device data cannot fit into one message, more than one UL will be subsequently transmitted to report all *N* devices.

NOTE 2: The scan results are normally reported in a UL immediately after the scan concludes but may be delayed due to duty cycle limitations (LoRa Alliance, Feb 2017).

8.1.4.1 Basic Reporting

Basic reporting occurs when no filter ranges are active. In this case, following each scan, the data from all discovered devices (up to a maximum *N*) are reported. The UL payload format is shown in Figure 8-2. Basic reporting is the default behaviour.

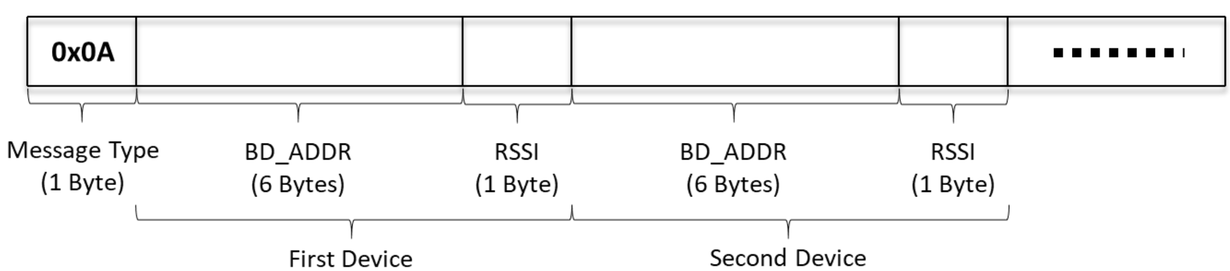


Figure 8-2: The BLE Report UL Payload Format for Basic Reporting

Each payload consists of a 1-byte header (0x 0A) followed by the data from each discovered device. If no devices were discovered during a scan (i.e., the scan failed), an empty list (i.e., only the header) is sent.

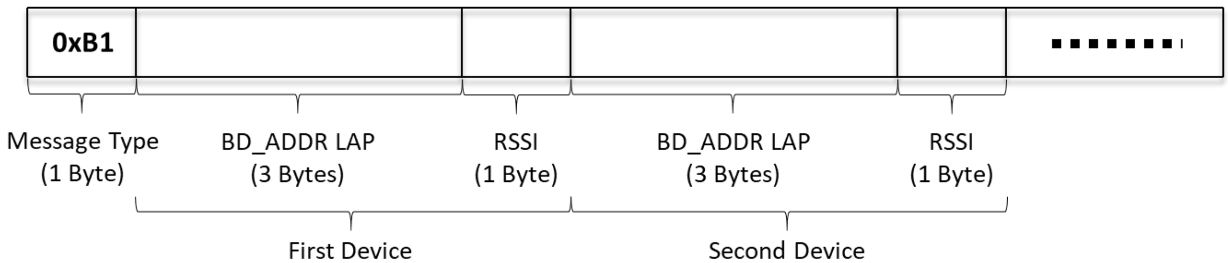
The data from each device consists of a 7-byte BD_{ADDR} and RSSI pair, where the BD_{ADDR} is the full 6-byte BLE Device MAC Address and the RSSI is a signed 1-byte number in units of [dBm].

The BD_{ADDR} and RSSI pairs for any other discovered devices are concatenated into the payload. The order of the listed devices depends on whether averaging mode is enabled or disabled.

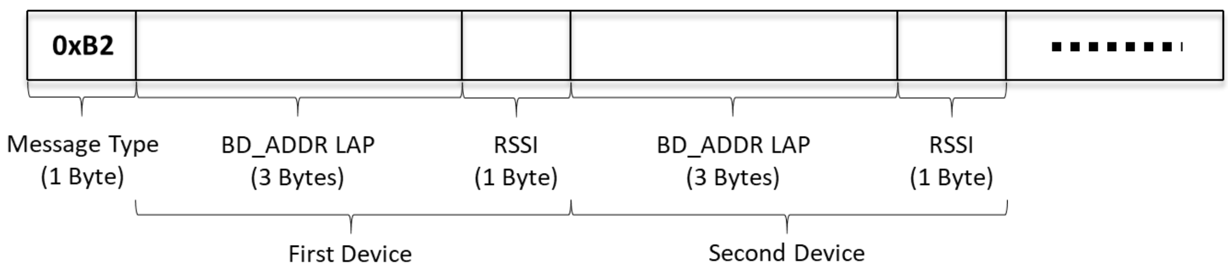
8.1.4.2 Filtered Reporting

Filtered reporting occurs when one or more filter range is active. In this case, following each scan, only discovered devices (up to a maximum *N*) from specified ranges of favorable BD_{ADDR}s are included in the report. The UL payload formats are shown in Figure 8-3.

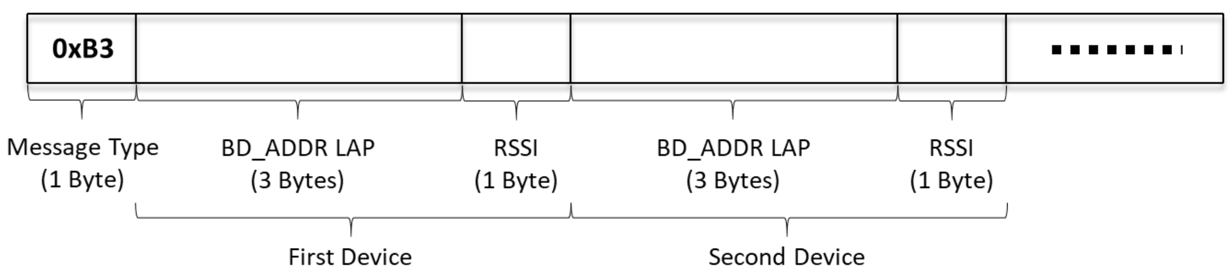
(a) Filter Range 0



(b) Filter Range 1



(c) Filter Range 2



(d) Filter Range 3

Figure 8-3: BLE Report UL Payload Formats for Filtered Reporting

Each payload consists of a 1-byte header followed by the data from each discovered device. The header denotes the filter range corresponding to these devices. Explicitly, BLE reports for ranges 0, 1, 2, and 3 have the headers 0x B0, 0x B1, 0x B2, and 0x B3, respectively. If no devices were discovered during a scan for a particular filter range, an empty list (i.e., only the header) is sent.

The data from each device consists of a 4-byte *LAP* and RSSI pair, where the *LAP* is the 3 LSBs of the BD_{ADDR} and the RSSI is a signed 1-byte number in units of [dBm]. The *OUI* is implicitly known due to the definition of the filter range, so only the *LAP* is necessary for unique identification. See §8.1.3 for more details about filter operation.

The *LAP* and RSSI pairs for any other discovered devices are concatenated into the payload. The order of the listed devices depends on whether averaging mode is enabled or disabled (see §8.1.2).

There will always be at least 1 report corresponding to each active range following every BLE scan. Each report is sent in a separate UL.

8.1.4.3 Example UL Payloads

- **0x 0A 64 7F DA 00 00 01 C9**
  - Header = 0x 0A → basic BLE data report
  - 0x 64 7F DA 00 00 01 = BD_{ADDR} = 64:7F:DA:00:00:01
  - 0x C9 = RSSI = -55 × 1 dBm = -55 dBm

- **0x B0 12 34 56 C4 AB CD EF 3F**
  - Header = 0x B0 → BLE data report for filter range 0
  - 0x 12 34 56 = device 1 BD_{ADDR} *LAP* = 12:23:56
  - 0x C4 = device 1 RSSI = -60 × 1 dBm = -60 dBm
  - 0x AB CD EF = device 2 BD_{ADDR} *LAP* = AB:CD:EF
  - 0x 3F = device 2 RSSI = -63 × 1 dBm = -63 dBm

Configuration Settings

Table 8-1 shows the list of configuration registers which affect BLE scanning and reporting behaviour. In this table, the bit indexing scheme is as shown in Figure 3-2 .To access these registers, a command must be formatted and sent according to the details described in Section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x50	BLE Mode	R/W	1 B	• Bit 7: 0/1 = Averaging mode off/on • Bit 6: 0/1 = Report BLE DZ status disabled/enabled • Bits 0-5: Number of reported devices 0: Disables BLE scans	*ble_mode {* *ble_avg_mode: <value>* *(string/no unit)* *ble_dz_status_report: <value>* *(string/no unit)* *ble_num_reported_devices : <value>* *(number/no unit)* *}*	Averaging mode enabled Danger zone status reports enabled Number of reported devices: 0 **0x C0**

Address	Name	Access	Size	Description	JSON Variable	Default
0x51	BLE Scan Duration	R/W	1 B	• Scan duration for periodic reports (1 sec/LSb) 0: Invalid	*ble_scan_duration_periodic : <value>* *(number/sec)*	BLE scan duration: 3s
0x52	BLE Scan Interval	R/W	2 B	• Scan interval (1 msec/LSb) • Acceptable values: 3, …, 10000 • Other values: Invalid	*ble_scan_interval: <value>* *(number/msec)*	**BLE scan interval: 30s**
0x53	BLE Scan Window	R/W	2 B	• Scan window (1 msec/LSb) • Acceptable values: 3, …, "Scan Interval" • Other values: Invalid	*ble_scan_window: <value>* *(number/msec)*	BLE scan window: 30s
0x54	BLE Range 0 Definition	R/W	9 B	• Range 0 for whitelisted BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 48-71: OUI = B_0:B_1:B_2 • Bits 24-47: LAP_{start} = B_3:B_4:B_5 • Bits 0-23: LAP_{end} = B_6:B_7:B_8	*ble_range0 {* *ble_range0_bd_addr_oui: <value>* *(string/no unit)* *ble_range0_bd_addr_start: <value>* *(string/no unit)* *ble_range0_bd_addr_end: <value>* *(string/no unit)* *}*	BLE range 0: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x55	BLE Range 1 Definition	R/W	9 B	• Range 1 for whitelisted BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 48-71: OUI = B_0:B_1:B_2 • Bits 24-47: LAP_{start} = B_3:B_4:B_5 • Bits 0-23: LAP_{end} = B_6:B_7:B_8	*ble_range1 {* *ble_range1_bd_addr_oui: <value> (string/no unit)* *ble_range1_bd_addr_start: <value> (string/no unit)* *ble_range1_bd_addr_end: <value> (string/no unit)* *}*	BLE range 1: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00
0x56	BLE Range 2 Definition	R/W	9 B	• Range 2 for whitelisted BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 48-71: OUI = B_0:B_1:B_2 • Bits 24-47: LAP_{start} = B_3:B_4:B_5 • Bits 0-23: LAP_{end} = B_6:B_7:B_8	*ble_range2 {* *ble_range2_bd_addr_oui: <value> (string/no unit)* *ble_range2_bd_addr_start: <value> (string/no unit)* *ble_range2_bd_addr_end: <value> (string/no unit)* *}*	BLE range 2: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x57	BLE Range 3 Definition	R/W	9 B	• Range 3 for whitelisted BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 48-71: OUI = B_0:B_1:B_2 • Bits 24-47: LAP_{start} = B_3:B_4:B_5 • Bits 0-23: LAP_{end} = B_6:B_7:B_8	*ble_range3 {* *ble_range3_bd_addr_oui: <value> (string/no unit)* *ble_range3_bd_addr_start: <value> (string/no unit)* *ble_range3_bd_addr_end: <value> (string/no unit)* *}*	BLE range 3: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00

Table 8-1: BLE Configuration Registers

8.1.4.4 Periodic Scanning and Reporting Configuration

If BLE scans are enabled and configured, scans will occur periodically, and BLE reports are sent to the application according to the rules defined in section 4.2

- In Normal state, SEAL/SEAL Ex scans for devices using the "Tick in Normal State" period.
- In Emergency mode, SEAL/SEAL Ex scans for devices using the "Tick in Emergency State" period.

8.1.4.5 Operational Configuration

The *BLE Rx Mode* register, 0x 50, controls 3 settings:

- *BLE scan enable/disable* setting bits 0 through 6 to all 0s disables all BLE scanning, even if BLE is defined as one of the geolocation scans. NOTE: this value is ignored if the device is in beacon mode; it is impossible to conduct any scanning while in beacon mode.
- *Number of reported devices, N*: The results of each scan will only include up to *N* discovered devices. If *N* or fewer devices are discovered, all devices are reported. If more than *N* devices are discovered, *N* devices are reported, and they are chosen based on whether averaging mode is enabled (see §8.1.2).
- *Averaging mode enable/disable* setting bit 7 to 1 enables averaging mode.

The scan parameters, namely the *BLE scan durations*, *BLE scan interval*, and *BLE scan window*, are all defined by registers 0x 51, 0x 52, and 0x53, respectively.

Registers 0x 54 through 0x 57 define filter ranges 0 through 3, respectively.

8.1.4.5.1 Example DL Payloads

- Configure the tracker to report the strongest beacon only:
  - DL payload: **0x D0 81**
    - Register 0x 50 with bit 7 set to 1 = 0x D0
    - Number of reported devices = 1, Averaging mode enabled
      - Value bits 0 and 7 set to 1 = 0x 81

- Decrease the scan duty cycle to 50% from default while keeping scan durations the same to save battery life:
  - DL payload: **0x D3 00 0F**
    - Register 0x 53 with bit 7 set to 1 = 0x D3
    - Scan window 15 ms = 0x 00 0F

- Set filters to only report devices with MAC addresses ABCDEF000001 and ABCDEF500000 to ABCDEF999999:
  - DL payload: **0x D4 AB CD EF 00 00 01 00 00 01 D5 AB CD EF 50 00 00 99 99 99**
    - Register 0x 54 with bit 7 set to 1 = 0x D4
    - Filter range 0 = ABCDEF000001 to ABCDEF000001 = 0x AB CD EF 00 00 01 00 00 01
    - Register 0x 55 with bit 7 set to 1 = 0x D5
    - Filter range 1 = ABCDEF500000 to ABCDEF999999 = 0x AB CD EF 50 00 00 99 99 99

- Filter for only TEKTELIC BLE devices:
  - DL payload: **0x D4 64 7F DA 00 00 00 FF FF FF**
    - Register 0x 54 with bit 7 set to 1 = 0x D4
    - Filter range 0 = 647FDA000000 to 647FDAFFFFFF = 0x 64 7F DA 00 00 00 FF FF FF

8.2 BLE Danger Zones

SEAL/SEAL Ex supports the definition of danger zones using MAC addresses and RSSIs of discovered BLE devices. The following subsections detail the BLE danger zone scheme, uplink formats, and supported configuration options with examples.

8.2.1 Operational Description

Users can define up to four BLE MAC address ranges and the required RSSI threshold to set up as danger zones. If a discovered BLE device with a MAC address that falls within a defined danger zone MAC address range has an RSSI value lower than the defined RSSI threshold, SEAL/SEAL Ex triggers an alarm for that danger zone.

Like the 'Filtering mode' explained in section 8.1.4.2, after a BLE scan is complete, the list of discovered devices is filtered to include only those lying within one or more of the four possible DZ BD_ADDR ranges. If any of the BLE_ADDRs has an RSSI value that falls above the defined RSSI threshold for their respective DZ BD_ADDR ranges, the BLE DZ emergency is triggered for that DZ BD_ADDR range, and a status report indicating the change in emergency status is sent with the format shown in section 8.2.2

The following are the rules around using the 4 BD_ADDR ranges:

1. A BLE DZ range set to all 0's: An inactive range; otherwise, an active range.
2. A BLE DZ range with $LAP_{start} > LAP_{end}$: The range is active, but empty (i.e., BLE DZ status always reports *unknown*).
3. A BLE DZ active range with $LAP_{start} = LAP_{end}$: The BLE DZ range has only one BD_ADDR in it.
4. It is possible that the ranges overlap. A BD_ADDR that is in at least one of the ranges and is to be reported, is always reported under the first range (from BLE DZ Range 0 to 3) that it falls into.

There are four (4) possible BLE danger zone status explained below

- The SEAL/SEAL Ex is inside a given danger zone (DZ) if the average RSSI values of any BLE address (BLE_ADDR) in the range exceed the DZ RSSI threshold.
- If the SEAL/SEAL Ex detects any BLE_ADDR in the range but the average RSSI from the DZ BLE_ADDR is below the DZ RSSI threshold, the SEAL/SEAL Ex is near the given DZ.
- If the SEAL/SEAL Ex cannot discover any DZ BLE_ADDR from the range, the SEAL/SEAL Ex is said to be outside the given DZ.
- If any of the four BLE DZs are not set or are set incorrectly, the SEAL/SEAL Ex reports that particular DZ as unknown.

Note: A danger zone alarm is triggered when RSSI values exceed the threshold, not when they fall below it. Higher RSSI values indicate closer proximity to the beacon, while lower RSSI values indicate greater distance. For example, an RSSI of -70 dBm is closer than an RSSI of -100 dBm. Therefore, a threshold of -80 dBm would trigger an alarm for an RSSI of -70 dBm, not -100 dBm.

The following system behaviors are triggered when any of the four BLE danger zones are activated:

- Periodic flashing of all LEDs as detailed in section 5.3.4.1
- Transmission of a BLE Danger Zone (DZ) Status Report with the corresponding activated BLE DZ bit set to "1" (Refer to section 9.2.2)
- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using "Tick in Emergency State" as described in section 4.2

When all BLE danger zone alarms are cleared, the following system behaviors occur:

- Termination of the periodic LED flashes
- Transmission of a BLE Danger Zone (DZ) Status Report with the corresponding activated BLE DZ bit set to "0" (Refer to section 8.2.2)
- System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

8.2.2 Uplink Report Format

BLE DZ status reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in Table 8-2. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 8-2: BLE DZ Safety Status Reports

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
BLE DZ Status	0x 01	0x 95	1 B	Bitmap Input	• Bit 0-1: DZ0 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 2-3: DZ1 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 4-5: DZ2 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 6-7: DZ3 0 = Unknown 1 = Inside 2 = Outside 3 = Near	*ble_dz_status {* *ble_status_dz0: <value> (string/no unit)* *ble_status_dz1: <value> (string/no unit)* *ble_status_dz2: <value> (string/no unit)* *ble_status_dz3: <value> (string/no unit)* *}*

8.2.2.1 Example UL Payload

- UL payload: **0x 01 95 55**
  - Bits 0-1: 1 -> Inside BLE DZ0
  - Bits 2-3: 1 -> Inside BLE DZ1
  - Bits 4-5: 1 -> Inside BLE DZ2
  - Bits 6-7: 1 -> Inside BLE DZ3

Configuration Settings

Table 8-3 shows the list of configuration registers which affect BLE scanning and reporting behaviour. In this table, the bit indexing scheme is as shown in Figure 3-2 .To access these registers, a command must be formatted and sent according to the details described in Section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x50	BLE Mode	R/W	1 B	• Bit 7: 0/1 = Averaging mode off/on • Bit 6: 0/1 = Report BLE DZ status disabled/enabled • Bits 0-5: Number of reported devices 0: Disables BLE scans	*ble_mode {* *ble_avg_mode: <value>* *(string/no unit)* *ble_dz_status_report: <value>* *(string/no unit)* *ble_num_reported_devices : <value>* *(number/no unit)* *}*	Averaging mode enabled Danger zone status reports enabled Number of reported devices: 0 **0x C0**
0x58	BLE DZ Range 0 Definition	R/W	10 B	• Range for DZ0 BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 56-79: OUI = B_0:B_1: B_2 • Bits 32-55: LAP_{start} = B_3:B_4:B_5 • Bits 8-31: LAP_{end} = B_6:B_7:B_8 • Bits 0-7: RSSI Threshold (1 dBm/LSB, signed)	*ble_range0 {* *ble_dz_range0_bd_addr_oui: <value>* *(string/no unit)* *ble_dz_range0_bd_addr_start: <value>* *(string/no unit)* *ble_dz_range0_bd_addr_end: <value>* *(string/no unit)* *ble_dz_range0_rssi: <value>* *(string/no unit)* *}*	BLE DZ range 0: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00 RSSI: 0 dBm

Address	Name	Access	Size	Description	JSON Variable	Default

0x59	BLE DZ Range 1 Definition	R/W	10 B	• Range for DZ1 BD_ADDRs
				• B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8
				• Bits 56-79: OUI = B_0:B_1: B_2
				• Bits 32-55: LAP_{start} = B_3:B_4:B_5
				• Bits 8-31: LAP_{end} = B_6:B_7:B_8
				• Bits 0-7: RSSI Threshold (1 dBm/LSB, signed)
					ble_range1 {
					
					ble_dz_range1_bd_addr_oui: <value> (string/no unit)
					
					ble_dz_range1_bd_addr_start: <value> (string/no unit)
					
					ble_dz_range1_bd_addr_end: <value> (string/no unit)
					
					ble_dz_range1_rssi: <value> (string/no unit)
					
					}
						BLE DZ range 1:
						
						OUI: 00 00 00
						
						LAP Start: 00 00 00
						
						LAP End: 00 00 00
						
						RSSI: 0 dBm

0x5A	BLE DZ Range 2 Definition	R/W	10 B	• Range for DZ2 BD_ADDRs
				• B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8
				• Bits 56-79: OUI = B_0:B_1: B_2
				• Bits 32-55: LAP_{start} = B_3:B_4:B_5
				• Bits 8-31: LAP_{end} = B_6:B_7:B_8
				• Bits 0-7: RSSI Threshold (1 dBm/LSB, signed)
					ble_range2 {
					
					ble_dz_range2_bd_addr_oui: <value> (string/no unit)
					
					ble_dz_range2_bd_addr_start: <value> (string/no unit)
					
					ble_dz_range2_bd_addr_end: <value> (string/no unit)
					
					ble_dz_range2_rssi: <value> (string/no unit)
					
					}
						BLE DZ range 2:
						
						OUI: 00 00 00
						
						LAP Start: 00 00 00
						
						LAP End: 00 00 00
						
						RSSI: 0 dBm

Address	Name	Access	Size	Description	JSON Variable	Default
0x5B	BLE DZ Range 3 Definition	R/W	10 B	• Range for DZ3 BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • Bits 56-79: OUI = $B_0:B_1: B_2$ • Bits 32-55: LAP_{start} = $B_3:B_4:B_5$ • Bits 8-31: LAP_{end} = $B_6:B_7:B_8$ • Bits 0-7: RSSI Threshold (1 dBm/LSB, signed)	*ble_range3 {* *ble_dz_range3_bd_addr_oui: <value> (string/no unit)* *ble_dz_range3_bd_addr_start: <value> (string/no unit)* *ble_dz_range3_bd_addr_end: <value> (string/no unit)* *ble_dz_range3_rssi: <value> (string/no unit)* *}*	BLE DZ range 3: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00 RSSI: 0 dBm

Table 8-3: BLE Danger Zone Configuration Registers

8.2.2.2 *Example DL Payload*

- Set DZ0 MAC address range to only devices within MAC addresses ABCDEF000000 and ABCDEFFFFFFF and RSSI threshold of -100:
  - DL payload: **0x D8 AB CD EF 00 00 00 FF FF FF 9C**
    - Register 0x 58 with bit 7 set to 1 = 0x D8
    - DZ range 0 = ABCDEF000000 to ABCDEFFFFFFF = 0x AB CD EF 00 00 00 FF FF FF
    - RSSI threshold: -100 = 9C

9 Accelerometer

The SEAL/SEAL Ex is equipped with an accelerometer that can measure the direction and magnitude of acceleration on up to 3 individual axes: ±X, ±Y, and ±Z.

The accelerometer is ALWAYS enabled by default. It operates constantly in the background during all system operations, making measurements at a configurable *sample rate*.

The accelerometer measurement sampling can be used for 3 main sensor functions:

- **Orientation Detection:** the accelerations on each axis can be reported periodically and/or upon any EMERGENCY alarm activation.
- **Fall Detection Alarms:** if the acceleration samples meet certain defined threshold criteria for fall detection, fall detection alarm is triggered and the system is transitioned to EMERGENCY state by fall detection.
- **Inactivity SLEEP:** if acceleration samples meet certain threshold criteria within a specified period in NORMAL state, the SEAL/SEAL Ex can stop all periodic reportings and go to a low-power sleep state, until the acceleration samples meet the wake-up threshold.

By default, orientation reporting is disabled, but fall detection alarms and timeout to sleep features are enabled.

The general behaviour and configuration, as well as the descriptions of the supported accelerometer functions described above are detailed in the following subsections.

9.1 General Accelerometer Sampling

9.1.1 Operational Description

Regardless of which accelerometer function is being used, the basic measurement scheme is the same. A single accelerometer measurement sample is comprised of the direction and magnitude of acceleration on up to 3 individual axes: ±X, ±Y, and ±Z.

The acceleration magnitude is measured in units of *acceleration due to gravity*, *g*, where 1 *g* is equivalent to the acceleration experienced by a body at rest on earth's surface: 9.810 m/s^2. Measuring acceleration means detecting changes in movement.

The accelerometer is enabled always by default. It operates constantly in the background during all operation states, making measurements at a configurable *sample rate*. As with any physical sampling, any real acceleration value must be sustained longer than the sample period to be accurately measured. Quicker sample rates have a shorter period and can therefore resolve shorter physical acceleration events. However, sampling the transducer at a quicker rate increases the power consumption, impacting the battery life.

The *measurement range* is configurable and defines the full dynamic range of accelerations that can be monitored on any enabled axis. Since the accelerometer output is always an 8-bit signed number, a larger measurement range means less precision (i.e., a larger *g* unit per LSb). Explicitly, the supported measurement ranges of ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively[14]. If the physical acceleration magnitude is outside the current measurement range at the time of sampling, it will not be registered.

9.1.2 Configuration Settings

Table 9-1 shows the list of configuration registers which control general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 3-2 .To access these registers, a command must be formatted and sent according to the details described in Section 3.2.

Table 9-1: General Accelerometer Configuration Registers

Address	Name	Access	Size	Description	JSON Variable	Default
0x41	Accelerometer Sensitivity	R/W	1 B	• Bits 0-2: Sample Rate 0: Invalid 1/2/**3**/4/5/6/7 = 1/10/**25**/50/100/200/400 Hz • Bit 3: 0, otherwise invalid • Bits 4-5: Measurement Range[15] 0/1/**2**/3 = ±2/±4/**±8**/±16 *g* • Bits 6-7: 0, otherwise ignored	*accelerometer_sensitivity {* *accelerometer_measurement_range: <value> (number/g)* *accelerometer_sample_rate: <value> (number/Hz)* *}*	accelerometer measurement range: +/-8 g, accelerometer sample rate: 50 Hz

9.1.2.1 Example DL Payloads

- Set sample rate to 400 Hz and measurement range to ±2:
  - DL payload: **0x C1 07**
    - Register 0x 41 with bit 7 set to 1 = 0x C1
    - Sample rate option 7, measurement range option 0 = 0x 07

---

[14] The magnitudes are always reported by the sensor with 0.001 *g* = 1 m*g* resolution, regardless of attainable precision given the current measurement range.

[15] Measurement ranges ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical transducer output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively. Note that if an acceleration threshold for an event is set equal to or greater than the configured measurement full-scale (2 *g*, 4 *g*, 8 *g*, 16 *g*), then no such acceleration event will be triggered.

9.2 Orientation Detection

9.2.1 Operational Description

The sensor orientation is expressed quantitatively as an *acceleration vector*, $\vec{a}$:

$$\vec{a} = (x, y, z)$$

Where *x*, *y*, and *z* represent the measured acceleration components on each of the 3 axes X, Y, and Z, respectively. These components can be positive or negative, depending on the direction of net acceleration on each axis.

For a stationary sensor, the total acceleration *magnitude*[16] should be approximately 1 *g*; the only net acceleration experienced by a non-moving body is gravity. Therefore, the vector components can be used to determine the direction of gravity and therefore the sensor orientation.

The sensor can be configured to send an accelerometer vector report periodically. By default, vector reports are disabled.

9.2.2 UL Report Frame Formats

Accelerometer vector reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the safety report frame formats are listed in Table 9-2. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 9-2: Accelerometer Vector Report UL Frame Format

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration [1 mg/LSb] (signed)	*acceleration_vector {* *acceleration_x: <value>, (signed/g)* *acceleration_y: <value>, (signed/g)* *acceleration_z: <value> (signed/g)* *}*

9.2.2.1 Example UL Payloads

- **0x 00 71 00 00 00 00 03 E8**
  - Channel ID = 0x 03, Type ID = 0x 72 → acceleration vector data report
  - 0x 00 00 = 0 × 1 m*g* = 0.000 *g* in X-direction
  - 0x 00 00 = 0 × 1 m*g* = 0.000 *g* in Y-direction

[16] Acceleration magnitude is defined as $a = \|\vec{a}\| = \sqrt{x^2 + y^2 + z^2}$

- 0x 03 E8 = 1000 × 1 m*g* = 1.000 *g* in Z-direction

- **0x 00 71 00 00 FB 50 00 00**
  - Channel ID = 0x 03, Type ID = 0x 72 → acceleration vector data report
  - 0x 00 00 = 0 × 1 m*g* = 0.000 *g* in X-direction
  - 0x FB 50 = -1200 × 1 m*g* = -1.200 *g* in Y-direction
  - 0x 00 00 = 0 × 1 m*g* = 0.000 *g* in Z-direction

9.2.3 Configuration Settings

All user-configurable registers for Accelerometer vector reporting are listed in
Table 9-3. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between GNSS reports and BLE (if enabled) in EMERGENCY state. • Default = 1 tick • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state • Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min **0x 00 01**
0x24	Ticks per Accelerometer Reports	R/W	2 B	• Ticks between accelerometer reports • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic accelerometer reports • Other values: Invalid	*ticks_accelerometer: <value> (number/no unit)*	0 ticks **0x 00 00**

Table 9-3: Accelerometer Vector Reporting Configuration Registers

Note: Accelerometer report is transmitted at every "Tick per Accelerometer Reports" while the SEAL/SEAL Ex is in the NORMAL state, and at every "Tick in EMERGENCY state" while the SEAL/SEAL Ex is in the EMERGENCY state.

9.2.3.1 Example DL Payload

- Schedule accelerometer vector reports every 48 hours:
  - DL payload: **0x A0 00 00 0E 10 A4 00 30**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 3600 s/core tick = 0x 00 00 0E 10
    - Register 0x 24 with bit 7 set to 1 = 0x A4
    - Report every 48 ticks = 0x 00 30

9.3 Fall Detection

The SEAL/SEAL Ex continuously samples and monitors accelerations, comparing them with a set of conditions. If these conditions are met, a human fall is detected, and an alarm is raised. The following subsections explain this concept in detail.

9.3.1 Operation Description

To detect human fall events, the SEAL/SEAL Ex uses the accelerometer and its internal timer to check for the following conditions. All conditions must be met within the specified time for a fall to be detected. If a condition takes longer than the condition time, the algorithm is reset, and all progress is lost.

1. Free Fall Event: The accelerometer is first triggered by a free fall event. This occurs when the magnitudes of all unfiltered axes (X, Y, and Z) drop below a certain threshold for a short duration, known as the free-fall interval.

   Example: Imagine a worker slipping and falling off a ladder. During the fall, there would be a brief moment where the person (and the worn SEAL/SEAL Ex device) are in free fall, causing the accelerometer readings to drop below the set threshold.

2. Fall Impact: After the free fall event is registered, the accelerometer must detect an impact. This happens when the magnitude of any unfiltered axis exceeds a threshold known as the impact threshold. Following the impact, there is an impact blackout duration during which no impact or activity is monitored. This blackout period helps ignore random vibrations or minor impacts that do not represent significant human motion.

   Example: After the free fall, the person hits the ground. The impact of hitting the ground causes the accelerometer to register a high magnitude on one or more axes, surpassing the impact threshold. The subsequent blackout period helps to ignore any minor vibrations from the immediate aftermath of the fall.

3. Torpidity: This is a short period of inactivity following the impact. For the torpidity condition to be met, the acceleration magnitude must remain below the torpidity threshold for a specified duration, known as the torpidity interval.

   Example: After hitting the ground, the person lies still for a few moments. During this period of inactivity, the accelerometer readings stay below the torpidity threshold for the specified torpidity interval, confirming the fall. This period of inactivity is crucial in differentiating between a jump and a fall. A jump involves an immediate resumption of activity while a fall usually involves a moment of stillness.

NOTE: The system suspends all activities during LoRa radio operations (Tx and Rx) to prioritize transmissions and receptions. During this period, accelerometer samples are saved in a buffer and processed after the radio operations are completed. This may lead to a delay in device responsiveness to falls if a fall occurs simultaneously with an uplink or downlink.

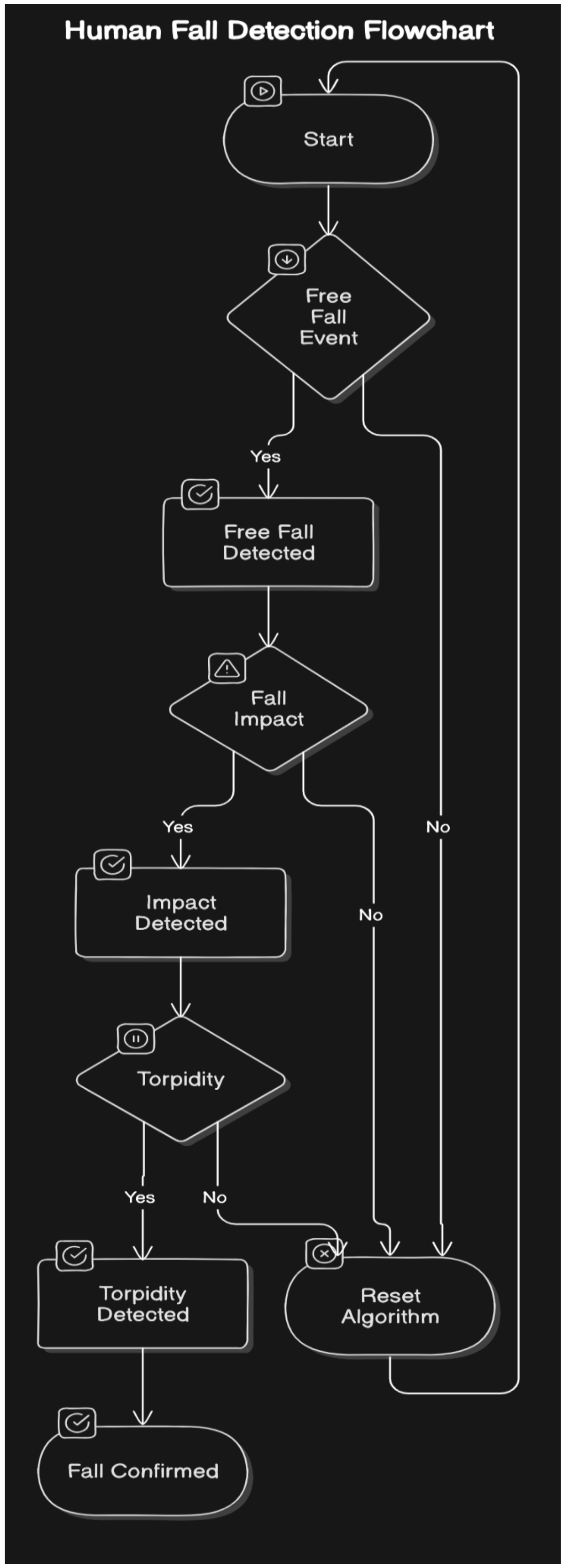


Figure 9-1: Fall Detection Algorithm

A fall alarm is raised by the system once all three conditions—free fall, impact, and torpidity—are met. For further details on systems behaviour in an active fall detection alarm state, please refer to section 6.3.

9.3.2 Uplink Frame Report Format

Safety reports featuring fall detection status are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the uplink frame formats are listed in Table 9-4. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Safety Status	0x 02	0x 95	1 B	Bitmap Input	• Bit 0: 0/1 = EB Inactive/Active • Bit 1: 0/1 = Fall Cleared/Active • Bit 2: 0/1 = SH OFF/ON Always = 0 for non-clip variants • Bit 3: 0/1 = EAR Alert Inactive/Active • Bit 4: 0/1 = Pressure Alarm Inactive/Active Bits 5-7: 0, otherwise invalid	*safety_status {* *safety_status_eb: <value> (string/no unit)* *safety_status_fall: <value> (string/no unit)* *safety_status_sh: <value> (string/no unit)* *safety_status_ear: <value> (string/no unit)* *safety_status_pressure <value> (string/no unit)* *}*

Table 9-4: Fall Detection Status UL Frame Formats

9.3.2.1 Example UL Payloads

- **0x 02 95 02**
  - Channel ID = 0x 02, Type ID = 0x 95 → safety status report
  - 0x 02 = Fall Alarm Bit turned to “1”

9.3.3 Configuration Settings

All user-configurable registers for fall detection are listed in Table 9-5. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x48	Free Fall	R/W	4 B	• Bits 16-31: Free Fall Acceleration Threshold 1 mg/LSB (unsigned) Acceptable values: 0-800 • Bits 0-15: Free Fall Acceleration Interval 1 msec/LSB (unsigned) 0: Invalid	*freefall {* *free_fall_acceleration_threshold: <value> (number/g)* *free_fall_acceleration_interval: <value> (number/sec)* *}*	Threshold = 0.5 *g* Interval = 0.4 s **0x 48 01 F4 01 90**
0x49	Impact	R/W	4 B	• Bits 16-31: Impact Threshold 1 mg/LSB (unsigned) Acceptable values: 1500-8000 • Bits 0-15: Impact Blackout Duration 1 msec/LSB (unsigned) Acceptable values: 0-65535	*impact {* *impact_threshold: <value> (number/g)* *impact_blackout_duration: <value> (number/sec)* *}*	Threshold = 5 *g* Blackout Duration = 2 s **0x 49 13 88 07 D0**

Address	Name	Access	Size	Description	JSON Variable	Default
0x4A	Torpidity	R/W	3 B	• Bits 0-7: Torpidity Interval 1 sec/LSB (unsigned) Acceptable values: 0-255 • Bits 8-23: Torpidity Threshold 1 mg/LSB (unsigned) Acceptable values: 100-3000	*torpidity {* *torpidity_threshold: <value> (number/g)* *torpidity_interval: <value> (number/sec)* *}*	Threshold = 2 *g* Interval = 1 s **0x 07 D0 01**

Table 9-5: Fall Detection Configuration Registers

9.3.3.1 Example DL Payloads

- Set Free Fall Acceleration Threshold to 0.25 g and Free Fall Acceleration Interval to 0.2 s
  - DL payload: **0x C8 00 FA 00 C8**
    - Register 0x 48 with bit 7 set to 1 = 0x C8
    - 0x 00 FA = 250 mg
    - 0x 00 C8 = 200 ms

- Set Impact Acceleration Threshold to 2 g and Impact Blackout Interval to 1 s
  - DL payload: **0x C9 07 D0 03 E8**
    - Register 0x 49 with bit 7 set to 1 = 0x C9
    - 0x 07 D0 = 2000 mg
    - 0x 03 E8 = 1000 ms

- Set Torpidity Threshold to 1 g and Torpidity Interval to 2s
  - DL payload: **0x CA 03 E8 02**
    - Register 0x 4A with bit 7 set to 1 = 0x CA
    - 0x 00 FA = 1000 mg
    - 0x 02 = 2000 ms

9.4 Inactivity Sleep

The SEAL/SEAL Ex uses the accelerometer to continuously monitor motion for the purpose of putting the device to sleep when there is an extended period of inactivity. By default, the device is put to sleep after the accelerometer measure 10 minutes of inactivity. The default sensitivity threshold is set to 250mg – a threshold low enough to ignore small and insignificant vibrations but sensitive enough to human movements or motion.

9.4.1 Operation Description

The SEAL/SEAL Ex transitions into a low-power SLEEP state when it does not detect motion exceeding a configurable threshold for a set period in the NORMAL state. For safety reasons, this SLEEP mode cannot be entered from the EMERGENCY state.

In SLEEP mode:

- All transducers, except the accelerometer, are set to their lowest energy states.
- No data is reported from the SEAL/SEAL Ex.
- The accelerometer continues to monitor motion events.

If motion exceeding the configurable sleep threshold is detected, the SEAL/SEAL Ex wakes up and returns to the NORMAL state. Upon transitioning back to the NORMAL state, any motion that exceeds the sleep acceleration threshold value will disable the motion detection interrupt for 10% of the timeout to SLEEP duration and reset the timeout to SLEEP to 0.

For example:

- If the timeout to SLEEP is set to 10 minutes and the SEAL/SEAL Ex detects motion, the motion detection interrupt is disabled for 1 minute (10% of 10 minutes).
- After 1 minute, the motion detection interrupt is re-enabled.
- This cycle continues as long as the SEAL/SEAL Ex is in use.

When the SEAL/SEAL Ex is placed in a stationary position (e.g., after work hours), it will go to SLEEP after 10 minutes without triggering the motion detection interrupt.

Note: Upon waking from inactivity SLEEP, the SEAL/SEAL Ex sends all enabled periodic reports immediately, and then continues to send them periodically according to their respective ticks.

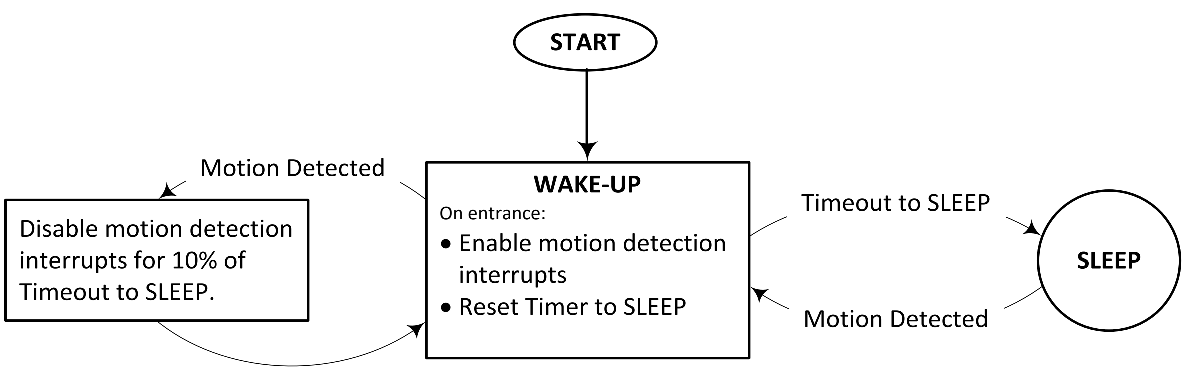


Figure 9-2: Inactivity SLEEP operation

NOTE: Do not confuse the inactivity SLEEP mode with DEEP SLEEP mode.

- SLEEP mode: This is a low-power state for normal operation. When the device wakes up from SLEEP mode, it immediately resumes normal activity without needing to reconnect to the network.

- DEEP SLEEP mode This is a full power-down of the system. When the device wakes up from DEEP SLEEP mode, it needs to reconnect to the network before resuming normal activity.

9.4.2 Configuration Settings

All user-configurable registers for inactivity SLEEP are listed in Table 9-6. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x42	SLEEP Acceleration Threshold	R/W	2 B	• Bits 0-15: SLEEP Acceleration Threshold 1 mg/LSB (unsigned)	*sleep_acceleration_threshold: <value> (number/g)*	250 mg **0x 00 FA**
0x43	Timeout to SLEEP	R/W	1 B	• No-motion duration, in min, before the SEAL/SEAL EX goes to SLEEP • 0: Disables going to SLEEP	*timeout_to_sleep: <value> (number/min)*	15 min **0x 0F**

Table 9-6: Inactivity SLEEP Configuration Settings

9.4.2.1 Example DL Payloads

- Increase the wake-up motion sensitivity by setting the acceleration threshold to 150, and disable inactivity SLEEP timeout:
  - DL payload: **0x C2 00 96 C3 00**
    - Register 0x 42 with bit 7 set to 1 = 0x C2
    - 0x 00 96 = 150 mg
    - Register 0x 43 with bit 7 set to 1 = 0x C3
    - 0x 00 = 100mins

10 Environmental Sensing

The SEAL/SEAL Ex features the capability to measure and report environmental conditions such as barometric pressure and temperature. Additionally, it supports functions based on environmental monitoring, such as pressure/elevation alarms and threshold-based temperature reporting. These functions enhance the safety features of the SEAL/SEAL Ex.

10.1 Barometer

The SEAL/SEAL Ex utilizes a pressure sensor based on a capacitive sensing principle and temperature compensation, ensuring high precision during temperature changes. Below are the typical and maximum specifications for the barometer:

1. Pressure sensor precision: ± 0.002 hPa (or ±0.02 m) (high precision mode)

   In high precision mode, the sensor provides extremely accurate pressure readings, which is crucial for applications requiring fine altitude measurements and pressure monitoring.

2. Pressure Relative accuracy: ± 0.06 hPa (or ±0.5 m)

   Relative accuracy refers to the sensor's ability to consistently report pressure changes accurately within the specified system operating range. This level of accuracy ensures reliable data for applications such as weather monitoring and elevation tracking.

3. Pressure Absolute accuracy: ± 1 hPa (or ±8 m)

   Absolute accuracy indicates the sensor's accuracy in reporting the true pressure value, considering all possible errors. This specification ensures that the sensor provides a reliable reference for applications requiring precise altitude or pressure data.

The following subsections discusses the two main functions the SEAL/SEAL Ex uses the barometric pressure for:

1. Periodic Pressure Reporting
2. Pressure/Elevation Alarm

10.1.1 Periodic Pressure Reporting

The SEAL/SEAL Ex supports periodic sampling and reporting of pressure data based on the configured interval settings

10.1.1.1 Operation Description

The SEAL/SEAL Ex samples barometric pressure using the barometer at a configurable sample rate.
These samples are reported periodically based on the configured tick per pressure interval, if enabled.

Setting the sample time to 0 disables the barometer. The maximum period between pressure samples is 60 seconds. The periodic reports are sent with the Tick per Pressure interval when in NORMAL state, and with the Tick per Emergency interval when in EMERGENCY state.

Note: If the reporting period is set to a value lower than the sample period, the SEAL/SEAL Ex may report the same value multiple times, as a new sample would not have been taken within that shorter interval.

10.1.1.2 UL Report Frame Format

Periodic pressure reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the uplink frame formats are listed in Table 10-1. For the general description of sensor data report formats and behaviour, see section 3.1.

Table 10-1: Periodic Barometric Pressure Data Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Barometric Pressure	0x00	0x73	2 B	Barometric Pressure	0.1 hPa/LSB (unsigned)	• *barometric_pressure: <value> (unsigned/float/hPa)*

10.1.1.2.1 Example UL Payloads

- **0x 00 73 23 56**
  - Channel ID = 0x 00, Type ID = 0x 73 → barometric pressure report
  - 0x 23 56 = 9046 × 0.1hPa = 904.6 hPa

10.1.1.3 Configuration Settings

All user-configurable registers for periodic pressure reporting are listed in Table 10-2. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**

Address	Name	Access	Size	Description	JSON Variable	Default
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between GNSS reports and BLE (if enabled) in EMERGENCY state. • Default = 1 tick • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state • Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min **0x 00 01**
0x27	Ticks per Pressure Reports	R/W	2 B	• Ticks between pressure reports • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic pressure reports • Other values: Invalid	*ticks_pressure: <value> (number/no unit)*	0 ticks **0x 00 00**
0x3B	Seconds per pressure sample	R/W	1 B	• Bits 0 – 5: Seconds between consecutive pressure samples (1s/LSb) 0: Barometer Disabled • Acceptable values: 0,1,2…60 • Bits 6 – 7: 0, otherwise invalid	*seconds_pressure_sample: <value> (unsigned/seconds)*	60s **0x 3C**

Table 10-2: Periodic Barometric Pressure Reporting Configuration Settings

Note: Pressure report is transmitted at every "Tick per Pressure Reports" while the SEAL/SEAL Ex is in the NORMAL state, and at every "Tick in EMERGENCY state" while the SEAL/SEAL Ex is in the EMERGENCY state.

10.1.1.3.1 Example DL Payloads

- Schedule pressure reports every 48 hours:
  - DL payload: **0x A0 00 00 0E 10 A7 00 30**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 3600 s/core tick = 0x 00 00 0E 10

        - Register 0x 27 with bit 7 set to 1 = 0x A7
        - Report every 48 ticks = 0x 00 30

- Et the seconds per pressure sample to 15:
    - DL payload: **0x BB 0F**
        - Register 0x 3B with bit 7 set to 1 = 0x BB
        - Set pressure sample to 15 = 0F

10.1.2 Pressure/Elevation Alarm

The SEAL/SEAL Ex supports the definition of a pressure range as a pressure/elevation alarm range. When SEAL/SEAL Ex reports pressure data within this defined range, it triggers a pressure/elevation alarm.

The fundamental idea of this feature is that barometric pressure can be reliably used to estimate elevation. By comparing the pressure-converted elevation of a known stationary reference unit with that of multiple mobile units, valuable information can be obtained about the worker wearing the mobile units. This comparison allows for monitoring the worker's location and movement relative to the stationary reference unit.

Note: Pressure and elevation are used interchangeably in this document due to the inverse relationship between them. While the application interprets the data as elevation, the device processes it as pressure.

10.1.2.1 Operation Description

The SEAL/SEAL Ex Pressure/Elevation feature requires at least two SEAL units: one stationary at the ground floor (SEAL_ref) and one worn by the mobile user (SEAL_user). For simplicity, "SEAL" represents both the SEAL and SEAL Ex variants in this subsection.

An application server, such as LEAP-X, is also necessary for updating the thresholds regularly to account for changing environmental conditions.

The following steps outlines the steps required to calibrate the mobile SEAL/SEAL Ex using the stationary SEAL/SEAL Ex

10.1.2.1.1 Calibrating the devices

1. **Power On Devices**: Ensure the SEAL_ref and SEAL_user devices are powered on and connected to the LoRa network. Integrate both devices with the application server. Enable periodic pressure reporting on both SEAL_ref and SEAL_user devices, setting the periodicity to 60 seconds.

2. **Base Level Calibration**: Place SEAL_user and SEAL_ref side by side at the base level of the location of interest. This could be the ground floor of a new building or the 10th floor of a building undergoing renovation. All elevations are measured with respect to this base level. Ensure the stationary reference unit and the mobile units are sampling and reporting pressure at least once every minute.

3. **Fetch Calibration Value:**

a. Fetch the most recent SEAL_ref barometric pressure value (SEAL_ref_P_uncal) and send it to SEAL_user on **port 100** using register 0x3C (see section 10.1.2.3).
b. Upon receiving this command, SEAL_user computes a one-time calibration offset using the formula:

$$SEAL_{user}\ Onetime\ Offset = SEAL_{user\_P\_uncal} - SEAL_{ref\_P\_uncal}$$

4. **Saving Calibration Offset**: SEAL_user saves this one-time offset to its flash memory[17], then applies this calibration offset to convert all its subsequent raw pressure values to calibrated pressure values using the formula below report:

$$SEAL_{user\_P\_cal} = SEAL_{user\_P\_uncal} - Onetime\ Offset$$

5. **Reporting Calibrated Pressure**: SEAL_user starts reporting the calibrated pressure using the calibrated pressure register (0x00 74) rather than the uncalibrated pressure register (0x00 73). These separate Cayenne headers for 'P_uncal' and 'P_cal' reports ensure a clear distinction between a calibrated SEAL_user and an uncalibrated SEAL_user

6. The SEAL_user device is now calibrated to the SEAL_ref unit and can be worn by a mobile user.

Note: The calibration process is only required again if the SEAL_ref unit is replaced.

10.1.2.1.2 Setting Alarm Thresholds

Next, it is required to set both ends of the pressure alarm threshold to enable the pressure alarm on SEAL/SEAL Ex. SEAL/SEAL Ex accepts two limits that must be defined to turn on the Pressure/Elevation feature – maximum pressure threshold and minimum pressure threshold. Maximum pressure threshold corresponds to the minimum elevation allowed, and the minimum pressure threshold corresponds to the maximum elevation allowed.

The following steps outline how to achieve this.

4. To set the maximum and minimum pressure threshold, the application is required to send a downlink command using register 0x 3D to the calibrated SEAL_user devices (see section 10.1.2.3). This register accepts 4 bytes, with the first two bytes being the maximum pressure threshold and the last two byte being the minimum pressure threshold.
5. An alternative user-friendly method is to program the application to perform the following to get the minimum and maximum pressure thresholds.
   a. Fetch the latest base elevation pressure value from the stationary SEAL_ref unit
   b. Convert this pressure value to baseline elevation in meters using the pressure-to-elevation formula below

[17] FW supports up to 10,000 one-time offset writes to flash

$$Elevation\ (m) = \left(\left(1 - \left(\frac{Pressure\ (hPa)}{1013.25}\right)^{0.190284}\right)145366.45\right)0.3048$$

c. Accept a maximum and minimum elevation threshold values in meters. For example, setting an alarm for an elevation range of between 100m and 50m above base elevation level would mean the following:

Maximum Elevation threshold = Baseline Elevation + 100m
Minimum Elevation threshold = Baseline Elevation + 50m

d. Next, convert the elevation thresholds to pressure thresholds using the elevation-to-pressure formula, a reversed form of the pressure-to elevation formula.

$$Pressur(hPa) = 1013.25\left(-\frac{Elevation\ (m)}{44307.633}\right) + 1)^{5.255303}$$

e. Given the inverse proportionality relationship between pressure and elevation, program the application to generate downlinks with the derived pressure thresholds and send to the SEAL_user devices.

Maximum Elevation Threshold = Minimum Pressure threshold

Minimum Elevation Threshold = Maximum Pressure threshold

6. These thresholds are inclusive of the range limits, so a pressure alarm threshold of 900 to 905 hPa would trigger if the calibrated pressure report is 900 hPa or 905 hPa.

7. The pressure alarm is triggered for the calibrated mobile SEAL_user unit if the following condition applies.

$$\min pressure\ threshold \leq SEAL_{user\_p\_cal} \leq \max pressure\ threshold$$

3. When the pressure alarm is triggered for any SEAL_user unit, the following behavior changes occur (see section 6.5 for more details)
   - Activation of the emergency active buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
   - Periodic flashing of all LEDs as detailed in section 5.3.4.1
   - Transmission of a Safety Status Report with the Pressure/Elevation Alarm bit set to “1” (Refer to section 6.6)

- Accelerated and Periodic transmission of all transducer data such as temperature, pressure, accelerometer, and battery life information, using “Tick in Emergency State” as described in section 4.2

4. 4. The pressure alarm is deactivated when the SEAL_user device samples a pressure value that falls outside the defined pressure alarm thresholds. This can happen either by moving the device away from the elevation or due to environmental changes affecting the pressure level. The latter is why updating the thresholds according to environmental changes is vital to the success of this feature (see section 10.1.2.1.4.2.11).

   The following behavior are experienced when the pressure alarm is deactivated

   - Activation of the emergency inactive buzz pattern as detailed in section 5.2.1.1, if the buzzer is enabled.
   - Termination of the periodic LED flashes
   - Transmission of a Safety Status report with the Pressure/Elevation Alarm bit set to “0” (Refer to section 6.6)
   - System state transition to NORMAL state i.e. all transducers enabled before the emergency starts using their respective ticks as described in section 4.2

10.1.2.1.3 Updating Alarm Thresholds

A good practice to follow is updating the thresholds with respect to the base pressure/elevation (SEAL_ref) every 15 minutes[18]. This reduces the number of false triggers experienced by the SEAL_user device. This can be done by programming the application to send automatic downlinks to all the SEAL_user with the updated thresholds at regular intervals.

The following steps outline how to achieve this.

1. At defined intervals, the application fetches the latest SEAL_ref pressure report and applies the thresholds to this latest value, then sends it to the SEAL_user device using steps defined in section 10.1.2.1.2 above.
2. On receiving the commands, the SEAL_user device updates its threshold to account for the environmental shifts and changes since the last threshold was set.
3. This cycle is repeated at regular intervals.

10.1.2.1.4 Example use-case

The following example aims to consolidate all the steps into one summarized section.

10.1.2.1.4.1 Requirements

- Two SEAL units: SEAL_ref (stationary) and SEAL_user (mobile).

[18] This is TEKTELIC’s recommendation

- An application server, such as LEAP-X, for regular threshold updates.

10.1.2.1.4.2 Operation

10.1.2.1.4.2.1 1. Power On Devices

- Ensure SEAL_ref and SEAL_user devices are powered on and connected to the LoRa network.
- Integrate both devices with the application server.
- Enable periodic pressure reporting every 60 seconds.

10.1.2.1.4.2.2 Base Level Calibration

- Place SEAL_user and SEAL_ref side by side at the base level (e.g., ground floor).
- Ensure both devices sample and report pressure at least once every minute.

10.1.2.1.4.2.3 Fetch Calibration Value

- Fetch the most recent SEAL_ref barometric pressure value (e.g., SEAL_ref_P_uncal = 1010 hPa) and send it to SEAL_user on port 100 using register 0x3C.
- SEAL_user computes the one-time calibration offset using the SEAL_ref_P_uncal and its most recent SEAL_user_P_uncal (e.g. 1015 hPa):

$$Onetime\ Offset = SEAL_{user_{Praw}} - SEAL_{refPraw}$$
$$Onetime\ Offset = 1015 - 1010 = 5\ hPa$$

10.1.2.1.4.2.4 Save Calibration Offset

- SEAL_user saves this one-time offset to its flash memory.
- SEAL_user applies this offset to convert its subsequent uncalibrated pressure values to calibrated pressure values. Three examples are shown below

$$SEAL_{user_{Pcal}} = SEAL_{user_{Praw}} - Onetime\ Offset$$
$$SEAL_{user_{Pcal}}\ 1 = 1010 - 5 = 1005\ hPa$$
$$SEAL_{user_{Pcal}}\ 2 = 1014 - 5 = 1009\ hPa$$
$$SEAL_{user_{Pcal}}\ 3 = 1012 - 5 = 1007\ hPa$$

10.1.2.1.4.2.5 Reporting Calibrated Pressure

- SEAL_user starts reporting calibrated pressure using the calibrated pressure register (0x00 74).
    - 1005 hPa = 0x 00 74 03 ED
    - 1009 hPa = 0x 00 74 03 F1
    - 1007 hPa = 0x 00 74 03 EF

10.1.2.1.4.2.6 Setting Alarm Thresholds

- Define and send the maximum (e.g., 1018 hPa) and minimum (e.g., 1005 hPa) pressure thresholds using register 0x3D on port 100.
    - Payload: 0xBD 03 FA 03 ED

- Register ox 3D with bit “7” set to write = 0x BD
- Max pressure threshold = 03 FA = 1018hPa
- Min pressure threshold = 03 ED = 1005 hPa

10.1.2.1.4.2.7 Pressure Alarm Activation

- The Pressure/Elevation alarm triggers if:

$$\min pressure\ threshold \leq SEAL_{user\_p\_cal} \leq \max pressure\ threshold$$

$$1005\ hPa \leq SEAL_{user_{p_{cal}}} \leq 1018\ hPa$$

  - 1000 hPa = No Pressure/Elevation Alarm
  - 1005 hPa = Pressure/Elevation Alarm triggered
  - 1009 hPa = Pressure/Elevation Alarm triggered
  - 1018 = Pressure/Elevation Alarm triggered
  - 1020 = No Pressure/Elevation Alarm

10.1.2.1.4.2.8 Activation Behavior

- Activation of emergency buzz pattern and LED flashes.
- Transmission of a Safety Status Report with the Pressure/Elevation Alarm bit set to “1”.
- Accelerated transmission of transducer data (temperature, pressure, accelerometer, battery life).

10.1.2.1.4.2.9 Deactivation of Pressure Alarm

- The alarm deactivates when SEAL_user samples a pressure value outside the defined thresholds.
- Regular updates to the thresholds are crucial for adapting to environmental changes.

10.1.2.1.4.2.10 Deactivation Behavior

- Activation of the emergency inactive buzz pattern.
- Termination of periodic LED flashes.
- Transmission of a Safety Status report with the Pressure/Elevation Alarm bit set to “0”.
- Transition to NORMAL state for all transducers.

10.1.2.1.4.2.11 Updating Alarm Thresholds

- Update thresholds every 15 minutes to reduce false triggers.
- Fetch the latest SEAL_ref pressure report, apply thresholds, and send updates to SEAL_user devices.
  - After 15 minutes, the minimum pressure threshold is now 1006 hPa and the maximum is 1017 hPa, indicating a pressure change of 2 hPa across the range.
  - New threshold downlink is now
    - Payload: 0xBD 03 FA 03 ED
      - Register ox 3D with bit “7” set to write = 0x BD
      - Max pressure threshold = 03 F9 = 1017hPa
      - Min pressure threshold = 03 EE = 1006 hPa
- Repeat this cycle at regular intervals

10.1.2.2 UL Report Frame Formats

Pressure/Elevation alarm reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in section 4.3.2. The specific details for the uplink frame formats are listed in Table 10-3. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Calibrated Barometric Pressure	0x00	0x74	2 B	Barometric Pressure	0.1 hPa/LSB (unsigned)	*barometric_pressure: <value>* *(unsigned/float/hPa)*
Safety Status	0x 02	0x 95	1 B	Bitmap Input	• Bit 0: 0/1 = EB Inactive/Active • Bit 1: 0/1 = Fall Cleared/Active • Bit 2: 0/1 = SH OFF/ON Always = 0 for non-clip variants • Bit 3: 0/1 = EAR Alert Inactive/Active • Bit 4: 0/1 = Pressure Alarm Inactive/Active Bits 5-7: 0, otherwise invalid	*safety_status {* *safety_status_eb: <value>* *(string/no unit)* *safety_status_fall: <value>* *(string/no unit)* *safety_status_sh: <value>* *(string/no unit)* *safety_status_ear: <value>* *(string/no unit)* *safety_status_pressure <value>* *(string/no unit)* *}*

Table 10-3: Elevation/Pressure Data Report UL Frame Formats

10.1.2.2.1 Example UL Payloads

- **0x 00 74 23 56 02 95 16**
    - Channel ID = 0x 00, Type ID = 0x 74 → calibrated barometric pressure report
    - 0x 23 56 = 9046 × 0.1hPa = 904.6 hPa
    - Channel ID = 0x 02, Type ID = 0x 95 → safety status report
    - 0x 16 = Elevation alarm active

10.1.2.3 Configuration Settings

All user-configurable registers for elevation/pressure alarm are listed in Table 10-4. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between GNSS reports and BLE (if enabled) in EMERGENCY state. • Default = 1 tick • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state • Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min **0x 00 01**
0x27	Ticks per Pressure Reports	R/W	2 B	• Ticks between pressure reports • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic pressure reports • Other values: Invalid	*ticks_pressure: <value> (number/no unit)*	0 ticks **0x 00 00**

Address	Name	Access	Size	Description	JSON Variable	Default
0x3B	Seconds per pressure sample	R/W	1 B	• Bits 0 – 5: Seconds between consecutive pressure samples (1s/LSb) 0: Barometer Disabled • Acceptable values: 0,1,2…60 • Bits 6 – 7: 0, otherwise invalid	*seconds_pressure_sample: <value> (unsigned/seconds)*	60s **0x 3C**
0x3C	Calibration Reference Pressure	R/W	2 B	• Bits 0 – 15: Refers to the pressure reported by the stationary calibrating unit (1s/LSb) 0: Equivalent to no calibration • Acceptable values: 0,1,2…65535 • Bits 6 – 7: 0, otherwise invalid	*calibration_reference_pressure: <value>* *(unsigned/float/hPa)*	0 hPa **0x 00 00**
0x3D	Pressure Thresholds {min, max}	R/W	4 B	• Bits 0-15: Min Pressure threshold (0.1hPa/LSb) Acceptable values: Max threshold – 0,1,2…65535 • Bits 16-31: Max Pressure threshold (0.1 hPa/LSb) Acceptable values: Min threshold – 0,1,2…65535	*pressure_threshold* *{pressure_threshold_max: <value> (unsigned/float/hPa)* *pressure_threshold_min: <value> (unsigned/float/hPa) }*	Min Pressure Threshold: 0hPa Max Pressure Threshold: 0 hPa 0x 00 00 00 00

Table 10-4: Pressure/Elevation Alarm Configuration Settings

10.1.2.3.1 Example DL Payloads

- Schedule calibrated pressure reports every 48 hours:
    - DL payload: **0x A0 00 00 0E 10 A7 00 30**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - 3600 s/core tick = 0x 00 00 0E 10
        - Register 0x 27 with bit 7 set to 1 = 0x A7
        - Report every 48 ticks = 0x 00 30
- Set the seconds per pressure sample to 15:
    - DL payload: **0x BB 0F**
        - Register 0x 3B with bit 7 set to 1 = 0x BB
        - Set pressure sample to 15 = 0F

10.2 Temperature

The SEAL is equipped with an onboard temperature sensor in the MCU that functions as a system thermometer. The vents in the enclosure allow ambient air to flow through the sensor, enabling the temperature [°C] data to be reported via a LoRaWAN uplink.

Threshold ranges can also be set, such that moving in or out of these ranges triggers additional ambient data reports.

The following subsections describe periodic and threshold-based reporting in detail.

10.2.1 Temperature Reporting

The SEAL/SEAL Ex supports periodic sampling and reporting of temperature data based on the configured interval settings. The periodic reports are sent with the Tick per Temperature interval when in NORMAL state, and with the Tick per Emergency interval when in EMERGENCY state.

10.2.1.1 Operational Description

The SEAL/SEAL Ex samples temperature readings from the MCU temperature sensor as part of its normal operation. It can be configured to periodically report the temperature in units of celsius via a LoRaWAN uplink. By default, temperature reporting is disabled.

Note 1: During changes in temperature, it may take some time for the SEAL/SEAL Ex to reflect and report the new values due to the time required for air to flow through the enclosure vents. Results may vary depending on the mounting orientation with respect to air flow direction.

Note 2: Since the temperature sensor is in `the MCU, readings may be influenced by heat emitted by surrounding components or the PCB itself.

10.2.1.2 UL Report Frame Formats

Temperature reports are sent on *LoRaWAN port 10* and have the frame format as shown in section 4.3.2. The specific details for the uplink frame formats are listed in

Table 10-5. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Temperature	0x 00	0x 67	2 B	Temperature	• Bit 0-15: Temperature reports [0.1°C/LSb] (signed)	*temperature: <value> (signed/°C)*

Table 10-5: Temperature Data Report UL Frame Formats

10.2.1.2.1 Example UL Payloads

- **0x 00 67 00 96**
  - Channel ID = 0x 00, Type ID = 0x 67 → temperature data report
  - 0x 00 96 = 150 × 0.1°C = 15°C

10.2.1.3 Configuration Settings

All user-configurable registers for temperature reporting are listed in

Table 10-6. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between GNSS reports and BLE (if enabled) in EMERGENCY state. • Default = 1 tick • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state • Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min **0x 00 01**

Address	Name	Access	Size	Description	JSON Variable	Default
0x25	Ticks per Temperature Reports	R/W	2 B	• Ticks between temperature reports • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic temperature reports • Other values: Invalid	*ticks_temperature: <value>* *(number/no unit)*	0 ticks **0x 00 00**

Table 10-6: Periodic Temperature Configuration Settings

Note: Temperature report is transmitted at every "Tick per Temperature Reports" while the SEAL/SEAL Ex is in the NORMAL state, and at every "Tick in EMERGENCY state" while the SEAL/SEAL Ex is in the EMERGENCY state.

10.2.1.3.1 Example DL Payloads

- Schedule temperature reports every 48 hours:
    - DL payload: **0x A0 00 00 0E 10 A5 00 30**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - 3600 s/core tick = 0x 00 00 0E 10
        - Register 0x 25 with bit 7 set to 1 = 0x A5
        - Report every 48 ticks = 0x 00 30

10.2.2 Threshold-Based Reporting

In addition to periodic temperature data reporting, the SEAL/SEAL Ex supports sending additional data reports based on crossing configurable thresholds.

10.2.2.1 Operational Description

When a temperature threshold is enabled, the sensor reports the environment data when it leaves the configured *threshold window*, and once again when it re-enters the threshold window. The threshold window is an open interval, meaning that even if the environment data is equal to the *low threshold* or *high threshold*, the sensor is considered to have left the threshold window.

When the temperature is inside the threshold window, the SEAL/SEAL Ex is in the *idle* sampling state. When outside, the SEAL/SEAL Ex is in the *active* sampling state. This is illustrated using the default configurations in Figure 10-1.

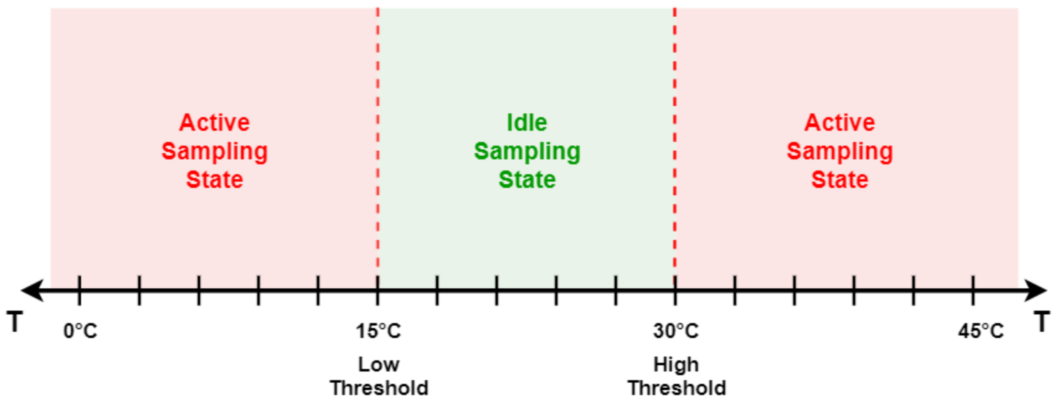


Figure 10-1: Ambient Temperature Window

The sampling periods are configurable and determine how often the temperature transducer is checked when the reported value is inside/outside the threshold window. When first enabled, the temperature transducer starts in the idle sampling state.

By default, threshold-based reporting is disabled.

Threshold-based reporting is compatible with periodic reporting of the temperature data; both can be disabled and enabled independently[19].

10.2.2.1.1 UL Report Frame Formats

The UL report frame formats for threshold-based temperature reports are identical to those for periodic temperature reports (See section 10.2.1.2)

10.2.2.2 Configuration Settings

All user-configurable registers for threshold-based temperature reports are listed in Table 10-7. In this table, the bit indexing scheme is as shown in Figure 3-2. To access these registers, a command must be formatted and sent according to the details described in section 3.2.

Address	Name	Access	Size	Description	JSON Variable	Default

[19] See section 10.2.1 for details about periodic ambient environment data reporting configuration.

Address	Name	Access	Size	Description	JSON Variable	Default
0x60	Temperature Sample Period in Idle State	R/W	4 B	• Bits 0 – 31: Sample period of temperature in sec in Idle state (1s/LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid	*temperature_sample_period_idle: <value> (number/sec)*	Idle state sample period: 300s
0x61	Temperature Sample Period in Active State	R/W	4 B	• Bits 0-31: Sample period of temperature in sec in Active state (1s/LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid	*temperature_sample_period_active: <value> (number/sec)*	Active state sample period: 60s
0x62	Temperature High/Low Thresholds	R/W	2 B	• Bits 8-15: High temperature threshold (signed, 1°C/LSb) • Bits 0-7: Low temperature threshold (signed, 1°C/LSb) • High threshold ≤ Low threshold: Invalid	*temperature_thresholds { temperature_threshold_high: <value> (number/°C) temperature_threshold_low: <value> (number/°C) }*	temperature_threshold_high: 30 °C temperature_threshold_low: 15 °C
0x63	Temperature Thresholds Status	R/W	1 B	• Bit 0: 0/1 = Temperature thresholds disabled/enabled • Bits 1-7: 0, otherwise invalid	*temperature_thresholds_status: <value> (string/no unit)*	Temperature Threshold disabled 0x 00

Table 10-7: Temperature Threshold based Configuration Settings

10.2.2.2.1 Example DL Payloads

- Enable temperature threshold-based reporting with a window between -10°C and 35°C:
  - DL payload: **0x E2 23 F6 E3 01**
    - Register 0x 62 with bit 7 set to 1 = 0x E2

        - High temperature threshold = 35°C = 0x 23
        - Low temperature threshold = -10°C = 0x F6
        - Register 0x 63 with bit 7 set to 1 = 0x E3
        - Thresholds enabled = 0x 01

- Read current sample periods:
    - DL payload: **0x 60 61**
        - Registers 0x 60 and 0x 61 with bits 7 set to 0 = 0x 60 61

11 System Diagnostics

The SEAL/SEAL Ex has a system diagnostics mechanism for managing and recording resets, transducer failures, and other unexpected operational issues that may arise during sensor usage.

11.1 Operation Description

The system is designed to continue functioning in the event of non-critical failures while attempting to surgically recover from system errors and failures. Regardless of the recovery outcome, a log is maintained and can be retrieved by sending a DL command. Additionally, the log keeps track of the reset count to monitor the number of disruptions the system experiences.

The supported component error diagnostics counters are described below

- Barometer Failure: occurs when system is unable to communicate with the barometer
- I2C Bus Failure: occurs when the system is unable to communicate with its I2C peripherals

The sensor will increment the respective error counter immediately after the error occurs and before it takes remediate action, such as forcing the failed peripheral/component to restart or rebooting the system.

The supported reset error diagnostics counters are described below

- Push-Button Reset: occurs when the reset mute button pattern is pressed.
- SW Command Reset: occurs when a SW reset occurs (including if the sensor receives a downlink (sent on LoRaWAN port 100) containing the sensor reset command (see section 4.4.2)
- Independent Watchdog Reset: occurs when the system gets locked up due to a SW bug.
- Power Loss Reset: occurs when the Sensor's battery is removed or experiences a brown-out.
- Other resets: refers to all other types of reset causes not covered within the scope of this document

Upon a successful JOIN event, the SEAL/SEAL Ex sends the diagnostics reports as the first set of uplinks.

11.2 UL Frame Report Format

System diagnostics reports are sent on ***LoRaWAN port 5*** and have the frame format as shown in section 4.3.2. The specific details for the uplink frame formats are listed in Table 11-1. For the general description of sensor data report formats and behaviour, see section 3.1.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Sensor Reset Diagnostics	0x40	0x06	5 B	Reset History	• Bits 0-7: Push-button reset counter • Bits 8-15: SW reset counter • Bits 16-23: Independent watchdog reset counter • Bits 24-31: Power loss reset counter • Bits 32-39: Latest reset reason code 0x01 = Push-button reset 0x02 = SW reset (incl. DL request) 0x04 = Independent watchdog reset 0x10 = Power loss reset 0x80 = Other resets	*reset_diagnostics {* *reset_reason: <value>, (string/no unit)* *power_loss_reset_count: <value>, (unsigned/no unit)* *watchdog_reset_count: <value>, (unsigned/no unit)* *sw_reset_count: <value>, (unsigned/no unit)* *button_reset_count: <value> (unsigned/no unit)* *}*
Sensor Error Diagnostics	0x40	0x07	3 B	Error History	• Bits 0-7: I2C Bus Failure • Bits 8-15: Barometer Failure • Bits 16-23: RFU	*error_diagnostics {* *barometer_failure: <value>, (string/no unit)* *i2c_failure: <value>, (string/no unit)* *}*

Table 11-1: Ambient Environment Data Report UL Frame Formats

11.2.1 Example UL Payloads

- **0x 40 06 02 01 00 03 04**
  - Channel ID = 0x 40, Type ID = 0x 06 → sensor reset diagnostics
  - 0x 02 = latest reset reason code: SW reset,
  - 0x 01 = power loss reset count: 1,

    - 0x 00 = watchdog reset count: 0,
    - 0x 03 = SW reset count: 3,
    - 0x 04 = push button reset count: 4

- **0x 40 07 00 03 01**
    - Channel ID = 0x 40, Type ID = 0x 07 → sensor error diagnostics
    - 0x 00 = RFU,
    - 0x 03 = barometer failure: 3,
    - 0x 01 = i2c bus failure: 1

11.3 Configuration Settings

The read-only register for querying the system diagnostics report is tabulated in Table 11-2. This query code must be sent on *port 5* to request for the latest systems diagnostics report.

Address	Name	Access	Description
0x40	Systems Diagnostics Query	R only	Query systems diagnostics information from sensor

Table 11-2: Systems Diagnostics Configuration Registers

11.3.1 Example DL Payloads

- Read latest systems diagnostics report
    - DL payload: **0x 40**

Appendix 1 – List of Uplink Registers and Payload Formats

LoRaWAN ports 5, 10, and 16 Uplinks

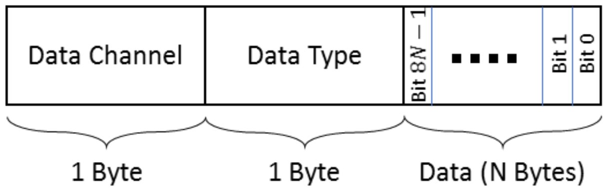


Figure 0-1: The UL Frame Format for port 5, 10, and 16 Uplinks

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Remaining Battery Capacity	0x00	0xD3	1 B	Percentage	1% / LSb (unsigned)	*rem_batt_capacity: <value>* *(unsigned/%)*
Remaining Battery Lifetime	0x00	0xBD	2 B	Days	1 day / LSb	*rem_batt_days: <value>* *(unsigned/days)*
UTC Timestamp	0x00	0x85	4 B	Timestamp	• Bits 0-5: Second [0-60][20] • Bits 6-11: Minute [0-59] • Bits 12-16: Hour [0-23] • Bits 17-21: Day [1-31] • Bits 22-25: Month [1-12] • Bits 26-31: [Year]−2020	*utc_timestamp {* *year: <value>* *(number/202(<value>))* *month: <value>* *(number/year)* *day: <value>* *(number/day)* *hour: <value>* *(number/hour)* *minute: <value>* *(number/min)* *second: <value>* *(number/s)* *}*

[20] The maximum possible value for "second" is 60 to allow for leap seconds.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Position Coordinates	0x00	0x88	8 B	Coordinates	• Bits 40-63: Latitude (signed, $\frac{90^{\circ}}{2^{23}}$/LSB) • Bits 16-39: Longitude (signed, $\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 0-15: [Altitude] + 500m (unsigned, $\frac{9500}{2^{16}}$ m/LSB)	*coordinates {* *latitude: <value> (number/°)* *longitude: <value> (number/°)* *altitude: <value> (number/m)* *}*
Ground Speed	0x00	0x92	1 B	Speed	0.27778 m/s/LSB	*ground_speed: <value> (number/m/s)*
No GNSS position fix	0x00	0x00	1B	Bitmap Input	0: invalid GNSS fix	*gnss_fix: invalid <value> (string/no unit)*
GNSS DZ Status	0x00	0x 95	1 B	Bitmap Input	• Bit 0-1: DZ0 0 = Unknown 1 = Inside 2 = Outside • Bit 2-3: DZ1 0 = Unknown 1 = Inside 2 = Outside • Bit 4-5: DZ2 0 = Unknown 1 = Inside 2 = Outside • Bit 6-7: DZ3 0 = Unknown 1 = Inside 2 = Outside	*gnss_dz_status {* *gnss_status_dz0: <value> (string/no unit)* *gnss_status_dz1: <value> (string/no unit)* *gnss_status_dz2: <value> (string/no unit)* *gnss_status_dz3: <value> (string/no unit)* *}*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
BLE DZ Status	0x 01	0x 95	1 B	Bitmap Input	• Bit 0-1: DZ0 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 2-3: DZ1 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 4-5: DZ2 0 = Unknown 1 = Inside 2 = Outside 3 = Near • Bit 6-7: DZ3 0 = Unknown 1 = Inside 2 = Outside • 3 = Near	*ble_dz_status {* *ble_status_dz0: <value> (string/no unit)* *ble_status_dz1: <value> (string/no unit)* *ble_status_dz2: <value> (string/no unit)* *ble_status_dz3: <value> (string/no unit)* *}*
Safety Status	0x 02	0x 95	1 B	Bitmap Input	• Bit 0: 0/1 = EB Inactive/Active • Bit 1: 0/1 = Fall Cleared/Active • Bit 2: 0/1 = SH OFF/ON Always = 0 for non-clip variants • Bit 3: 0/1 = EAR Alert Inactive/Active • Bit 4: 0/1 = Pressure Alarm Inactive/Active • Bits 5-7: 0, otherwise invalid	*safety_status {* *safety_status_eb: <value> (string/no unit)* *safety_status_fall: <value> (string/no unit)* *safety_status_sh: <value> (string/no unit)* *safety_status_ear: <value> (string/no unit)* *safety_status_pressure <value> (string/no unit)* *}*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration [1 m*g*/LSb] (signed)	*acceleration_vector { acceleration_x: <value>, (signed/g) acceleration_y: <value>, (signed/g) acceleration_z: <value> (signed/g) }*
Barometric Pressure	0x00	0x73	2 B	Barometric Pressure	• 0.1 hPa/LSB (unsigned)	• *barometric_pressure: <value>* *(unsigned/float/hPa)*
Calibrated Barometric Pressure	0x00	0x74	2 B	Barometric Pressure	• 0.1 hPa/LSB (unsigned)	*barometric_pressure: <value>* *(unsigned/float/hPa)*
Temperature	0x 00	0x 67	2 B	Temperature	• Bit 0-15: Temperature reports • [0.1ºC/LSb] (signed)	*temperature: <value> (signed/ºC)*
Number of Visible Satellites	0x0D	0x3C	1 B	Integer	Bits 0-7: Number of satellites used to calculate the GNSS fix. If no fix was obtained, this value is the total number of visible satellites • (unsigned, 1/LSB)	*num_satellites: <value> (unsigned/no unit)*
Average Satellite SNR	0x0D	0x64	2 B	Generic	• Bits 0-15: Average SNR of all satellites used in getting the GNSS fix (signed, 0.1 dB/LSB) • 0x 00 00 = No satellites visible for calculating average	*avg_satellite_snr: <value> (signed/dB)*
Most recent log entry number	0x0D	0x0F	2 B	Integer	Bits 0-15: Most recent log entry number • (unsigned, 1/LSB)	*log_num: <value> (unsigned/ no unit)*
GNSS Fix Type	0x0D	0x95	1 B	Bitmap Input	• Bits 0-1: The type of fix acquired by the receiver (unsigned) Possible types are: 0 = No fix available 2 = 2D fix 3 = 3D fix • Bits 2-7: 0, otherwise, invalid	*fix_type: <value> (unsigned/ no unit)*
GNSS Time-to-fix	0x0D	0x96	2 B	Stopwatch	Bits 0-15: The total time the GNSS receiver spent scanning for an acceptable fix • (Unsigned, 1s/LSB)	*time_to_fix: <value> (unsigned/s)*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
GNSS Fix Accuracy	0x0D	0x97	4 B	Fix Accuracy	• Bit 0-15: Horizontal fix accuracy (unsigned, 1m/LSB) • Bits 16-31: Vertical fix accuracy (unsigned, 1m/LSB)	*gnss_fix_accuracy {* *gnss_horizontal_accuracy: <value> (unsigned/m)* *gnss_vertical_accuracy: <value> (unsigned/m)* *}*
Ground Speed Accuracy	0x0D	0x98	4 B	Speed Accuracy	• Bits 0-31: Ground speed accuracy (unsigned, 0.001m/s/LSB)	*ground_speed_accuracy: <value> (unsigned/m/s)*
Number of fixes per scan	0x0D	0x99	1 B	Integer (unsigned)	• Bits 0-7: Number of fixes per scan (unsigned, 1/LSB)	*num_of_fixes: <value> (unsigned/no unit)*

Figure 0-2: List of All Uplink Registers

LoRaWAN port 25 Uplinks

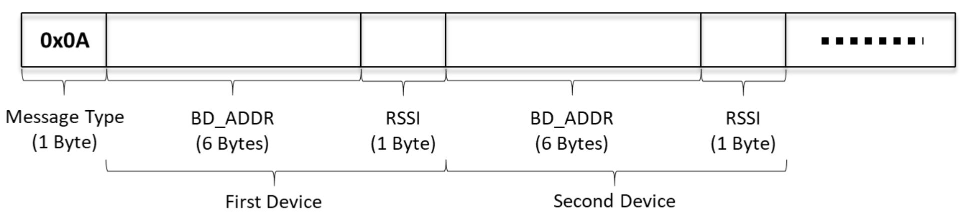
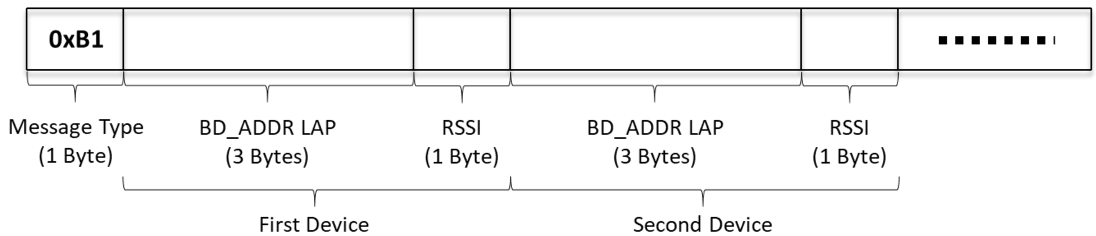
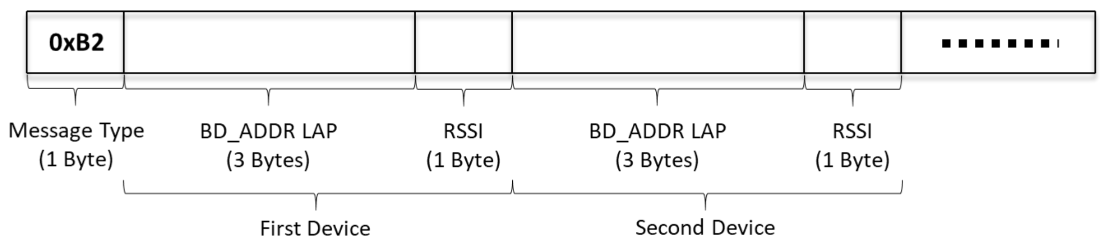


Figure 0-3: The BLE Report UL Payload Format for Basic Reporting

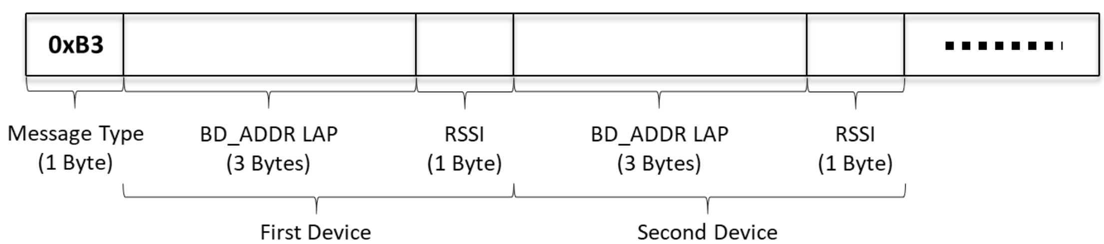
(a) Filter Range 0



(b) Filter Range 1



(c) Filter Range 2



(d) Filter Range 3

Figure 0-4: BLE Report UL Payload Formats for Filtered Reporting

LoRaWAN Port 100 and 101 UL Frame Formats

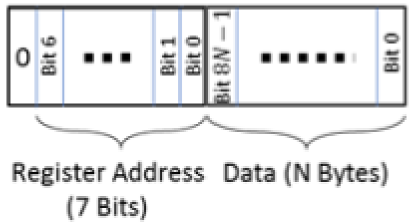


Figure 0-5: The *LoRaWAN Port 100* Read Response Format

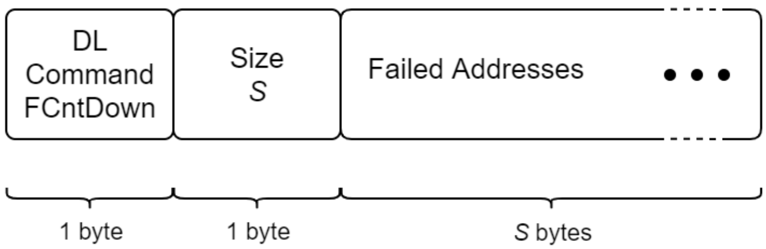
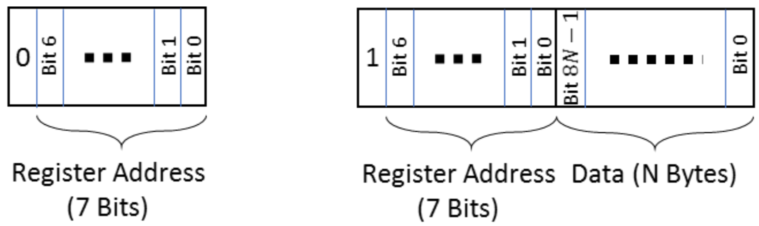


Figure 0-6: The *LoRaWAN port 101* Write Response Format

Appendix 2 – Lists of Configuration Registers and DL Payload Formats



a) Read Command Block (b) Write or Executable Command Block

Figure 0-1: The *LoRaWAN Port 100* DL Formats for Configuration and Control Message Blocks

Table 0-1: List of All Configuration Registers

Address	Name	Access	Size	Description	JSON Variable	Default
0x10	Join Mode	R/W	2 B	• Bits 0-14: RFU • Bit 14: ABP/OTAA mode	*loramac_join_mode: <value> (unsigned/no unit)*	OTAA mode
0x11	Options	See description	2 B	• Bits 0 (Read/Write): 0: Unconfirmed 1: Confirmed • Bit 1 (Read Only): 1 0: Private Sync Word 1: Public Sync Word • Bit 2 (Read/Write): 0: Duty Cycle Disabled 1: Duty Cycle Enabled • Bit 3 (Read/Write): 0: ADR Disabled 1: ADR Enabled • Bits 4-15: 0, otherwise invalid	*loramac_opts: {* *confirm_mode: <value>, (unsigned/no unit)* *sync_word: <value>, (unsigned/no unit)* *duty_cycle: <value>, (unsigned/no unit)* *adr: <value> (unsigned/no unit)* *}*	*Unconfirmed UL* *Public Sync Word* *Duty Cycle Enabled*[21] *ADR Enabled*

[21] **WARNING**: Disabling the duty cycle in certain regions makes the sensor non-compliant with the LoRaWAN Specifications [4]. It is recommended that the duty cycle remains enabled. In the LoRa RF regions where there is no duty cycle limitation, the "enabled duty cycle" configuration is ignored.

Address	Name	Access	Size	Description	JSON Variable	Default
0x12	DR and Tx Power[22]	R/W	2 B	• Bits 0-3: Default Tx power • Bits 4-7: RFU • Bits 8-11: Default DR number • Bits 12-15: 0, otherwise invalid	*loramac_dr_tx: {* *dr_number: <value>, (unsigned/no unit)* *tx_power_number: <value> (unsigned/no unit)* *}*	*DR4* *Tx Power 0 (as per* Table 4-2*)*
0x13	Rx2 Window	R/W	5 B	• Bits 0-7: DR for Rx2 • Bits 8-39: Channel frequency in Hz for Rx2	*loramac_rx2: {* *frequency: <value>, (unsigned/Hz)* *dr_number: <value> (unsigned/no unit)* *}*	*As per* Table 4-2
0x20	Seconds per Core Tick	R/W	4 B	• Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid	*seconds_per_core_tick: <value> (number/sec)*	60 s = 1 min **0x 00 00 00 3C**
0x21	Ticks per Battery	R/W	2 B	• Ticks between battery reports • Acceptable values: 1,2…65535 • 0, Other values: Invalid	*ticks_battery: <value> (number/no unit)*	1440 ticks = 1 day period **0x 05 A0**
0x22	Ticks in NORMAL State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in NORMAL state. • Acceptable values: 0, 1, 2, …, 65535 • 0: Disables periodic reports in NORMAL state • Other values: Invalid	*ticks_normal_state: <value> (number/no unit)*	15 ticks = 15 mins period **0x 00 0F**
0x23	Ticks in EMERGENCY State	R/W	2 B	• Ticks between enabled geolocation technology (GNSS, BLE) reports in EMERGENCY state. • Acceptable values: 0, 1, …, 65535 0: Disables periodic reports in EMERGENCY state Other values: Invalid	*ticks_emergency_state: <value> (number/no unit)*	1 tick = 1 min period **0x 00 01**

[22] Tx power number *m* translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [5].

Address	Name	Access	Size	Description	JSON Variable	Default
0x24	Ticks per Accelerometer	R/W	2 B	• Ticks between accelerometer reports • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic accelerometer reports • Other values: Invalid	*ticks_accelerometer: <value>* *(number/no unit)*	0 tick = disabled **0x 00 00**
0x25	Ticks per Temperature	R/W	2 B	• Ticks between temperature reports • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic temperature reports • Other values: Invalid	*ticks_temperature: <value>* *(number/no unit)*	0 tick = disabled **0x 00 00**
0x26	Ticks for Safety Status in NORMAL State	R/W	2 B	• Ticks between Safety Status reports in NORMAL state • Acceptable values: 0, 1, …, 65535 • 0: Disables periodic Safety Status reports in NORMAL state • Other values: Invalid	*ticks_safety_status_normal: <value>* *(number/no unit)*	5 ticks = 5 mins **0x 00 05**
0x27	Tick per Pressure report (either uncalibrated or calibrated)	R/W	2 B	• Bits 0 – 7: Period between consecutive pressure reports • Acceptable values: 0,1,2…65535 • 0: Disables periodic pressure reports • Other values: Invalid	*ticks_pressure: <value>* *(unsigned/number/no unit)*	0 tick = disabled **0x 00 00**
0x 28	Active Emergency Buzzer Config	R/W	3 B	• Bits 0-7: Emergency Active Buzz Pattern Period 0: Invalid • Bits 8-15: Emergency Active Buzz OFF time in milliseconds (0.1 sec/LSB) 0: Invalid • Bits 16-23: Emergency Active Buzz ON time in milliseconds (0.1 sec/LSB) 0: Invalid	*active_emerg_buzz_config{* *emerg_buzz_active_num_on_offs: <value>* *(number/no unit)* *emerg_buzz_active_off_time: <value>* *(number/sec)* *emerg_buzz_active_on_time: <value>* *(number/sec)* *}*	ON/OFF: 3 OFF: 1s ON: 500ms **0x 05 0A 03**

Address	Name	Access	Size	Description	JSON Variable	Default
0x 29	Inactive Emergency Buzzer Config	R/W	3 B	• Bits 0-7: Emergency Inactive Buzz Pattern Period 0: Invalid • Bits 8-15: Emergency inactive Buzz OFF time in milliseconds (0.1 sec/LSB) 0: Invalid • Bits 16-23: Emergency Inactive Buzz ON time in milliseconds (0.1 sec/LSB) 0: Invalid	*inactive_emerg_buzz_config{* *emerg_buzz_inactive_num_on_offs: <value>* *(number/no unit)* *emerg_buzz_inactive_off_time: <value>* *(number/sec)* *emerg_buzz_inactive_on_time: <value>* *(number/sec)* *}*	ON/OFF: 3 OFF: 200ms ON: 200ms **0x 02 02 03**
0x2C	Safety Hook Debounce Interval	R/W	1 B	• SHB debounce period in seconds • Acceptable values: 0,1, 2, 3, …, 255 • 0: disables debounce • other values: Invalid	*sh_debounce_interval: <value>* *(number/sec)*	10 s **0x 0A**
0x 2D	Safety Hook Alarm Buzzer Config	R/W	5 B	• Bits 0-7: SH Buzz period (0.1s/LSB) 0: Invalid • Bits 8-15: Buzz ON/OFF cycle (1/LSB) 0: Invalid • Bits 16-23: SH Buzz OFF time (0.1s/LSB) 0: Invalid • Bits 24-31: SH Buzz ON time (0.1s/LSB) 0: Invalid • Bits 32-33: SH Alarm trigger 0: Always 1: IN GNSS DZ ONLY 2: IN BLE DZ ONLY 3: IN ANY DZ • Bits 34-39: 0, otherwise invalid	*safety_hook_buzz_config {* *sh_buzz_period: <value>* *(number/sec)* *sh_buzz_num_on_offs: <value>* *(number/no unit)* *sh_buzz_ off_time: <value>* *(number/sec)* *sh_buzz_ on_time: <value>* *(number/sec)* *sh_buzz_ trigger_type: <value>* *(string/no unit)* *}*	Period: 10s ON/OFF: 2 times OFF: 100ms ON: 400ms Trigger: ANY DZ **0x 03 04 01 02 64**
0x30	GNSS Mode	R/W	1 B	• Bits 0-6: 0, otherwise invalid • Bit 7: 0/1 = GNSS receiver disabled/enabled	*gnss_receiver: <value>* *(string/no unit)*	GNSS receiver enabled **0x 80**

Address	Name	Access	Size	Description	JSON Variable	Default
0x31	GNSS Report Options	R/W	1 B	• Bit 0: 0/1 = UTC and Position Coordinates report disabled/enabled • Bit 1: 0/1 = Ground Speed report disabled/enabled • Bit 2: 0/1 = GNSS DZ Status report disabled/enabled • Bits 0-2 = 0: invalid • Bits 3-7: 0, otherwise invalid	*gnss_report_option {* *gnss_dz_status_report: <value> (string/no unit)* *gnss_ground_speed_report: <value> (string/no unit)* *gnss_utc_coordinates_report: <value> (string/no unit)* *}*	UTC and position reports enabled Groundspeed reports enabled GNSS dangerzone status reports enabled **0x 07**
0x32	GNSS DZ 0 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^\circ}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^\circ}{2^{23}}$/LSB)	*gnss_dz0 {* *gnss_dz0_latitude: <value> (number/°)* *gnss_dz0_longitude: <value> (number/°)* *gnss_dz0_radius: <value> (number/m)* *}*	GNSS DZ 0 Undefined 0x00 00 00 00 00 00 00 00
0x33	GNSS DZ 1 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^\circ}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^\circ}{2^{23}}$/LSB)	*gnss_dz1 {* *gnss_dz1_latitude: <value> (number/°)* *gnss_dz1_longitude: <value> (number/°)* *gnss_dz1_radius: <value> (number/m)* *}*	GNSS DZ 1 Undefined 0x00 00 00 00 00 00 00 00
0x34	GNSS DZ 2 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^\circ}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^\circ}{2^{23}}$/LSB)	*gnss_dz2 {* *gnss_dz2_latitude: <value> (number/°)* *gnss_dz2_longitude: <value> (number/°)* *gnss_dz2_radius: <value> (number/m)* *}*	GNSS DZ 2 Undefined 0x00 00 00 00 00 00 00 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x35	GNSS DZ 3 Definition	R/W	8 B	• Bits 0-15: Radius (10 m/LSB) • Bits 16-39: Center Longitude ($\frac{180^\circ}{2^{23}}$/LSB) • Bits 40-63: Center Latitude ($\frac{90^\circ}{2^{23}}$/LSB)	*gnss_dz3 {* *gnss_dz3_latitude: <value> (number/°)* *gnss_dz3_longitude: <value> (number/°)* *gnss_dz3_radius: <value> (number/m)* *}*	GNSS DZ 3 Undefined 0x00 00 00 00 00 00 00 00
0x36	GNSS Diagnostics Report Options	R/W	1 B	• Bit 0: 0/1 = Number of Visible Satellites report disabled/enabled • Bit 1: 0/1 = Average Satellite SNR report disabled/enabled • Bit 2: 0/1 = Fix Type report disabled/enabled • Bit 3: 0/1 = Time-To-Fix report disabled/enabled • Bit 4: 0/1 = Most Recent Log Entry # report disabled/enabled • Bit 5: 0/1 = GNSS fix accuracy, groundspeed accuracy, and number of fixes report disabled/enabled	*gnss_diagnostics_tx {* *num_of_sats: <value>, (unsigned/no unit)* *avg_sat_snr: <value>, (unsigned/no unit)* *reported_fix_type: <value>, (unsigned/no unit)* *time_to_reported_fix: <value> (unsigned/no unit)* *fix_log_num: <value> (unsigned/no unit)* *fix_acc_and_num_fixes_report: <value> (unsigned/no unit)* *}*	No diagnostics report enabled **0x 00**

Address	Name	Access	Size	Description	JSON Variable	Default
0x 39	Active Emergency State LED Config	R/W	4 B	• Bits 0-7: Emergency Active LED period (1sec/LSB) 0: Invalid • Bits 8-15: Emergency Active LED number of ON-OFFs (1/LSB) 0: Invalid • Bits 16-23: Emergency Active LED OFF time (0.01s/LSB) 0: Invalid • Bits 24-31: Emergency Active LED ON time (0.01s/LSB) 0: Invalid	*active_emerg_led_config {emerg_led_active_period: <value> (number/seconds)* *emerg_led_active_priodicity: <value> (number/no unit)* *emerg_led_active_off_time: <value> (number/sec)* *emerg_led_active_on_time: <value> (number/sec)* *}*	Period: 500ms ON/OFF: 3 times OFF: 1s ON: 500ms 0x 03 39 32 64 03 06
0x3B	Seconds per pressure sample	R/W	1 B	• Bits 0 – 5: Seconds between consecutive pressure samples (1s/LSb) 0: Barometer Disabled Acceptable values: 0,1,2…60 • Bits 6 – 7: 0, otherwise invalid	*seconds_pressure_sample: <value> (unsigned/seconds)*	60s **0x 3C**
0x3C	Calibration Reference Pressure	R/W	2 B	• Bits 0 – 15: Refers to the pressure reported by the stationary calibrating unit (1s/LSb) 0: Equivalent to no calibration • Acceptable values: 0,1,2…65535 Bits 6 – 7: 0, otherwise invalid	*calibration_reference_pressure: <value>* *(unsigned/float/hPa)*	0 hPa **0x 00 00**

Address	Name	Access	Size	Description	JSON Variable	Default
0x3D	Pressure Thresholds {min, max}	R/W	4 B	• Bits 0-15: Min Pressure threshold (0.1hPa/LSb) Acceptable values: Max threshold – 0,1,2…65535 • Bits 16-31: Max Pressure threshold (0.1 hPa/LSb) Acceptable values: Min threshold – 0,1,2…65535	*pressure_threshold* *{pressure_threshold_max: <value> (unsigned/float/hPa)* *pressure_threshold_min: <value> (unsigned/float/hPa)* *}*	Min Pressure Threshold: 0hPa Max Pressure Threshold: 0 hPa 0x 00 00 00 00
0x42	SLEEP Acceleration Threshold	R/W	2 B	• Bits 0-15: SLEEP Acceleration Threshold 1 mg/LSB (unsigned)	*sleep_acceleration_threshold: <value> (number/g)*	250 mg **0x 00 FA**
0x43	Timeout to SLEEP	R/W		• No-motion duration, in min, before the SEAL/SEAL EX goes to SLEEP 0: Disables going to SLEEP	*timeout_to_sleep: <value> (number/min)*	15 min **0x 0F**
0x48	Free Fall	R/W	4 B	• Bits 16-31: Free Fall Acceleration Threshold 1 mg/LSB (unsigned) Acceptable values: 0-800 • Bits 0-15: Free Fall Acceleration Interval 1 msec/LSB (unsigned) 0: Invalid	*freefall {* *free_fall_acceleration_threshold: <value> (number/g)* *free_fall_acceleration_interval: <value> (number/sec)* *}*	Threshold = 0.5 g Interval = 0.4 s **0x 48 01 F4 01 90**
0x49	Impact	R/W	4 B	• Bits 16-31: Impact Threshold 1 mg/LSB (unsigned) Acceptable values: 1500-8000 • Bits 0-15: Impact Blackout Duration 1 msec/LSB (unsigned) Acceptable values: 0-65535	*impact {* *impact_threshold: <value> (number/g)* *impact_blackout_duration: <value> (number/sec)* *}*	Threshold = 5 g Blackout Duration = 2 s **0x 49 13 88 07 D0**

Address	Name	Access	Size	Description	JSON Variable	Default
0x4A	Torpidity	R/W	3 B	• Bits 0-7: Torpidity Interval 1 sec/LSB (unsigned) Acceptable values: 0-255 • Bits 8-23: Torpidity Threshold 1 mg/LSB (unsigned) Acceptable values: 100-3000	*torpidity {* *torpidity_threshold: <value>* *(number/g)* *torpidity_interval: <value>* *(number/sec)* *}*	Threshold = 2 g Interval = 1 s **0x 07 D0 01**
0x50	BLE Mode	R/W	1 B	• Bit 7: 0/1 = Averaging mode off/on • Bit 6: 0/1 = Report BLE DZ status disabled/enabled • Bits 0-5: Number of reported devices 0: Disables BLE scans	*ble_mode {* *ble_avg_mode: <value>* *(string/no unit)* *ble_dz_status_report: <value>* *(string/no unit)* *ble_num_reported_devices: <value>* *(number/no unit)* *}*	Averaging mode enabled Danger zone status reports enabled Number of reported devices: 0 **0x C0**
0x51	BLE Scan Duration	R/W	B	• Scan duration for periodic reports (1 sec/LSb) • 0: Invalid	*ble_scan_duration_periodic: <value>* *(number/sec)*	BLE scan duration: 3s
0x52	BLE Scan Interval	R/W	2 B	• Scan interval (1 msec/LSb) • Acceptable values: 3, …, 10000 • Other values: Invalid	*ble_scan_interval: <value>* *(number/msec)*	**BLE scan interval: 30s**
0x53	BLE Scan Window	R/W	2 B	• Scan window (1 msec/LSb) • Acceptable values: 3, …, "Scan Interval" • Other values: Invalid	*ble_scan_window: <value>* *(number/msec)*	BLE scan window: 30s

Address	Name	Access	Size	Description	JSON Variable	Default
0x54	BLE Range 0 Definition	R/W	9 B	• Range 0 for whitelisted BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • Bits 48-71: OUI = $B_0:B_1: B_2$ • Bits 24-47: $LAP_{start} = B_3:B_4:B_5$ • Bits 0-23: $LAP_{end} = B_6:B_7:B_8$	*ble_range0 {* *ble_range0_bd_addr_oui:* *<value>* *(string/no unit)* *ble_range0_bd_addr_start:* *<value>* *(string/no unit)* *ble_range0_bd_addr_end:* *<value>* *(string/no unit)* *}*	BLE range 0: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00
0x55	BLE Range 1 Definition	R/W	9 B	• Range 1 for whitelisted BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • Bits 48-71: OUI = $B_0:B_1: B_2$ • Bits 24-47: $LAP_{start} = B_3:B_4:B_5$ • Bits 0-23: $LAP_{end} = B_6:B_7:B_8$	*ble_range1 {* *ble_range1_bd_addr_oui:* *<value>* *(string/no unit)* *ble_range1_bd_addr_start:* *<value>* *(string/no unit)* *ble_range1_bd_addr_end:* *<value>* *(string/no unit)* *}*	BLE range 1: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00
0x56	BLE Range 2 Definition	R/W	9 B	• Range 2 for whitelisted BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • Bits 48-71: OUI = $B_0:B_1: B_2$ • Bits 24-47: $LAP_{start} = B_3:B_4:B_5$ Bits 0-23: $LAP_{end} = B_6:B_7:B_8$	*ble_range2 {* *ble_range2_bd_addr_oui:* *<value>* *(string/no unit)* *ble_range2_bd_addr_start:* *<value>* *(string/no unit)* *ble_range2_bd_addr_end:* *<value>* *(string/no unit)* *}*	BLE range 2: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x57	BLE Range 3 Definition	R/W	9 B	• Range 3 for whitelisted BD_ADDRs • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 • Bits 48-71: OUI = B_0:B_1: B_2 • Bits 24-47: LAP_{start} = B_3:B_4:B_5 Bits 0-23: LAP_{end} = B_6:B_7:B_8	*ble_range3 {* *ble_range3_bd_addr_oui: <value> (string/no unit)* *ble_range3_bd_addr_start: <value> (string/no unit)* *ble_range3_bd_addr_end: <value> (string/no unit)* *}*	BLE range 3: OUI: 00 00 00 LAP Start: 00 00 00 LAP End: 00 00 00
0x60	Temperature Sample Period in Idle State	R/W	4 B	• Bits 0 – 31: Sample period of temperature in sec in Idle state (1s/LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid	*temperature_sample_period_idle: <value> (number/sec)*	Idle state sample period: 300s
0x61	Temperature Sample Period in Active State	R/W	4 B	• Bits 0-31: Sample period of temperature in sec in Active state (1s/LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid	*temperature_sample_period_active: <value> (number/sec)*	Active state sample period: 60s
0x62	Temperature High/Low Thresholds	R/W	2 B	• Bits 8-15: High temperature threshold (signed, 1°C/LSb) • Bits 0-7: Low temperature threshold (signed, 1°C/LSb) • High threshold ≤ Low threshold: Invalid	*temperature_thresholds {* *temperature_threshold_high: <value> (number/°C)* *temperature_threshold_low: <value> (number/°C)* *}*	temperature_threshold_high: 30 °C temperature_threshold_low: 15 °C
0x63	Temperature Thresholds Status	R/W	1 B	• Bit 0: 0/1 = Temperature thresholds disabled/enabled Bits 1-7: 0, otherwise invalid	*temperature_thresholds_status: <value> (string/no unit)*	Temperature Threshold disabled 0x 00

Address	Name	Access	Size	Description	JSON Variable	Default
0x68	Battery Report Options	1 B	R/W	• Bits 0, 3-7: 0, otherwise invalid • Bit 1: 0/1 = Remaining battery capacity [%] not reported/reported • Bit 2: Remaining battery lifetime [days] not reported/reported • Bits 1-2 all set to 0: Invalid	*battery_options{* *battery_lifetime_dys_report: <value>* *(string/no unit)* *battery_lifetime_pct_report: <value>* *(string/no unit)* *}*	Only battery lifetime report in percentage enabled **0x 02**
0x69	Low Battery Threshold	2 B	R/W	• Bits 0-13: Low battery threshold value in case of percentage: 1%/LSB in case of days: 1 day/LSB • Bits 14-15: Threshold type 1: Threshold on capacity in percentage 2: Threshold on remaining lifetime in days • Bit 0,3: 0, otherwise invalid.	*battery_threshold {* *low_battery_threshold_value: <value>* *(number/%-days)* *low_battery_threshold_type: <value>* *(string/no unit)* *}*	Threshold = 10% Threshold type = threshold on battery capacity in percentage **0x 40 0A**
0x 6A	Low Battery LED Config	R/W	4 B	5. Bits 0-7: Low Battery Active LED period (1sec/LSB) 0: Invalid 6. Bits 8-15: Low Battery Active LED count per ON/OFF (1/LSB) 0: Invalid 7. Bits 16-23: Low Battery Active LED OFF time (0.01s/LSB) 0: Invalid 8. Bits 24-31: Low Battery Active LED ON time (0.01s/LSB) 0: Invalid	*low_battety_led_config* *{* *low_battery_led_active_period:* *<value>* *(number/seconds)* *low_battery_led_active_priodicity:* *<value>* *(number/no unit)* *low_battery_led_active_off_time: <value>* *(number/sec)* *low_battery_led_active_on_time: <value>* *(number/sec)* *}*	Period: 180s ON/OFF: 10 times OFF: 180ms ON: 50ms **0x 05 12 0A B4**

Address	Name	Access	Size	Description	JSON Variable	Default
0x6C	Buzzer Disable Timeout	R/W	1 B	• Buzzer disable timeout in mins • Acceptable values: 1, 2, 3, …, 255 9. 0, other values: Invalid	*buzzer_disable_timeout: <value>* *(number/min)*	60 mins **0x 3C**
0x 70	Flash Write Command	2 B	X	• Bit 14: 0/1 = Do not write/Write LoRaMAC Configuration • Bit 13: 0/1 = Do not write/Write App Configuration • Bit 0: 0/1 = Do not restart/Restart Sensor • Bits 1-12, 15: Ignored	*write_to_flash {* *app_config: <value>, (unsigned/no unit)* *lora_config: <value>, (unsigned/no unit)* *restart_sensor: <value> (unsigned/no unit)* *}*	
0x 71	FW Metadata	7 B	RO	• Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRa Basics modem version major • Bits 16-23: LoRa Basics modem version minor • Bits 8-15: LoRa Basics modem version revision • Bits 0-7: LoRaMAC region number[23]	*metadata {* *app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value>, (unsigned/no unit)* *app_ver_revision: <value>, (unsigned/no unit)* *modem_ver_major: <value>, (unsigned/no unit)* *modem_ver_minor: <value>, (unsigned/no unit)* *modem_ver_revision: <value>, (unsigned/no unit)* *loramac_region: <value> (unsigned/no unit)* *}*	
0x 72	Reset Configuration to Factory Defaults	1 B	X	• 0x 0A: Reset app configuration • 0x B0: Reset LoRaMAC configuration • 0x BA: Reset both App and LoRaMAC configurations Any other value: Invalid	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*	

[23] Defined by Table 4-7.

Address	Name	Access	Description
0x40	Systems Diagnostics Query	R only	Query systems diagnostics information from sensor

Table 0-2: Systems Diagnostics Configuration Registers

References

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Revision History

TRM Version	Date	Editor	Comments
0.1	July 13, 2021	Reza Nikjah	• First draft (based on T0006279_TRM and T0007705_SDS).
0.2	Aug 16, 2021	Reza Nikjah	• Added mute button spec • Added device free fall spec • Decoupled the enabling of pressure report from BLE and GNSS • Payload for Battery Voltage uplink (with header 0x00 D3) changed from 1 byte to 2 bytes (1 mV/LSB). This is for easier formatting, also applicable to a wider range of battery choices. Correspondingly, the Low Battery Threshold register (Register 0x69) format was changed to free up 14 bits for the battery voltage threshold in mV. • Changed the Fall Alert NbTrans register 0x4D to 0x4F, so there will be two more registers available to configure human fall detection (Registers 0x48 to 0x4E now).
0.3	Aug 25, 2021	Reza Nikjah	• Added the EB state machine, motion detection state machine to support the SLEEP state, and the buzzer enable/disable state machine, for more clarity. • Rephrased SLEEP Timeout as Timeout to SLEEP. • Changed payload size of the Battery Lifetime in Days to 2 bytes. • Updated the name of JSON variables. • Updated uplink table by modifying the UTC and Position Coordinates formats to match those in the new uplink formats (4 bytes for UTC, 8 bytes for Position). • Removed the transition from EMERGENCY to SLEEP. • Changed the NbTrans mechanism for sending alerts. Now, the Alert is an UL message consisting of the EB, Fall, and SH statuses, that is sent periodically with configurable periods in the NORMAL and EMERGENCY states. The Alert periodic report is stopped upon receiving a DL from the cloud-based application, but resumed upon any status change on EB, Fall, or SH. The Alert periodic report is also resumed upon receiving a DL command. • Ticks were introduced for sending Alert in NORMAL and EMERGENCY states (registers 0x26 and 0x27). • Changed EMERGENCY State Timeout to EB (Emergency Button) Active Timeout, such that it's only applicable to EB Active (an EB event remains active to a maximum of EB Active Timeout). • Explained the idea of periodically checking motion while in the NORMAL state. Upon detecting motion, the accelerometer interrupts are disabled for an amount of time equal to 10% of the "Timeout to SLEEP". • Removed EB Grace Period. After EB is Active, the EB may be pressed for 0.7 sec to register EB Active again (and again). Each time of doing this would sound the buzzer and resets the EB Active Timer. But no new Alert is sent as the EB status hasn't changed. • Abbreviated designated/danger zone with DZ.
0.4	Sep 14, 2021	Reza Nikjah	• Split EB Buzz Config register 0x28 into two registers 0x28 and 0x29, corresponding to EB Active Buzz Config and EB Inactive Buzz Config. • Minor updates to the name of JSON variables. • Changed "Alert" to "Safety Status". • Added human fall detection registers. • Added illustrations for non-periodic and periodic buzzer and LED indications.
0.5	Sep 22, 2021	Reza Nikjah	• Added impact blackout configuration for human fall detection. • Rearranged Fall Configuration Registers by combining related registers, e.g., Torpidity Threshold and Torpidity Interval.
0.6	Oct 14, 2021	Reza Nikjah	• Corrected a typo in the acceptable values for the Temperature Sample Period in Idle and Active States.

			• Corrected the rising-falling edge description for the SH switch as it is a normally closed switch. • Changed “On” and “Off” to “ON” and “OFF” for better clarity. • Added an appendix section for the data converter as a placeholder. • Abbreviated Mute Button to MB. • Changed the EB to MB for DEEP SLEEP operation. • Summarized the MB behavior.
0.7	Oct 19, 2021	Reza Nikjah	• Updated the SEAL product codes. • Included the HW variants with and without the safety clip. For variants without the safety clip, it is assumed that the SH status is always OFF (= 0). • Modified the conditions of transitioning from EMERGENCY to NORMAL around the DL App request and introduction of register 0x3A).
0.8	Nov 2, 2021	Reza Nikjah	• Edited a couple of JSON variable names. • Reordered register bits description from MSb to LSb. • Added default value of EAR Active Timeout to be 60 min.
0.9	Aug 21, 2023	Adedolapo Adegboye	• FW version: 0.2.16 and above • Updated product name from WGT to SEAL/SEAL Ex • Updated MB and EB active and inactive patterns • Updated DL response port number for command and config to 101 • Added/Updated info on all transducer operations (Sections 1.2 to 1.12) • Updated module-level T-codes • Changed low battery LED periodic flashes to 3 mins • Added UL register for failed/invalid gnss scan attempt • Changed Emergency LED flashes from only Top LEDs to ALL LEDs • Added UL register for failed/invalid log request • Change definition of BLE DZ from single device per zone to range of devices per zone • Modified Low battery LED indication • Added ‘unknown’ status to BLE DZ UL register options • Added ability to mute buzzer while buzzer is buzzing • Added GNSS scan diagnostics ULs for debugging • Disabled emergency timeout for all emergencies • Change default accelerometer threshold for sleep • Disabled pressure and BLE reporting by default
1.0	Jan 1, 2024	Adedolapo Adegboye	• FW version: 1.1.0 to FW 1.1.8 • Added elevation alarm feature
1.1	Feb 28, 2024	Adedolapo Adegboye	• Added system diagnostics uplinks and query downlinks • Added “Access” type to all downlink registers • Added note on accelerometer buffering during radio operations • Added notes on system self-recovery after failures
2.0	June 18, 2024	Adedolapo Adegboye	• FW version: 1.2.0 and above • Updated TRM format to latest systems format • Added examples to all uplink and downlink sections • Added more figures on algorithms and process • Added appendix section • Minor grammatical corrections