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Breeze/Breeze-V

Technical Reference Manual (Sensor)

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Revision History

Version	Date	Editor	FW Version	Comments
1.0	May 9, 2022	Shania Stewart	2.0.12	• Release based on T0007805_Sensor_TRM_ver0.6.
1.1	Sept. 30, 2022	Shania Stewart	2.0.20	• Added Sensor FW versions to document revision history. • Minor wording and formatting fixes. • Clarified how the value of register 0x33 changes when the CO_2 calibration button is used. • Added light transducer support for Rev B and onwards. • Added PIR support for the Breeze-V. • Fixed issue with limits on register 0x68 so that active mode can end at 12:00 AM.
1.2	Feb 15, 2023	Shania Stewart	2.0.20	• Minor typo and formatting fixes. • Added notes about light transducer support for sensors with module revisions A and B. • Updated uplink payload examples.

Table of Contents

List of Tables

List of Figures

Acronyms and Glossary

ABC.. automatic baseline correction
ABP.. activation by personalization
ADR .... adaptive data rate
BLE.. Bluetooth Low Energy
CO_2 .... carbon dioxide
CRC .... cyclic redundancy check
DL .... downlink
DR.. data rate
EIRP .... effective isotropic radiated power
Flash memory .... Non-volatile memory on the Sensor (contains application & configuration settings)
FW .... firmware
hr .... hour
ID .... identity
IIR .... infinite impulse response
IoT .... Internet of things
LED .... light emitting diode
LoRa .... a patented “long-range” IoT technology acquired by Semtech
LoRAMAC .... LoRaWAN MAC
LoRaWAN.............................. LoRa wide area network (a network protocol based on LoRa)
LSB... least significant bit
MAC....................................... medium access control
MCU .... microcontroller unit
min .... minute(s)
MSb .... most significant bit
MSB .... most significant byte
NS .... network server
OTA .... over-the-air
OTAA .... OTA activation
PIR .... passive infrared
POST...................................... power on self-test
RH.. relative humidity
RF .... radio frequency
RO.. read-only
RTC .... real time clock
R/W .... read/write
Rx .... receiver
sec .... second(s)

Sensor .... Breeze/Breeze-V Sensor
SW .... software
transducer .... sensing element on the Sensor (e.g. PIR or temperature transducers)
TRM .... technical reference manual (this document)
Tx .... transmitter
UL .... uplink
UTC .... universal coordinated time
WO .... write-only

1 Overview

IMPORTANT: Not all features described in this manual may be available on devices programmed with older FW versions. Refer to the Revision History table to verify which FW versions included the addition of new features. To check the FW version of your device, send a command to query your device as described in Section 4.2.12.

This document contains technical information about the supported functionally of the TEKTELIC Breeze/Breeze-V Sensor variants, referred to as the Sensor henceforth. In particular, this TRM describes the LoRa IoT uplink and downlink payload structures user accessible configuration settings (pseudo registers) in detail. This document is intended for a technical audience, such as application developers, with an understanding of the LoRaWAN NS and its command interfaces.

The Breeze/Breeze-V are all multi-purpose LoRaWAN IoT sensors packed into a very small form factor. The Breeze and Breeze-V are variants in the same sensor family, which differ in some of their sensing features. The Sensor is ideal for monitoring and reporting CO_2, human motion, ambient temperature and relative humidity, light,[1] and barometric air pressure in a home/office environment.

Sensors can also be ordered to come with a 2.9″ wireless e-Ink BLE Display that allows room occupants to locally view the latest measurements from select transducers taken in real-time. The Display will show the most recent CO_2, temperature, and humidity measurements taken from the Sensor, as well as the remaining battery capacity of the Sensor and Display. The Sensor is designed to only communicate with the BLE Display that is shipped with the Sensor.

Sensors may also be ordered without a BLE Display. The only functional differences between a Sensor that comes with or without a Display is that a Sensor that is not programmed to communicate with a Display will not perform any BLE communication or report the remaining battery capacity of the Display. Details concerning the BLE communication between the Sensor and e-Ink Display, beyond select configuration options, are outside the scope of this document.

Table 1-1 lists the Sensor variants for regions identified by the LoRa Alliance [1]—see [1] for the Tx and Rx bands in each LoRaMAC region. The different RF variants shown in Table 1-1 use the same HW, but are distinguished through different parameters in the FW.

Table 1-1: Breeze/Breeze-V Order Codes for Region Specific Variants

LoRaWAN RF Variant	Functional Variant	Product Code, Module-Level T-Code	Product Code, PCBA-Level T-Code	Order Code
US915	Breeze Sensor with Display	T0007838	T0007938	SMTBCDUS915

[1] Light transducer support is not available on sensors with module revision A or B.

LoRaWAN RF Variant	Functional Variant	Product Code, Module-Level T-Code	Product Code, PCBA-Level T-Code	Order Code
US915	Breeze-V Sensor with Display	T0007806	T0007937	SMTBMDUS915
US915	Breeze Sensor without Display	T0007838	T0007938	SMTBCNUS915
US915	Breeze-V Sensor without Display	T0007806	T0007937	SMTBMNUS915
EU868	Breeze Sensor with Display	T0007838	T0007938	SMTBCDEU868
EU868	Breeze-V Sensor with Display	T0007806	T0007937	SMTBMDEU868
EU868	Breeze Sensor without Display	T0007838	T0007938	SMTBCNEU868
EU868	Breeze-V Sensor without Display	T0007806	T0007937	SMTBMNEU868
AU915	Breeze Sensor with Display	T0007838	T0007938	SMTBCDAU915
AU915	Breeze-V Sensor with Display	T0007806	T0007937	SMTBMDAU915
AU915	Breeze Sensor without Display	T0007838	T0007938	SMTBCNAU915
AU915	Breeze-V Sensor without Display	T0007806	T0007937	SMTBMNAU915
AS923	Breeze Sensor with Display	T0007838	T0007938	SMTBCDAS923
AS923	Breeze-V Sensor with Display	T0007806	T0007937	SMTBMDAS923
AS923	Breeze Sensor without Display	T0007838	T0007938	SMTBCNAS923
AS923	Breeze-V Sensor without Display	T0007806	T0007937	SMTBMNAS923

1.1 Information Streams

The main LoRaWAN UL and DL information streams supported by the Sensor are summarized in Table 1-2.

Table 1-2: Breeze/Breeze-V Information Streams

Stream Direction	Stream Name	Data Type	Sent on LoRaWAN Port
UL (Sensor to NS)	Reported Transducer Data Stream	Readings obtained from on-board transducers	**10**
	Timestamp Acquisition Stream	Local timestamp acquisition requests and response from the Sensor	**20**
	Sensor Application Configuration Stream	Response to read commands from the NS	**100**
		Response to write commands from the NS	**101**
DL (NS to Sensor)	Timestamp Acquisition Stream	Local timestamp acquisition requests and response from the Application Server	**20**
	Sensor Application Configuration Stream	Configuration and control commands from the NS used to change the Sensor's behavior or inquire the Sensor for the values of configuration registers	**100**

1.2 Dynamic Reporting Modes

The Sensor supports multiple reporting modes so that transducer measurements can be reported to the LoRaWAN NS (and BLE Display, if applicable) at different configurable frequencies based on the time of day.

This feature is best suited for applications where rooms are expected to be occupied or vacant during specific hours of the day and days of the week, such as in a school. The Sensor can be configured to report transducer measurements at a different frequency during the expected active hours than at other times where rooms are expected to be vacant. For example, the Sensor can be configured with an active period of 9:00 AM to 5:00 PM from Monday to Friday in which it reports the CO_2 concentration every 5 minutes. Outside of that active period, including the entirety of Saturday and Sunday, the Sensor reports the CO_2 concentration every 1 hour.

The Sensor will periodically request timestamps in order to obtain and maintain an accurate time reference. An external application is required to send downlinks to the Sensor in response to uplinks containing timestamp requests. Uplink and downlink frame formats for local timestamp acquisition and current sensor timestamp requests/responses are detailed in Section 3. Additional details concerning application design are outside the scope of this document.

The DL configuration registers used to configure the dynamic reporting modes and timestamp acquisition behavior OTA are defined in Section 4.2.10.

Note: It is highly recommended that this feature be used to achieve optimum battery life. If this feature is not used, users may want to modify the default reporting and transducer sampling periods (if applicable) to ensure a long battery life for the Sensor.

1.2.1 Active and Inactive Modes

The Sensor supports two different reporting modes: Active and Inactive mode. Active mode is intended to be used when the Sensor should report more frequently than when it is in Inactive mode. If dynamic reporting mode is enabled and the Sensor acquires a time reference, it will alternate between Active and Inactive mode configurations based on the Sensor's perceived time of day and configured active hour settings (configured according to Section 4.2.10.3). When the Sensor first joins the LoRaWAN network, it will assume Active mode configurations until it can verify that it is outside the configured Active mode time period using an acquired time reference. If dynamic reporting mode is disabled, the Sensor will only use the registers associated with Active mode configurations, regardless of the date and time.

The Active and Inactive reporting periods are controlled by two separate time synchronization registers. Active mode uses the Seconds per Core *Tick* register defined in Section 4.2.2 (0x20), while Inactive mode uses the Seconds per Core *Tick* register defined in Section 4.2.10 (0x69). Additionally, the CO_2 Sampling Parameters register defined in Section 4.2.4 (0x30) are used in Active mode, while the CO_2 Sampling Parameters register defined in Section 4.2.10 (0x6A) are used in Inactive Mode. The reporting frequencies of individual transducers are determined by the *tick* registers presented in Section 4.2.2 for both Active and Inactive modes. However, the *tick* registers are synchronized with the Seconds per Core *Tick* register associated with the current mode.

1.2.2 Default Reporting Configuration

The default reporting configurations are specified in Table 1-3 for active and inactive reporting modes when dynamic reporting mode is enabled. Since the dynamic reporting mode feature is disabled by default, the Sensor will act as if it is exclusively in active mode.

Note: Motion is reported by the Breeze-V model only.

Table 1-3: Breeze/Breeze-V Default Reporting Behavior

Parameter	Report Destination	Default Reporting Frequency	
		During Active Mode	During Inactive Mode
Remaining Battery Capacity of the Sensor	NS and Display	Every 5 (five) minutes	Every 1 (one) hour
Remaining Battery Capacity of the Display	NS and Display	Every 5 (five) minutes	Every 1 (one) hour
Ambient Temperature	NS and Display	Every 5 (five) minutes	Every 1 (one) hour
Ambient Relative Humidity	NS and Display	Every 5 (five) minutes	Every 1 (one) hour
CO_2 Concentration	NS and Display	Every 5 (five) minutes	Every 1 (one) hour
Pressure	NS only	Every 5 (five) minutes	Every 1 (one) hour
Motion	NS only	Report motion after 1 (one) PIR event Clear motion after 5 (five) minutes of no motion	Report motion after 1 (one) PIR event Clear motion after 5 (five) minutes of no motion

1.3 External Interfaces

The Breeze/Breeze-V include two push-buttons and four onboard LEDs. Figure 1-1 shows the location of the push-buttons and LEDs relative to a user facing the Sensor. The buttons can be pressed by applying gentle pressure with a pin, such as a paperclip.

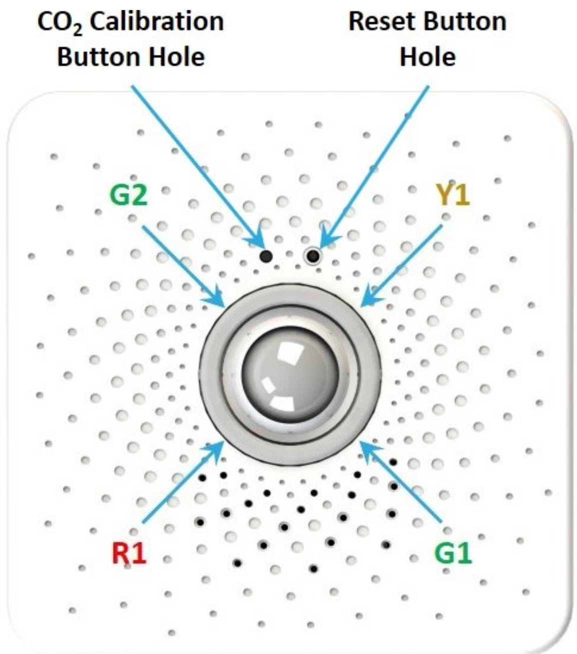


Figure 1-1: Breeze-V with Marked Push-Button and LED Positions

1.3.1 CO_2 Calibration Button

The Sensor features a push-button that can be used to manually calibrate the CO_2 transducer when it is exposed to fresh air. The CO_2 calibration button must be pressed and held for 2 to 10 seconds, then released. Around 30 seconds after the button is released, the Sensor performs a background CO_2 calibration with a target of 400 ppm.

For optimal results, users should ensure that the Sensor is exposed to fresh air for several minutes before the calibration occurs. It is also recommended that users move away from the Sensor after pressing the button so as to reduce the risk of an inaccurate calibration. More information on how to calibrate the CO_2 transducer can be found in Section 4.2.4.4.

1.3.2 Reset Button

There is a reset button on the device that will restart the Sensor's MCU. All the configuration parameters saved in the Flash memory are remembered during the reset.

1.3.3 LED Behavior

The Sensor is equipped with four LEDs: two green (G1 and G2), one yellow (Y1), and one red (R1) as shown in Figure 1-1.

Table 1-4 shows the LED behavior defined for the Sensor in certain situations.

Table 1-4: List of Breeze/Breeze-V LED Behaviors

Situation	Behavior Description
Sensor Startup	1. **R1** is turned on when the POST begins. 2. When the POST ends, depending on the POST result: a. If the POST passed, **G1** and **G2** flashes 3 times for 0.6 sec. b. If the POST failed, **R1** flashes 3 times for 0.6 sec. 3. **R1** is turned off when the POST and subsequent LED flashing specified in item 2 end.
LoRaWAN Join	**Y1** is toggled on and off every 50 ms for the first hour. But after that, it flashes 2 times (on: time 50 ms, off time: 50 ms) every 10 seconds.
LoRa Tx/Rx (During and After Join)	1. **G1** flashes once for 25 ms right after transmitting a LoRa UL. 2. **G1** flashes once for 100 ms right after receiving a LoRa DL.
BLE Tx/Rx	1. **G2** flashes once for 25 ms every 0.5 seconds while the Sensor is attempting to communicate with the Display. This ends when the connection between the Sensor and Display is either closed or unsuccessful. 2. When the BLE Display event ends, depending on the result: a. If the Sensor successfully communicated with the Display, **G2** flashes 2 times for 0.2 sec right after the BLE connection has been closed. b. If the BLE connection has been unsuccessful or closed prematurely, **R1** flashes 2 times for 0.2 seconds right after the BLE connection has been closed.
CO_2 Calibration (Regardless of Type)	1. If the CO_2 calibration push button is pressed and released, **Y1** flashes 3 times for 0.6 seconds. 2. After any CO_2 calibration is successfully complete, **G2** flashes 3 times for 0.6 seconds. 3. After any CO_2 calibration fails, **R1** flashes 3 times for 0.6 seconds.

2 Reported Transducer Data Stream

The reported transducer data stream is used to exchange transducer data between a Sensor and an application server via LoRaWAN. Uplinks containing measurement data from the on-board transducers are ***sent on LoRaWAN port 10***.

2.1 Uplink Frame Payload to Report Transducers Data

Each data field from the Sensor is encoded in a frame format shown in Figure 2-1. A big-endian format (MSb/MSB first) is always followed.

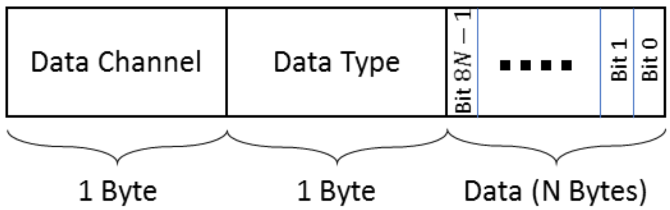


Figure 2-1: Frame format of transducer data in an UL payload.

A Sensor message payload can include multiple transducer data frames, but the frames can be in any order. A single payload may include data from any given transducer. The Sensor's payload frame values are shown in Table 2-1. In this table, the bit indexing scheme is as shown in Figure 2-1. Payload frame values in Table 2-1 have been grouped by bolded boundaries. This grouping is only to indicate which payloads are related to the same physical transducer; it *does not imply* that the payloads within the same group are uplinked together.

Table 2-1: UL Frame Payload Values for Transducer Data

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Battery Voltage	0x00	0xBA	2 B	Analog Voltage	• 1 mV / LSB (unsigned) • 0x FF FF if unavailable	*battery_voltage: <value> (unsigned/V)*
Remaining Battery Capacity of Sensor	0x00	0xD3	1 B	Percentage	• 1% / LSB (unsigned) • 0x FF if unavailable	*rem_batt_capacity_sensor: <value> (unsigned/%)*
Remaining Battery Capacity of Display	0x11	0xD3	1 B	Percentage	• 1% / LSB (unsigned) • 0x FF if unavailable	*rem_batt_capacity_display: <value> (unsigned/%)*
CO_2 Concentration (Pressure Compensated)	0x0B	0xE4	2 B	CO_2	• 1 ppm / LSB (unsigned) • 0x FF FF if unavailable	*co2_pressure_compensated: <value> (unsigned/ppm)*
CO_2 Concentration (Raw)	0x0E	0xE4	2 B	CO_2	• 1 ppm / LSB (unsigned) • 0x FF FF if unavailable	*co2_raw: <value> (unsigned/ppm)*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Barometric Pressure	0x0C	0x73	2 B	Pressure	• 0.1 hPa / LSB (unsigned) • 0x FF FF if unavailable	*barometric_pressure: <value>* *(unsigned/hPa)*
Motion (PIR) Event State	0x0A	0x00	1 B	Digital	• 0x00 = No motion • 0xFF = Motion detected	*motion_event_state: <value>* *(string/no unit)*
Motion (PIR) Event Count	0x0D	0x04	2 B	Counter	• Number	*motion_event_count: <value>* *(unsigned/no unit)*
Ambient Temperature	0x03	0x67	2 B	Temperature	• 0.1°C / LSB (signed)	*temperature: <value>* *(signed/°C)*
Ambient RH	0x04	0x68	1 B	RH	• 0.5% / LSB	*relative_humidity: <value>* *(unsigned/%)*
Ambient Light State†	0x02	0x00	1 B	Digital	• 0x00 = Dark • 0xFF = Bright	*light_state: <value>* *(string/no unit)*
Ambient Light Intensity†	0x10	0x02	2 B	Analog	• Light intensity (uncalibrated) • 0.1 µA / LSB	*light_intensity: <value>* *(unsigned/µA)*

† Light transducer support is not available on sensors with module revisions A or B.

When the Sensor is powered on, it will go through its standard startup procedure and then attempt to join the LoRaWAN network. Once the Sensor has successfully joined the LoRaWAN network, it will send a confirmed UL frame with an empty payload (UL0)[2]. After about two minutes, if periodic reporting is enabled, the Sensor will send its first periodic report containing transducer data (UL1) to the NS. It will also report the CO_2, temperature, humidity, and battery level measurements to the e-Ink Display using BLE (if applicable).
The Sensor supports both periodic and event-based transmissions of transducer data. Periodic transmissions can be configured as shown in Section 4.2.2, where the Sensor will send transducer data according to configured time intervals. Event-based transmissions are supported by select transducers, in which the Sensor will transmit transducer data in response to specific triggers (e.g., waving a hand in front of the Sensor in order to trigger the PIR transducer).

Examples:

In the following example payloads, the data channel ID and data type ID are boldfaced:

- 0x **03 67** 00 0A **04 68** 28
  - $0\text{x}\ \mathbf{03\ 67}\ (\text{Ambient Temperature}) = (0\text{x}\ 00\ 0\text{A}) \times 0.1°\text{C} = 1°\text{C}$

[2] "ULn" represents the UL with associated FCount (frame counter) number n (e.g., UL0 has FCount 0, UL1 has FCount 1, etc.).

- $0x\ \mathbf{04\ 68}\ (\text{Ambient RH}) = (0x\ 28) \times 0.5\% = 20\%$

- 0x **0B E4** 01 E0 **0C 73** 23 28 **00 D3** 56
  - $0x\ \mathbf{0B\ E4}\ (\text{Pressure Compensated } CO_2) = (0x\ 01\ E0) \times 1\ \text{ppm} = 480\ \text{ppm}$
  - $0x\ \mathbf{0C\ 73}\ (\text{Barometric Pressure}) = (0x\ 23\ 28) \times 0.1\ \text{hPa} = 900\ \text{hPa}$
  - $0x\ \mathbf{00\ D3}\ (\text{Remaining Battery Capacity of Sensor}) = (0x\ 56) \times 1\% = 86\%$
- 0x **00 BA** 01 6C **02 00** FF **10 02** 00 7D
  - $0x\ \mathbf{00\ BA}\ (\text{Battery Voltage}) = (0x\ 01\ 6C) \times 0.01\ \text{V} = 3.64\ \text{V}$
  - $0x\ \mathbf{02\ 00}\ (\text{Ambient Light State}) = 0xFF = \text{Bright}$
  - $0x\ \mathbf{10\ 02}\ (\text{Ambient Light Intensity}) = (0x\ 00\ 7D) \times 0.1\ \mu\text{A} = 12.5\ \mu\text{A}$
- 0x **03 67** FF CC **0D 04** 00 02
  - $0x\ \mathbf{03\ 67}\ (\text{Ambient Temperature}) = (0x\ FF\ CC) \times 0.1°\text{C} = -5.2°\text{C}$
  - $0x\ \mathbf{0D\ 04}\ (\text{Motion Event Count}) = 0x\ 00\ 02 = 2\ motion\ events$

3 Timestamp Acquisition Stream

The timestamp acquisition stream is used to exchange timestamp acquisition data between a Sensor and application server via LoRaWAN. Uplinks and downlinks containing local time acquisition requests/responses and sensor timestamp requests/responses are ***sent on LoRaWAN port 20***.

3.1 Uplink Timestamp Requests and Response from Sensor

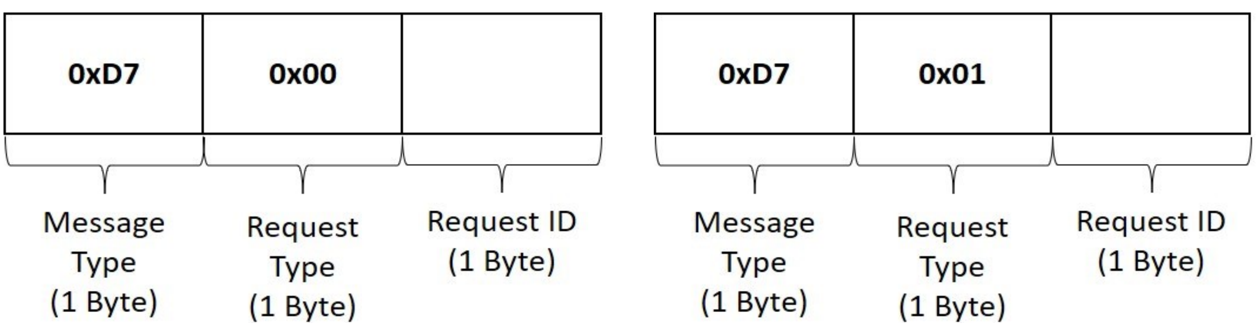
The Sensor uplinks ***sent on LoRaWAN port 20*** contain either a local timestamp acquisition request or a sensor timestamp response. These two types of messages are distinguished by the first byte of the uplink payload:

- **0xD7** for local timestamp acquisition requests
- **0x85** for sensor timestamp responses

3.1.1 Local Timestamp Acquisition Requests

If dynamic reporting mode is enabled, the Sensor will send uplinks to request the current local time. Once this setting is written to flash memory, and the Sensor has been reset and reconnected with the LoRaWAN network, the sensor will begin sending timestamp requests. If the Sensor does not have an existing[3] time reference, it will begin sending uplinks containing local timestamp acquisition requests every minute until it receives its first timestamp. The Sensor will continue to send timestamp requests until it has either received a timestamp request response from the NS or after 15 minutes have passed without a response. In the case where the Sensor has not received a timestamp after 15 minutes, dynamic reporting mode is disabled. Users can re-enable dynamic reporting mode through DL configuration register 0x66 (see Section 4.2.10.1).

Uplinks containing timestamp acquisition requests are ***sent on LoRaWAN port 20***. The uplink payload formats are shown in Figure 3-1. A big-endian format (MSb/MSB first) is always followed.



(a) Acquire initial time reference (b) Update existing time reference

Figure 3-1: Frame format of local timestamp acquisition request in an UL payload.

[3] The Sensor loses any previous time reference once it is powered-off/reset or when the dynamic reporting mode is disabled using DL configuration register 0x66 (see Section 4.2.10).

The first byte indicates the message type, where local timestamp acquisition requests and responses use 0xD7. The second byte represents the request type. The Sensor uses 0x00 if it does not have an existing time reference, and it uses 0x01 when it wishes to update its existing time reference. The third byte is the Request ID, which is first generated as a pseudo-random number when the Sensor sends its first timestamp request, and then increments for each subsequent timestamp request. The Request ID wraps to 0 after it reaches the maximum value.

After the Sensor has successfully calculated an initial reference time, it will send periodic timestamp requests (the frequency of which is determined by DL configuration register 0x67) in order to update its existing time reference. This is necessary to account for daylight savings time and cumulative timing error due to the inaccuracy of the Sensor's RTC. Periodic timestamp update requests are sent at 3:00 AM (as perceived by the Sensor) on days determined by the configured timestamp update period. See Section 4.2.10.2 for more information on the timestamp update period. The way in which the Sensor calculates and tracks the local time from the acquired timestamp is described in Section 3.2.1.

3.1.2 Sensor Timestamp Response

The application may request the Sensor's current perceived timestamp by sending DL frames containing sensor timestamp requests as described in Section 3.2.2. If the Sensor receives a sensor timestamp request (***sent on LoRaWAN port 20***), the Sensor responds immediately with a UL following the payload format shown in both Figure 3-2 and Table 3-1. A big-endian format (MSb/MSB first) is always followed.

Figure 3-2: Frame format of sensor timestamp response in an UL payload.

The UL response begins with the message type corresponding to sensor timestamp requests and responses (i.e., 0x85). The four bytes that follow consist of a local timestamp indicating the Sensor's current perceived local time. The local timestamp is a Unix timestamp with an offset to account for the local UTC offset. If the Sensor does not have an existing time reference, the Sensor will report the local timestamp as 0.

Table 3-1: Sensor Timestamp Response Payload Format Description

Value	Size	Description
Message Type	1 B	• Message type to indicate that this is a sensor timestamp response (0x85)
Local Timestamp	4 B	• Seconds in current Epoch since January 1, 1970 (UTC) + local UTC offset (in seconds) • 1 sec / LSB (unsigned)

3.2 Downlink Timestamp Requests and Response from Application

Downlinks containing either a local timestamp acquisition response or a sensor timestamp request are ***sent on LoRaWAN port 20***. These two types of messages are distinguished by the first byte of the downlink payload:

- **0xD7** for local timestamp acquisition responses
- **0x85** for sensor timestamp requests

3.2.1 Local Timestamp Acquisition Response

Once the NS receives a local timestamp acquisition request ***sent on LoRaWAN port 20*** from the Sensor, the application server should queue a DL response *specific to the individual UL request.* After the Sensor sends a UL timestamp request, it expects to receive a DL response to said request within the time it takes to send the next two uplinks, regardless of what those two uplinks contain. If the Sensor has not received a response right before sending the second subsequent uplink (after the request), the Sensor ignores any future attempts to respond to that specific timestamp request.

Downlinks containing a timestamp acquisition response are ***sent on LoRaWAN port 20***. The downlink payload format is detailed in both Figure 3-3 and Table 3-2. A big-endian format (MSb/MSB first) is always followed.

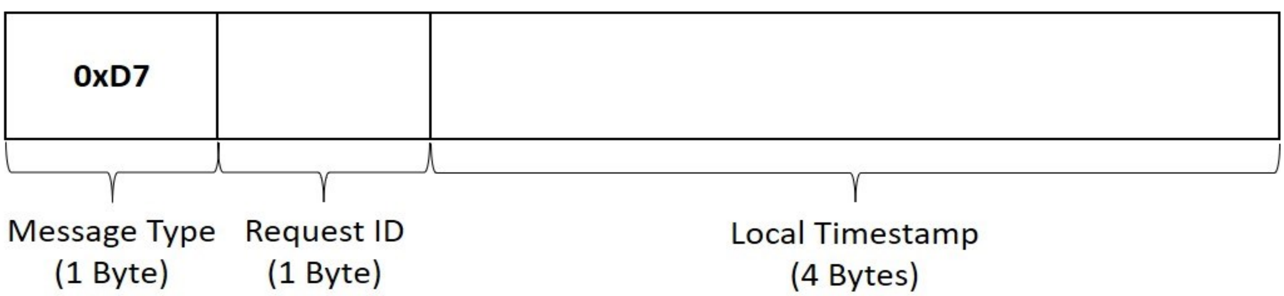


Figure 3-3: Frame format of local timestamp acquisition response in a DL payload.

The DL response must begin with the message type corresponding to local timestamp acquisition requests and responses (i.e., 0xD7). The next byte must include the Request ID matching that of the UL timestamp request that the DL is responding to. The last four bytes consist of a local timestamp indicating when the UL timestamp request with the matching Request ID was received by the NS. The application server should send a Unix timestamp that is offset by the local UTC offset (in seconds) so that the Sensor has the correct local time.

Table 3-2: Local Timestamp Acquisition Response Payload Format Description

Value	Size	Description
Message Type	1 B	• Message type to indicate that this is a local timestamp acquisition response (0xD7)
Request ID	1 B	• Request ID matching the UL timestamp request associated with timestamp
Local Timestamp	4 B	• Seconds in current Epoch since January 1, 1970 (UTC) + local UTC offset (in seconds) • 1 sec / LSB (unsigned)

Once the Sensor has a time reference, it will track the time of day and alternate between the two independently-configured reporting modes based on the perceived time of day. The Sensor calculates the reference time received from the application according to the following formula:

Current time = Unix timestamp with local offset + time elapsed between request sent and response received

Note: It is recommended that the application send a sensor timestamp request (see Section 3.2.2) after the Sensor has successfully received a time reference for the first time in order to verify that the local timestamp has been configured correctly.

Example:

Figure 3-4 shows a general example of the transactions between the Sensor, NS, and application.

If the Sensor sends a timestamp request in ULa, it expects to receive a response in either of the LoRa receive windows following ULa or ULb. If a response is not received prior to sending ULc, the Sensor stops tracking the time since it sent ULa. If a response is received prior to sending ULc, the Sensor calculates the elapsed time between when it sent ULa and when it received the response to ULa. The Sensor then calculates the current time to use as its time reference.

Also note that if the response to ULa is not received before the Sensor transmits ULb, ULb can also contain another timestamp request. In that case, the Sensor keeps track of both times since ULa and ULb were sent. If the Sensor does not receive a response to timestamp requests in ULa and ULb prior to receiving ULc, the Sensor stops tracking the time since ULa was sent, and instead begins tracking the time since ULc was sent, and so on.

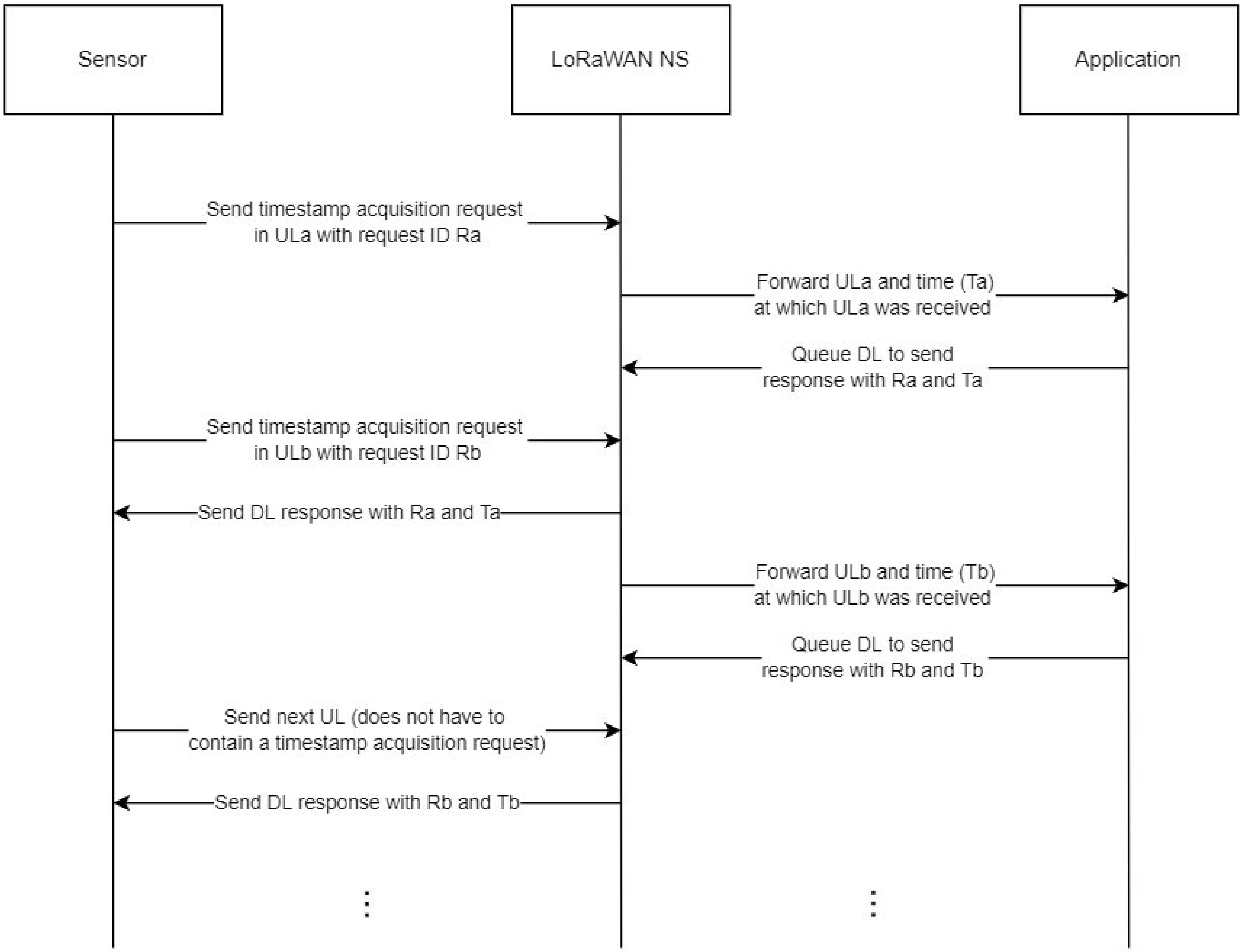


Figure 3-4: Example of Sensor, NS, and application timestamp acquisition transactions.

Examples of local timestamp acquisition response payloads:

- Generating a response to UL request with payload: {0x D7 00 1A}
  - Assume the UL was received on the NS at 2027-09-21 19:47:59 (without local offset), or 1821556079 seconds in Unix time and the Sensor is operating in a time zone that uses UTC-7:00 (-25200 sec).
  - DL response payload would be: {0x D7 1A 6C 92 5A FF}
    - Message Type = 0x D7
    - Request ID = 0x 1A
    - Local timestamp calculated as 1821556079 - 25200 = 1821530879 (2027-09-21 12:47:59) or 0x 6C 92 5A FF

    - When the Sensor receives this response, it will calculate its perceived time to be 2027-09-21 12:47:59 + time elapsed between UL with Request ID 0x1A sent and response to UL with Request ID 0x1A received.
- Generating a response to UL request with payload: {0x D7 01 FE}
    - Assume the UL was received on the NS at 2021-06-11 14:10:24 (without local offset), or 1623420624 seconds in Unix time and the Sensor is operating in a time zone that uses UTC+9:30 (34200 sec).
    - DL response payload would be: {0x D7 FE 60 C3 F4 68}
        - Message Type = 0x D7
        - Request ID = 0x FE
        - Local timestamp calculated as 1623420624 + 34200 = 1623454824 (2021-06-11 23:40:24) or 0x 60 C3 F4 68
    - When the Sensor receives this response, it will calculate its perceived time to be 2021-06-11 23:40:24 + time elapsed between UL with Request ID 0xFE sent and response to UL with Request ID 0xFE received.

3.2.2 Sensor Timestamp Requests

The application may request the perceived local timestamp of the Sensor with a sensor timestamp request ***sent on LoRaWAN port 20***. The downlink payload format is shown in Figure 3-5, where only the message type of sensor timestamp requests and responses (i.e., 0x85) must be sent. The Sensor will then respond with its current perceived timestamp as specified in Section 3.1.2.

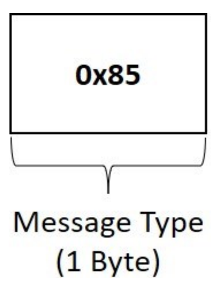


Figure 3-5: Frame format of sensor timestamp request in a DL payload.

4 Sensor Application Configuration Stream

The sensor application configuration stream is used to exchange configuration and control command data between a Sensor and an application server via LoRaWAN. Downlinks containing configuration and control commands to a Sensor are ***sent on LoRaWAN port 100***. Uplinks containing responses to configuration and control commands from a Sensor are ***sent on LoRaWAN port 100*** and/or ***LoRaWAN port 101*** (see Section 4.1 for more details).

4.1 Uplink Response to DL Configuration and Control Commands

Sensor responses to DL configuration and control commands (which are sent on ***LoRaWAN port 100***; see Section 4.2) are sent in the UL on ***LoRaWAN port 100*** and/or ***LoRaWAN port 101***. These responses include the following:

- Returning the value of (a) configuration register(s) in response to an inquiry from the NS.
- Writing to (a) configuration register(s).

In the first case, the Sensor responds with the address and value of each of the registers under inquiry on ***LoRaWan port 100***. The response can be in one or more consecutive UL packets depending on the maximum frame payload size allowed.

In the second case, the Sensor responds by immediately sending the last byte of the LoRaWAN DL frame counter value followed by a size byte indicating the number of registers that were **NOT** successfully written to, and then the addresses of the failed registers on ***LoRaWAN port 101***. The intent is to both inform the user which set of commands the end-device is referring to, and which (if any) of the write commands were seen as invalid. As a result, if a redundant write command is issued (i.e., the value of that register is not changing), then the Sensor will not report its address, because it was not an invalid command. In the case where all the write commands are performed successfully, the Sensor will send back a frame with only the last byte of the DL frame counter value and a size indication byte of “00” on ***LoRaWAN port 101***.

If the DL payload also had read commands, the address and value of each of the registers under inquiry are reported separately on ***LoRaWAN port 100***. In this case, the UL response to read commands on ***LoRaWAN port 100*** is handled before the UL response to write commands on ***LoRaWAN port 101***. The Sensor will respond this way to all read and/or write commands, except for the special case where the anti-bricking strategy is performed. See Section 4.2.2.4 for more details.

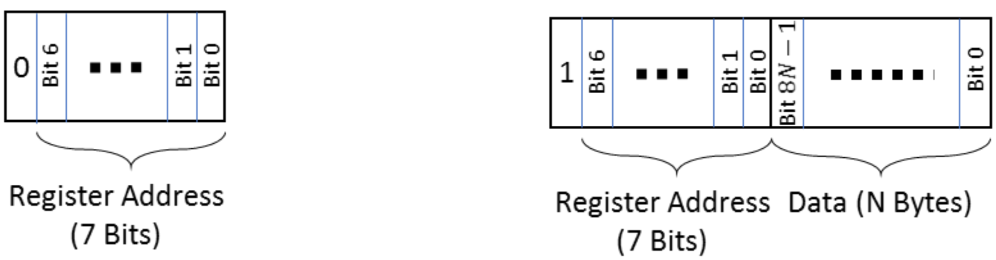
The default method in which the Sensor responds to write commands differs from previous iterations of TEKTELIC Sensors. Previously, the Sensor would respond with a CRC32 of the entire DL payload as the first 4 bytes of the UL frame. Users now have the option to select the desired response format through the configuration register detailed in Section 4.2.11. This option has been included in an attempt to accommodate applications designed for previous iterations of TEKTELIC Sensors that can decode the CRC. However, it is strongly recommended that users update their data encoders and decoders to accommodate the new response format.

4.2 Downlink Configuration and Control Commands

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 4-1. A big-endian format (MSb/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 4-1. 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. All of the DL configuration registers listed in the following sections follow the bit indexing scheme shown in Figure 4-1.



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

Figure 4-1: The format of a DL configuration and control message block.

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

When a write command is sent to the Sensor, the Sensor immediately responds by sending a UL containing the last byte of the LoRaWAN DL frame counter value followed by a size byte indicating the number of appended addresses, and the addresses of the registers that were not successfully written to on ***LoRaWAN port 101*** (see Section 4.1).

DL configuration and control commands fall into one of the following categories and are discussed in Sections 4.2.1 to 4.2.12.

- LoRaMAC Configuration
- Periodic Tx Configuration
- BLE Display Configuration
- CO_2 Transducer Configuration
- Barometer Configuration
- Temperature/RH Threshold Configuration

- Battery Management Configuration
- Light Transducer Configuration
- Motion Transducer Configuration
- Dynamic Reporting Mode Configuration
- Response to DL Commands Configuration
- Command and Control

4.2.1 LoRaMAC Configuration

LoRaMAC options can be configured using DL commands. These configuration options change the default MAC configuration that the Sensor loads on start-up. They can also change certain run-time parameters. Table 4-1 shows the MAC configuration registers. All the registers have R/W access.

Table 4-1: LoRaMAC Configuration Registers

Address	Value	Size	Description	JSON Variable (Type/Unit)
0x10	Join Mode	2 B	• Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored	*loramac_join_mode: <value>* *(string/no unit)*
0x11	Options	2 B	• Bit 0: 0/1 = Unconfirmed/Confirmed UL • Bit 1 = 1 (RO): 0/1 = Private/Public Sync Word • Bit 2: 0/1 = Disable/Enable Duty Cycle • Bit 3: 0/1 = Disable/Enable ADR • Bits 4-15: Ignored	*loramac_ul_type: <value>* *(string/no unit)* *loramac_duty_cycle: <value>* *(string/no unit)* *loramac_adr: <value>* *(string/no unit)*
0x12	DR and Tx Power[4]	2 B	• Bits 8-11: Default DR number • Bits 0-3: Default Tx power number • Bits 4-7, 12-15: Ignored	*loramac_default_dr: <value>* *(unsigned/no unit)* *loramac_default_tx_pwr:* *<value>* *(unsigned/no unit)*
0x13	Rx2 Window	5 B	• Bits 8-39: Channel frequency in Hz for Rx2 • Bits 0-7: DR for Rx2	*loramac_rx2_freq: <value>* *(unsigned/MHz)* *loramac_rx2_dr: <value>* *(unsigned/no unit)*

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

Note: Modifying these values only changes them in the Sensor. Options for the Sensor in the NS also need to be changed in order to not strand a Sensor. However, modifying configuration parameters in the NS is outside the scope of this document.

4.2.1.1 Default Configuration

Table 4-2, Table 4-3, and Table 4-4 show the default values for the LoRaMAC configuration registers (cf. [2], [1]).

Table 4-2: Default Values of LoRaMAC Configuration Registers

Address	Default Value
0x10	• OTAA mode
0x11	• Unconfirmed UL • Duty cycle enabled[5] • ADR enabled
0x12	• DR0 • Tx Power 0 (max power; see Table 4-3)
0x13	• As per Table 4-4

Table 4-3: Default Maximum Tx Power in Different LoRaMAC Regions

LoRaMAC Region	Max Tx EIRP [dBm]
EU868	16
US915	30
AS923	16
AU915	30
IN865	30
KR920	14
RU864	16

Table 4-4: Default Values of Rx2 Channel Frequency and DR Number in Different LoRaMAC Regions

LoRaMAC Region	Channel Frequency [Hz]	DR Number
EU868	869525000	0
US915	923300000	8
AS923	923200000	2
AU915	923300000	8
IN865	866550000	2
KR920	921900000	0

[5] In the LoRaMAC regions where there is no duty cycle limitation, such as US915, the "enabled duty cycle" configuration of the Sensor is ignored.

LoRaMAC Region	Channel Frequency [Hz]	DR Number
RU864	869100000	0

Examples:

- Switch Sensor to ABP Mode:
  - DL payload: { 0x **90** 00 00 }
- Set ADR enabled, no duty cycle, and confirmed UL payloads:
  - DL payload: { 0x **91** 00 0B }
- Set default DR number to 1 and default Tx power number to 2:
  - DL payload: { 0x **92** 01 02 }

4.2.2 Periodic Tx Configuration

All periodic transducer reporting is synchronized around *ticks*. A *tick* is simply a user configurable time-base that is used to schedule transducer measurements. For each transducer, the number of elapsed *ticks* before transmitting can be defined as shown in Table 4-5. All the registers in this table have R/W access.

Table 4-5: Periodic Transmission Configuration Registers

Address	Value	Size	Description	JSON Variable (Type/Unit)
0x20	Seconds per Core *Tick*	4 B	• *Tick* value for periodic events (1 sec / LSB) • Acceptable values: 0, 10, 11, …, 86400 • 0: Disables all periodic transmissions • Other values: Invalid and ignored	*seconds_per_core_tick: <value> (unsigned/sec)*
0x21	*Ticks* per Battery	2 B	• *Ticks* between battery reports • 0: Disables periodic battery reports	*ticks_battery: <value> (unsigned/no unit)*
0x22	*Ticks* per Ambient Temperature	2 B	• *Ticks* between ambient temperature reports • 0: Disables periodic ambient temperature reports	*ticks_temp: <value> (unsigned/no unit)*
0x23	*Ticks* per Ambient RH	2 B	• *Ticks* between ambient RH reports • 0: Disables periodic ambient RH reports	*ticks_rh: <value> (unsigned/no unit)*
0x25	*Ticks* per Ambient Light	2 B	• *Ticks* between ambient light reports • 0: Disables periodic ambient light reports	*ticks_light: <value> (unsigned/no unit)*
0x26	*Ticks* per CO_2	2 B	• *Ticks* between CO_2 reports • 0: Disables periodic CO_2 reports	*ticks_co2: <value> (unsigned/no unit)*
0x27	*Ticks* per Pressure	2 B	• *Ticks* between Pressure reports • 0: Disables periodic Pressure reports	*ticks_pressure: <value> (unsigned/no unit)*
0x28	*Ticks* per Motion (PIR)	2 B	• *Ticks* between motion (PIR) reports • 0: Disables periodic motion (PIR) reports	*ticks_motion_pir: <value> (unsigned/no unit)*

4.2.2.1 Seconds per Core Tick

All periodic Tx events are scheduled in *ticks*. This allows for transducer reads to be synchronized, reducing the total number of ULs required to transmit Sensor data. The minimum seconds per *tick* is 10 sec, and the maximum is 86,400 sec (one day). Values from 1 sec to 9 sec and values above 86,400 sec are invalid and ignored. A value of 0 (zero) disables all periodic reporting.

If Dynamic Reporting Mode is enabled, this register determines the seconds per *tick* while the Sensor is in Active Mode. See Section 1.2.1 for more details.

Note: While the seconds per core *tick* can be set as low as 10 seconds, it is important to keep in mind that the battery life of the Sensor is highly dependent on the frequency of periodic transmissions. It is recommended that the Core *Tick* and *Ticks* per <Transducer> registers be configured such that the Sensor transmits only as frequently as is reasonably necessary for the use case and environment.

4.2.2.2 Ticks per <Transducer>

This register sets the reporting period for a transducer in terms of *ticks*. Once the configured number of *ticks* has expired, the Sensor polls the specified transducer and reports the data in an UL message. A setting of 0 (zero) disables periodic reporting for the specified transducer.

CO_2, temperature, humidity, and the Sensor and Display's remaining battery capacity values will also be reported the e-Ink Display (if applicable) based on the values of the associated *tick* registers. The e-Ink Display updates shortly after LoRa transmissions occur. If any of the applicable *tick* registers are set to 0, the last reported measurement associated with said *tick* will remain on the Display.

Note: In the case of transducers with configurable sampling periods (i.e., CO_2/Barometer), the time between periodic reports should be set to be greater than or equal to the individually set sampling periods. This is so that the Sensor reports the most up-to-date measurements.

4.2.2.3 Default Configuration

Table 4-6 shows the default values for the periodic transmission configuration registers.

Table 4-6: Default Values of Periodic Transmission Configuration Registers

Seconds per Core Tick	300 (5 min)
***Ticks* per Battery**	1 (thus 5-min period)
***Ticks* per Ambient Temperature**	1 (thus 5-min period)
***Ticks* per Ambient RH**	1 (thus 5-min period)
***Ticks* per Ambient Light**	0 (periodic Tx disabled)
***Ticks* per CO_2**	1 (thus 5-min period)
***Ticks* per Pressure**	1 (thus 5-min period)
***Ticks* per PIR**	0 (periodic Tx disabled)

Examples:

- Disable all periodic events:
  - DL payload: { 0x **A0** 00 00 00 00 }
    - Register 0x20 with the write bit set to true
    - Seconds per *Tick* set to 0 (zero)—i.e., disable periodic transmissions
- Read current value of Seconds per *Tick*:
  - DL payload: { 0x **20** }
    - Register 0x20 with the write bit set to false
- Report Temperature every *tick* and RH every two *ticks*:
  - DL payload: { 0x **A2** 00 01 **A3** 00 02 }
    - Registers 0x22 and 0x23 with their write bits set to true
    - Temperature *Ticks* set to 1 (one)
    - RH *Ticks* set to 2 (two)

4.2.2.4 Anti-Bricking Strategy

Care has been taken to avoid stranding (hard or soft bricking) the Sensor during reconfiguration. Hard bricking refers to the condition that the Sensor does not transmit anymore as all periodic and event-based reporting (see subsequent sections) have been disabled and the configuration has been saved to the Flash memory. Soft bricking refers to the condition where the Sensor has been configured such that all event-based reporting is disabled and any periodic reporting is either disabled or has a period of larger than a week.

To avoid these situations, for any reconfiguration command sent to the Sensor, the following algorithm is executed:

After the reconfiguration is applied, if all event-based reporting (as explained in subsequent sections) is disabled, then periodic reporting is checked. If all periodic reporting is disabled or the minimum non-zero period is greater than a day, then to avoid bricking the Sensor, the core *tick* is set to 86,400 (i.e., one day), and the battery *tick* is set to 1 (one). The Sensor will first respond on ***LoRaWAN port 100*** with the value of the registers it has had to change internally so as to inform the application server of these changes. Then, the sensor will respond to the attempted reconfiguration on ***LoRaWAN port 101*** with the LoRaWAN DL frame counter value followed by what registers it has been unable to change as per normal (see Section 4.1).[6]

4.2.3 BLE Display Configuration

Sensors can communicate with an e-Ink Display using Bluetooth for room occupants to easily view select transducer measurements in real-time. *Only Sensors that come with Displays use BLE communication.* As a security measure, the Display has whitelisting capabilities while the Sensor is programmed to only

[6] This assumes that the response format is set to the default method (i.e., invalid-write response format). If the CRC method is selected, the Sensor will respond with the 4-byte CRC in response to the configuration command as per normal.

communicate to its associated Display. Table 4-7 shows a list of BLE Display configuration registers. All the registers have R/W access.

Table 4-7: BLE Display Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x2A	BLE Communication Options	1 B	• Bit 0: 0/1 = Sensor whitelisting on Display disabled/enabled • Bits 1-7: Ignored	*ble_display_whitelisting_enabled: <value>* *(string/no unit)*
0x2B	Language Options	1 B	• Acceptable values: • 0: English • 1: French • 2-255: Invalid and ignored	*ble_display_language: <value>* *(string/no unit)*

4.2.3.1 BLE Communication Options

The BLE Communication Options register is used to disable/enable the Display's whitelisting feature. Note that the Sensor will continue to attempt to communicate with the associated Display regardless of if Display whitelisting is disabled or enabled.

If whitelisting is enabled, the Display will only allow connections with the associated Sensor. Disabling whitelisting will cause the Display to allow connections from other devices, such as a cellphone used to perform a FW upgrade on the Display. It is strongly recommended that this feature not be disabled unless absolutely necessary so as to reduce the risk of unwanted connections from other BLE devices. If whitelisting is disabled to allow another temporary BLE connection, users should re-enable whitelisting soon after.

The Display can only communicate with one BLE device at a time. If the Sensor reports transducer measurements while the Display is connected to a different device, the Display will not be updated with the latest transducer measurements, but the Sensor will still transmit transducer measurements to the LoRaWAN NS. Similarly, other devices will not be able to communicate to the Display while the Sensor is actively communicating with the Display.

4.2.3.2 Language Options

The two language options currently supported by the Sensor are English and French, which can be selected using a value of 0 (English) or 1 (French). Since there are no words on the Display, the difference between the two options is whether the Sensor communicates the fractional precision of displayed measurements as periods for English, or commas (virgules) for French. All applicable values shown on the Display will have the appropriate notation the next time that the Display refreshes after the Sensor has received the command.

4.2.3.3 Default Configuration

Table 4-8 shows the default values for the BLE Display configuration registers.

Table 4-8: Default Values of BLE Display Configuration Registers

BLE Communication Options	Sensor whitelisting on Display enabled
Language Options	English

4.2.4 CO_2 Transducer Configuration

The Breeze and Breeze-V's CO_2 transducer is capable of measuring the CO_2 concentration in the air using non-dispersive infrared (NDIR). When the transducer is enabled, it will be sampling based on the configurable sampling parameters of the transducer. The reported CO_2 values are pressure compensated by the values obtained from the onboard barometer. Table 4-9 shows a list of CO_2 transducer configuration registers. All the registers have R/W access.

Table 4-9: CO_2 Transducer Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x30	Sampling Parameters	3 B	• Bits 8-23: Sample period of the CO_2 transducer (1 sec / LSB) • Acceptable values: 0, 10, 11, …, 65535 • 0: Disables the CO_2 sensing element • 1-9: Invalid and ignored • Bits 0-7: Number of subsamples integrated per reported measurement • Acceptable values: 1, 2, …, 255 • 0: Invalid and ignored • Sample period must be greater than number of subsamples multiplied by 0.2	*co2_sample_period: <value> (unsigned/sec)* *co2_num_subsamples: <value> (unsigned/no unit)*
0x31	Threshold Control	2 B	• Threshold level (1 ppm / LSB) • Acceptable values: 0, 1, …, 65535 • 0: Disables threshold-based reporting	*co2_threshold_level: <value> (unsigned/ppm)*
0x32	IIR Filter Control	1 B	• Bits 0-3: Static IIR filter "recall factor" • Acceptable values: 0, 1, 2, …, 9 • 0: Disables static IIR filter • 10-15: Invalid and ignored • Bit 4: 0/1 = Dynamic IIR filter disabled/enabled • Bit 4 set to 1 and bits 0-3 set to 0: Invalid and ignored • Bits 5-7: Ignored	*co2_static_iir_recall_factor: <value> (unsigned/no unit)* *co2_dynamic_iir_enabled: <value> (string/no unit)*
0x33	Calibration Control	4 B	• Bits 24-31: • 0: ABC calibration	*co2_calibration_type: <value>*

Address	Name	Size	Description	JSON Variable (Type/Unit)
			• 1: Target calibration • 2: Background calibration • 3: Zero calibration • 255: No calibration • Other values: Invalid and ignored • Bits 16-23: • 0: System default for ABC-cycle calibration period (180 hours) • Non-zero value: Calibration period for ABC cycle (1 hour / LSB) • Bits 0-15: • 0: System default for calibration target value (400 ppm) • Non-zero value: Target calibration value (1 ppm / LSB)	*(string/no unit)* *co2_calibration_period: <value> (unsigned/hrs)* *co2_calibration_target: <value> (unsigned/ppm)*
0x34	Report Options	1 B	• Bit 0: 0/1 = Raw CO_2 value not reported/reported • Bit 1: 0/1 = Pressure Compensated CO_2 not reported/reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-7: Ignored	*co2_raw_reported: <value> (string/no unit)* *co2_pressure_compensated_reported: <value> (string/no unit)*

4.2.4.1 Sampling Parameters

The sample period determines how often the CO_2 sensor is powered on and taking measurements in both periodic and threshold-based reporting modes. The sample period can be set to any value in the range of 10 sec to 65535 sec. Setting the sample period to 0 (zero) disables the CO_2 sensing element. Values from 1 to 9 are invalid and ignored. If Dynamic Reporting Mode is enabled, this register determines the CO_2 Sampling Parameters while the Sensor is in Active Mode. See Section 1.2.1 for more details.

The CO_2 transducer also features an adjustable number of integrated subsamples per reported measurement. Acceptable values for the number of subsamples are in the range of 1 to 255, while 0 (zero) is ignored. The reported measurements become more accurate by increasing the number of subsamples at the cost of also increasing the power consumption.

Since it takes approximately 200 ms to acquire each subsample, it is important to set the sample period to be greater than the number of subsamples multiplied by 0.2 so that the transducer has enough time to perform each measurement.

Example: if we want the transducer to report after 32 subsamples, then the sample period would have to be greater than 32×0.2 = 6.4 sec, meaning a minimum sample period of 7 seconds is required.

Note: The CO_2 sample period needs to be enabled (i.e., non-zero) for periodic transmission of both CO_2 and pressure measurements. Otherwise, in every transmission a repetitive CO_2 and/or pressure value residing in the MCU memory is reported. The sample period should also be set to be less than or equal to the time between periodic reports (if enabled) in order to report the most up-to-date CO_2 and pressure values.

4.2.4.2 Threshold Control

The Threshold Control register is used to set the CO_2 threshold value with a precision of 1 ppm per bit. Setting the threshold level to 0 (zero) disables threshold-based reporting. Setting the threshold level to any valid non-zero value will enable threshold-based reporting.

When first enabled, the Sensor is considered to be below the non-zero threshold value. If threshold-based reporting is enabled, the Sensor transmits whenever the threshold is crossed (i.e., when the current and previous samples lie both sides of the threshold). The Sensor uses the pressure compensated CO_2 concentration when it compares the measured CO_2 to the threshold value.

The e-Ink Display provides a visual indicator when the CO_2 threshold is crossed, where the colour of the background and text surrounding the CO_2 value will be inverted until the CO_2 level falls below the configured threshold.

4.2.4.3 IIR Filter Control

The IIR Filter Control register is used to set the static IIR filter "recall factor" and enable/disable the dynamic IIR filter in the CO_2 transducer. The purpose of filtering is to suppress the CO_2 reading noise across multiple measurements. The static IIR filter "recall factor" controls the noise suppressing capabilities of the filter. A higher value will result in a stricter filter with better noise suppression. Only the reported pressure compensated CO_2 concentration is filtered if filtering is enabled.

Bits 0-3 are used to determine the recall factor of the static IIR filter. Setting the recall factor to 0 (zero) disables the static IIR filter. A value between 1 and 9 will set the desired recall factor, while values between 10 and 15 are invalid and ignored. Bit 4 is used to toggle the dynamic IIR filter enable. The dynamic IIR filter cannot be enabled if the static IIR filter is disabled. The static IIR filter should only be enabled if the CO_2 transducer is sampling frequently (< 5 minutes).

The choice of enabling the dynamic IIR filter heavily depends on both the environment and the desired performance. The static IIR filter alone is best suited to suppress noise when there are minimal changes to the environment between sampling periods. However, changes in the environment will be slow to propagate through the subsequent measurements. The dynamic IIR filter is better at quickly accommodating for significant changes in the environment. This comes at the potential cost of increased noise in the resulting measurements due to the decreased noise suppression.

4.2.4.4 Calibration Control

The desired CO_2 transducer calibration method can be selected using Bits 24-31. Values from 4 to 254 are invalid and ignored, while a value of 255 disables calibration completely. Values 0 to 3 are used to select one of the following four calibration methods:

- ABC calibration
- Target calibration
- Background calibration
- Zero calibration

Details on how to calibrate the transducer can be found in the Customer Integration Guidelines provided by the manufacturer [3]. The methods are briefly described below.

Automatic Baseline Correction (ABC) calibration is enabled by default. Manual calibration does not typically need to be performed so long as the Sensor remains in a suitable environment. ABC calibration is best suited for environments where the CO_2 concentration will eventually drop to around outdoor-air levels sometime during the configured ABC calibration period. If ABC calibration is enabled, it normally takes around three ABC calibration cycles before the CO_2 readings will stabilize to more consistent and accurate values.

The ABC algorithm calibrates the transducer by applying an offset to each CO_2 measurement. This offset is calculated as the difference between the ABC target value (default of 400 ppm) and the lowest recorded CO_2 value measured within the calibration period. If the Sensor resides in an environment with unpredictable and/or consistently elevated CO_2 levels, ABC should be disabled and a different calibration method should be used instead. In this case, the manufacturer recommends that manual calibrations should be done every two to three years [4].

The time between ABC calibrations is controlled by setting Bits 16-23 to the desired number of hours between calibrations. A value of 0 will use the default calibration period of the transducer (every 180 hours i.e., 7 and a half days).

Target calibration can be performed by placing the Sensor in an environment with a known CO_2 value and setting the known target value in the transducer.

Background calibration uses a default value of 400 ppm as a baseline. The simplest way to calibrate the Sensor is by placing it in close proximity to outdoor air. Some suggestions include placing the Sensor near an open window or fresh air inlet free of combustion sources and human presence [3]. This calibration method can be used by either sending a downlink over LoRa, or by using the CO_2 calibration push-button described in Section 1.3.1. Using the CO_2 calibration push-button will change the value of this register as if a background calibration was performed with a downlink command.

Zero calibration requires the Sensor to be in a zero-ppm environment. This can be achieved by flushing the Sensor with nitrogen gas (N_2), for example.

If ABC calibration is disabled, the user may manually calibrate the CO_2 transducer by selecting either Target, Background, or Zero calibration instead. *In this case, the CO_2 transducer will be calibrated based on the first measurement taken immediately after the DL command is received by the Sensor.* For this reason, it is important to ensure that the Sensor is in the appropriate calibration environment before it receives the DL command. The target calibration value (if applicable) must also be set to the desired value within the same DL command.

The target calibration value can be adjusted when ABC, Background, or Target calibration is enabled by setting Bits 0-15 to the target value in ppm. A value of 0 (zero) will use the default calibration target value of 400 ppm (typical CO_2 concentration of fresh air). A target value of 400 ppm is typically used for ABC and Background calibration techniques.

While calibration can be disabled altogether, it is not recommended unless the CO_2 transducer has been previously calibrated.

Note: The CO_2 calibration will be maintained until another calibration is performed. This is true even when the Sensor is reset or the batteries are replaced. However, the Sensor will default to using ABC calibration on a reset unless another calibration method is written to flash (i.e., the Sensor maintains the previous calibration until the first ABC period has elapsed after the reset by default). If a manual calibration method is written to flash, then upon a reset, the Sensor will not calibrate itself again unless the user sends a DL command to trigger a calibration.

4.2.4.5 Report Options

The Report Options register determines the value that is reported in periodic or threshold-based transmissions. Bit 0 (Raw CO_2) and Bit 1 (Pressure Compensated CO_2) determine which values are transmitted to the NS when periodic reporting is enabled.

Note: Pressure Compensated CO_2 reporting must be enabled in order to update the CO_2 value on the e-Ink Display.

4.2.4.6 Default Configuration

Table 4-10 shows the default values for the CO_2 transducer configuration registers.

Table 4-10: Default Values of CO_2 Transducer Configuration Registers

Sampling Parameters	• Sample period of 300 sec • 16 subsamples
Threshold Control	• Threshold-based reporting enabled • Threshold level set to 1000 ppm
IIR Filter Control	Static and dynamic IIR filters disabled
Calibration Control	System default (ABC Calibration enabled with period of 180 hours and target value of 400 ppm)

Report Options	Pressure compensated CO_2 reported only

Examples:

- Set CO_2 Sampling Parameters:
  - DL payload: {0x **B0** 00 1E 04}
    - Register 0x30 with write bit set to true
    - Sampling period set to 30 sec
    - Number of subsamples set to 4
- Perform a manual background CO_2 calibration:
  - DL payload: {0x **B3** 02 00 01 90}
    - Register 0x33 with write bit set to true
    - Background calibration method selected
    - ABC period set to default value (not used for manual calibration)
    - Target set to 400 ppm

4.2.5 Barometer Configuration

The Breeze and Breeze-V include a barometer capable of measuring the barometric air pressure. The barometer is set to take pressure samples in its low precision mode according to the CO_2 transducer sampling period in order to provide pressure compensation for the CO_2 transducer (see Section 4.2.4.1). Table 4-11 shows the barometer configuration register. This register has R/W access.

Table 4-11: Barometer Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x38	IIR Filter Recall Factor	1 B	• Acceptable values: 0, 1, …, 15 • 0: Equivalent to no IIR filtering • 16-255: Invalid and ignored	*pressure_iir_recall_factor: <value> (unsigned/no unit)*

4.2.5.1 IIR Filter Recall Factor

An IIR filter is implemented in the Sensor as it is particularly useful for suppressing noise introduced by environmental disturbances, such as air turbulence from a fan or a slamming door or window. A higher recall factor will result in a stricter filter that is better for noise suppression between measurements. A value of 0 (zero) disables the IIR filter, while values from 1 to 15 determine the recall factor. Values in the range of 16 to 255 are invalid and ignored.

4.2.5.2 Default Configuration

Table 4-12 shows the default value for the barometer configuration register.

Table 4-12: Default Value of Barometer Configuration Register

IIR Filter Recall Factor	2

4.2.6 Temperature/RH Threshold Configuration

The Breeze and Breeze-V support threshold transmission on ambient temperature and ambient RH. When a threshold on a transducer is enabled, the Sensor reports the transducer value when it leaves the configured threshold window, and once again when the transducer value re-enters the threshold window.[7] The threshold mode is compatible with periodic reporting. Table 4-13 shows a list of configuration registers for the temperature and RH threshold setting. All the registers have R/W access.

Table 4-13: Temperature/RH Threshold Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x39	Temperature/RH Sample Period: Idle	4 B	• Sample period of ambient temperature/RH transducer: Idle state (1 sec / LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid and ignored	*temp_rh_sample_period_idle : <value> (unsigned/sec)*
0x3A	Temperature/RH Sample Period: Active	4 B	• Sample period of ambient temperature/RH transducer: Active state (1 sec / LSB) • Acceptable values: 10, 11, …, 86400 • Other values: Invalid and ignored	*temp_rh_sample_period_active: <value> (unsigned/sec)*
0x3B	Low/High Temperature Thresholds	2 B	• Bits 8-15: High temperature threshold (signed, 1°C / LSB) • Bits 0-7: Low temperature threshold (signed, 1°C / LSB) • High threshold $\leq$ Low threshold: Invalid and ignored	*temp_threshold_high: <value> (signed/°C)* *temp_threshold_low: <value> (signed/°C)*
0x3C	Temperature Thresholds Enabled	1 B	• Bit 0: 0/1 = Thresholds disabled/enabled • Bits 1-7: Ignored	*temp_thresholds_enabled: <value> (string/no unit)*
0x3D	Low/High RH Thresholds	2 B	• Bits 8-15: High RH threshold (unsigned, 1% RH / LSB) • Bits 0-7: Low RH threshold (unsigned, 1% RH / LSB)	*rh_threshold_high: <value> (unsigned/%)* *rh_threshold_low: <value> (unsigned/%)*

[7] Note that the threshold window here is defined as the open interval "(Low Threshold, High Threshold)", not e.g., the closed interval "[Low Threshold, High Threshold]"; i.e., even if the transducer value is equal to Low Threshold or High Threshold, the Sensor is considered to have left the threshold window.

Address	Name	Size	Description	JSON Variable (Type/Unit)
			• High threshold ≤ Low threshold: Invalid and ignored	
0x3E	RH Thresholds Enabled	1 B	• Bit 0: 0/1 = Thresholds disabled/enabled • Bits 1-7: Ignored	*rh_thresholds_enabled: <value> (string/no unit)*

4.2.6.1 Temperature/RH Sample Period: Idle

The idle sample period determines how often the transducer is checked when the reported value is within the threshold window. When first enabled, the transducer starts in the Idle state.

The minimum sample period in the Idle state is 10 (ten) sec, and the maximum is 86,400 sec (one day). Values smaller than 10 (ten) for this register are invalid and ignored.

4.2.6.2 Temperature/RH Sample Period: Active

The active sample period determines how often the transducer is checked when the reported value is outside the threshold window.

The minimum sample period in the Active state is 10 (ten) sec, and the maximum is 86,400 sec (one day). Values smaller than 10 (ten) for this register are invalid and ignored.

4.2.6.3 Temperature/RH Thresholds

The thresholds are stored in a single 2-byte register, with the MSB storing the upper threshold, and the LSB storing the lower threshold. Ambient Temperature thresholds have a precision of 1°C per bit, and are stored/transmitted as 2's complement numbers. The RH thresholds have a precision of 1% per bit, and are stored/transmitted as unsigned numbers.

In all cases, the upper threshold must be greater than the lower threshold. Otherwise, the configuration is considered invalid and ignored.

4.2.6.4 Temperature/RH Thresholds Enabled

The Thresholds Enabled registers enable and disable the threshold reporting on the specified transducer. Thresholds and sample periods can be configured but are not activated unless the Thresholds Enabled bit is set.

The e-Ink Display also provides a visual indicator when the temperature and/or RH threshold is crossed, where the colour of the background and text surrounding the temperature and/or RH value will be inverted until the measurement(s) fall between the configured high and low threshold(s).

4.2.6.5 Default Configuration

Table 4-14 shows the default values for the threshold configuration registers.

Table 4-14: Default Values of Threshold Configuration Registers

Temperature/RH Sample Period: Idle	60 sec
Temperature/RH Sample Period: Active	30 sec
Temperature Threshold: High	30°C
Temperature Threshold: Low	15°C
Temperature Thresholds Enabled	Disabled
RH Threshold: High	80%
RH Threshold: Low	15%
RH Thresholds Enabled	Disabled

Examples:

- Set Temperature Thresholds:
  - DL payload: { 0x **BB** 19 0A }
    - Register 0x3B with write bit set to true
    - High threshold set to 25°C
    - Low threshold set to 10°C
- Read Temperature/RH Sample Periods:
  - DL payload: { 0x **39 3A** }
    - Registers 0x39 and 0x3A with their write bits set to false
- Set and enable RH thresholds:
  - DL payload: { 0x **BD** 3C 14 **BE** 01 }
    - Registers 0x3D and 0x3E with their write bits set to true
    - High RH thresholds set to 60% RH
    - Low RH threshold set to 20% RH
    - RH thresholds enabled

4.2.7 Battery Management Configuration

The Breeze and Breeze-V includes the ability to evaluate the battery performance in a number of ways. *Only Sensors that come with Displays can report the remaining battery capacity of the Display.* Table 4-15 shows the battery management configuration register. This register has R/W access.

Table 4-15: Battery Management Configuration Register

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x40	Report Options	1 B	• Bit 0: 0/1 = Battery voltage not reported/reported • Bit 1:	*battery_voltage_reported: <value> (string/no unit)* *battery_capacity_sensor_reported: <value>*

Address	Name	Size	Description	JSON Variable (Type/Unit)
			0/1 = Remaining battery capacity of Sensor not reported/reported • Bit 2: 0/1 = Remaining battery capacity of Display not report/reported • Bits 0-2 all set to 0: Invalid and ignored • Bits 3-7: Ignored	*(string/no unit)* *battery_capacity_display_reported: <value>* *(string/no unit)*

4.2.7.1 Report Options

The Report Options register determines what information is reported in periodic transmissions. Bits 0-2 can be toggled in order to report the battery voltage, remaining battery capacity of the Sensor, and/or remaining battery capacity of the Display, respectively.

The e-Ink Display also provides a visual indicator when the remaining battery capacity of the Sensor or Display falls below 10%, where the colour of the background and text surrounding the respective battery level(s) will be inverted until the batteries of the corresponding device are replaced.

Remaining battery capacity of Sensor and Display reporting must be enabled in order to update the remaining battery capacity values shown on the e-Ink Display. Since the Sensor tracks the battery level of the Display, it is recommended that the Display be powered off while the Sensor is powered off. The Display is only powered off by removing its batteries.

Note: The Sensor assumes that if the batteries of the Sensor or Display are removed and replaced, the user has inserted new batteries into the respective device (i.e., the remaining battery capacity is reset to 100%). Performing a soft reset on the Sensor[8] will not reset the remaining battery capacity to 100%. As a result, if the batteries from the Sensor or Display are removed, it is important to insert new batteries so that the reported remaining battery capacity is accurate.

4.2.7.2 Default Configuration

Table 4-16 shows the default value for the battery management configuration register.

Table 4-16: Default Value of Battery Management Configuration Register

Report Options	Remaining battery capacity of Sensor and Display reported

[8] A soft reset on the Sensor is performed either by using the reset button or by using the LoRa downlink configuration register 0x70. A soft reset cannot be performed on the Display.

4.2.8 Light Transducer Configuration

NOTE: Light transducer support is not available on sensors with module revisions A or B.

The light transducer on the Breeze/Breeze-V allows for the detection of the presence or absence of light based on the built-in light sensing transducer. The sensing element light pipe is visible on the top surface of the Sensor's enclosure. The orientation of the Sensor relative to the light source impacts the measured level of light intensity. The light sensing capability supports both periodic and threshold-based transmissions. Table 4-17 shows a list of light transducer configuration registers. All the registers have R/W access.

Table 4-17: Light Transducer Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x47	Sampling Parameters	3 B	• Bits 8-23: Sample period of the light transducer (1 sec / LSB) • Acceptable values: 0, 10, 11, …, 65535 • 0: Disables the light sensing element • 1-9: Invalid and ignored • Bits 0-7: Number of subsamples integrated per reported measurement • Acceptable values: 1, 2, …, 255 • 0: Invalid and ignored	*light_sample_period: <value> (unsigned/sec)* *light_num_subsamples: <value> (unsigned/no unit)*
0x48	Threshold Control	2 B	• Threshold level (0.1 µA / LSB) • Acceptable values: 0, 1, …, 32767 • 0: Disables threshold-based reporting • Other values: Invalid and ignored	*light_threshold_level: <value> (unsigned/µA)*
0x49	Report Options	1 B	• Bit 0: 0/1 = State (dark or bright) not reported/reported • Bit 1: 0/1 Intensity (uncalibrated, in units of 0.1 µA) not reported/reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-7: Ignored	*light_state_reported: <value> (string/no unit)* *light_intensity_reported: <value> (string/no unit)*
0x4A	Subsample Processing	1 B	• Acceptable values: • 0: Max • 1: Min • 2: Average • 3-255: Invalid and ignored	*light_subsample_processing: <value> (string/no unit)*
0x4B	IIR Filter Recall Factor	1 B	• Acceptable values: 0, 1, …, 15 • 0: Equivalent to no IIR filtering	*light_iir_recall_factor: <value>*

Address	Name	Size	Description	JSON Variable (Type/Unit)
			• 16-255: Invalid and ignored	*(unsigned/no unit)*

4.2.8.1 Sampling Parameters

The light transducer is held off to preserve energy, but turned on periodically by the MCU to take samples. The light sensing sample period determines how often the light sensing transducer is powered on and checked for the presence of light. Acceptable values for the sample period are 0 (zero) and between 10 sec and 65535 sec. Setting the sample period to 0 (zero) disables the light sensing element. Values from 1 to 9 sec are invalid and ignored. Shorter sample periods result in an improved detection time but result in additional battery usage.

Additionally, the Sensor now features the ability to integrate an adjustable number of subsamples per reported light measurement. This can be useful for decreasing the likelihood of reporting false positive transitions in light state that could occur from something like a flickering LED light bulb, as an example. Acceptable values for the number of subsamples can be any value from 1 to 255, while 0 (zero) is ignored. Subsamples are taken every 10 ms.

Note: The light sensing sample period needs to be enabled for periodic transmission. Otherwise, in every transmission a repetitive light value residing in the MCU memory is reported. The sample period should also be set to be less than or equal to the time between periodic reports (if enabled) in order to report the most up-to-date light state and/or intensity.

4.2.8.2 Threshold Control

The Threshold Control register is used to set the dark/bright transition point for the Sensor. Acceptable values for the Threshold Control register are between 0 and 32767, with units of 0.1 µA/LSB, while values greater than 32767 are invalid and ignored. Setting the threshold level to 0 (zero) disables threshold-based reporting. Setting the threshold level to any valid non-zero value will enable threshold-based reporting.

A light value smaller than or equal to the threshold is interpreted as “dark” and values greater than the threshold as “bright.” Therefore, a threshold setting of 1 corresponds to the darkest threshold. Also, as the maximum light intensity corresponds to about 1900 (i.e., 190 µA), any threshold larger than 1900 translates into the Sensor being always in the dark state. When first enabled, the Sensor begins in the “dark” state.

If threshold-based reporting is enabled, the Sensor transmits whenever the threshold is crossed (i.e. when the current and previous samples lie both sides of the threshold).

4.2.8.3 Report Options

The Report Options register determines the value that is reported in periodic or threshold-based transmissions. The light state is either dark or bright (based on a comparison between the light intensity value and the light threshold) if threshold-based reporting is enabled. The light intensity is expressed as an uncalibrated value in units of 0.1 µA.

4.2.8.4 Subsample Processing

There are three ways in which light sensing subsamples can be processed. The Sensor will report either the maximum, minimum, or average value of each set of subsamples per reported measurement. Values from 0 to 2 select the subsample processing method, while values from 3 to 255 are invalid and ignored.

4.2.8.5 IIR Filter Recall Factor

An IIR filter with an adjustable recall factor is implemented for the light transducer in order to reduce noise and obtain more consistent measurements. A higher recall factor will result in a stricter filter that is better for noise suppression between measurements. A value of 0 (zero) disables the IIR filter, while values from 1 to 15 determine the recall factor. Values from 16 to 255 are invalid and ignored.

4.2.8.6 Default Configuration

Table 4-18 shows the default values for the light transducer configuration registers.

Table 4-18: Default Values of Light Transducer Configuration Registers

Sampling Parameters	• Light transducer disabled • 10 subsamples
Threshold Control	• Threshold-based reporting enabled • Threshold level set to 10 µA
Report Options	Light state reported only
Subsample Processing	Max
IIR Filter Recall Factor	2

4.2.9 Motion Transducer Configuration

The Sensor features a motion transducer (detector) that uses a PIR transducer for the detection of human motion in a room. *Only the Breeze-V model is capable of motion detection.* Due to the sensitive electronics used in the PIR motion detector, the Sensor is designed to behave as follows:

- For **120 sec** after power is first applied to the device, the PIR motion detector is disabled (*post-turn on hold-off interval*). This is required for the PIR transducer output to stabilize and avoids false detections. The post-turn on hold-off interval is configurable through register 0x54 (see Table 4-19).
- For approximately **10 sec** after a radio transmission or after sampling the temperature/RH transducer, the PIR motion detector is disabled (*post-disturbance hold-off interval*). The operation of the radio or the temperature/RH transducer may cause the PIR transducer to produce false positives so a "cool

down" period is required after each Tx. The post-disturbance hold-off interval is also configurable through register 0x54 (see Table 4-19).

The Sensor runs a simple state machine for reporting whether motion is detected. To conserve battery usage, motion is reported only when it is first detected and when motion has not been detected for a configurable Grace Period.

Note: The PIR transducer is designed to detect motion, so if a room is occupied but the occupants are not moving, the sensor may report "No Motion" after the Grace Period (see Section 4.2.9.1) expires.

Table 4-19 shows a list of motion transducer configuration registers. All the registers have R/W access.

Table 4-19: Motion Transducer Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x50	Grace Period	2 B	• Grace period (time before motion is no longer detected) (1 sec / LSB) • Acceptable values: 15, 16, …, 65535 • Other values: Invalid and ignored	*pir_grace_period: <value>* *(unsigned/sec)*
0x51	Threshold Count	2 B	• Number of PIR events before motion is detected • Acceptable values: 1, 2, …, 65535 • 0: Invalid and ignored	*pir_threshold_count: <value>* *(unsigned/no unit)*
0x52	Threshold Period	2 B	• Period over which PIR events are counted for threshold detection (1 sec / LSB) • Acceptable values: 5, 6, …, 65535 • Other values: Invalid and ignored	*pir_threshold_period: <value>* *(unsigned/no unit)*
0x53	Report Options	1 B	• Bit 0 (only applies to periodic Tx): 0/1 = Motion count not reported/reported • Bit 1 (only applies to periodic Tx): 0/1 = Motion state not reported/reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-5: Ignored • Bit 6: 0/1 = PIR event-based reporting disabled/enabled • Bit 7: 0/1 = PIR transducer disabled/enabled	*pir_motion_count_reported: <value>* *(string/no unit)* *pir_motion_state_reported: <value>* *(string/no unit)* *pir_event_based_reporting_enabled: <value>* *(string/no unit)* *pir_transducer_enabled: <value>* *(string/no unit)*

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x54	Hold-Off Intervals	2 B	• Bits 8-15: • 0: Default value (120 sec) • Non-zero value: Post-turn on hold-off interval (1 sec / LSB) • Bits 0-7: • 0: Default value (10 sec) • Non-zero value: Post-disturbance hold-off interval (1 sec / LSB)	*pir_post_turn_on_holdoff: <value> (unsigned/sec)* *pir_post_disturbance_holdoff: <value>* *(unsigned/sec)*

4.2.9.1 Grace Period

The grace period determines how long the Sensor waits before the previously reported PIR motion event is considered clear. For example, a grace period of 5 (five) min results in the sensor transmitting "Motion Detected" when someone enters the room, and "Motion Not Detected" 5 (five) min after the room is empty. Values less than 15 sec are invalid and ignored.

4.2.9.2 Threshold Count

The PIR transducer generates an event each time it detects motion in its field of view. Depending on the customer use case, it may be desirable to increase the threshold to reduce sensitivity. This feature was designed to allow customers to filter out short motion events (such as a person quickly entering a room to pick-up a notebook), while still allowing longer motion events (a team meeting) to be reported.

4.2.9.3 Threshold Period

The threshold period is the amount of time that motion events will be accumulated for threshold detection. For example, a threshold period of 10 (ten) sec accumulates motion detection events over a 10 (ten)-sec period from the time of first detection. If the Threshold is exceeded before the time expires, the Sensor reports "Motion Detected," otherwise it does not report. Values less than 5 for the threshold period are invalid and ignored.

4.2.9.4 Report Options

The Report Options register allows the customer to disable/enable the motion transducer, as well as change the type of data that is transmitted by the Sensor. When the PIR transducer is disabled, no events from the PIR are monitored. When enabled, the motion transducer always reports the "motion state" (i.e., only the presence or absence of movement) in event-based reporting, if event-based reporting is enabled. Bit 0 (motion count) and Bit 1 (motion state) determine which values are transmitted when periodic reporting is enabled.

4.2.9.5 Hold-Off Intervals

The PIR transducer has two configurable hold-off intervals (post-turn on and post-disturbance), where motion detection is temporarily disabled to avoid false positives. This has been explained in more detail at the beginning of Section 4.2.9.

The MSB of register 0x54 controls the post-turn on hold-off interval while the LSB controls the post-disturbance interval. Note that a value of 0 for either of these intervals is equivalent to the default value of that interval (120 sec for the post-turn on and 10 sec for the post-disturbance hold off).

4.2.9.6 Default Configuration

Table 4-20 shows the default values for the motion transducer configuration registers.

Table 4-20: Default Values of Motion Transducer Configuration Registers

Grace Period	300 sec (5 min)
Threshold Count	1
Threshold Period	15 sec
Report Options	• PIR transducer enabled • Event-based transmission enabled • Motion count reported only, in the case of a periodic transmission
Hold-Off Intervals	• Post-turn on hold-off interval 120 sec • Post-disturbance hold-off interval 10 sec

4.2.10 Dynamic Reporting Mode Configuration

The Breeze/Breeze-V includes the ability to support multiple independently-configured reporting modes based on the date and time. Refer to Section 3 for details concerning the UL and DL payload formats for different types of timestamp requests/responses. An external application server that interfaces with the LoRaWAN NS to provide timestamps to the Sensor is required to utilize the two dynamic reporting modes. Table 4-7 shows a list of Dynamic Reporting Mode configuration registers. All the registers have R/W access.

Table 4-21: Dynamic Reporting Mode Configuration Registers

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x66	Dynamic Reporting Mode Enabled	1 B	• Bit 0: 0/1 = Dynamic Reporting Mode disabled/enabled • Bits 1-7: Ignored	*drm_enabled: <value>* *(string/no unit)*
0x67	Timestamp Update Period	1 B	• Bits 4-7: Timestamp update period (1 day / LSB) • Acceptable values: 0, 1, …, 15 • 0: Disables timestamp update requests	*drm_request_update_period: <value>* *(unsigned/day)*

Address	Name	Size	Description	JSON Variable (Type/Unit)
			• Bits 0-3: Maximum number of timestamp requests per update period • Acceptable values: 1, …, 15 • 0: Invalid and ignored	*drm_max_update_requests: <value> (unsigned/no unit)*
0x68	Active Mode Options	3 B	• Bits 16-23: Start of active mode (24-hour format, 1 hour / LSB) • Acceptable values: 0, 1, …, 23 • Other values: Invalid and ignored • Bits 8-15: End of active mode (24-hour format, 1 hour / LSB) • Acceptable values: 1, 2, …, 24 • Other values: Invalid and ignored • End of active mode ≤ Start of active mode: Invalid and ignored • Bit 7: Ignored • Bits 0-6: Toggle individual bits to indicate which days of the week use active mode hours Bit 0: Sunday Bit 1: Monday Bit 2: Tuesday Bit 3: Wednesday Bit 4: Thursday Bit 5: Friday Bit 6: Saturday 0/1 = Active mode on <day of week> disabled/enabled • Bits 0-6 all set to 0: Invalid and ignored	*drm_active_start_hr: <value> (unsigned/hour)* *drm_active_end_hr: <value> (unsigned/hour)* *drm_active_on_sunday: <value> (string/no unit)* *drm_active_on_monday: <value> (string/no unit)* *drm_active_on_tuesday: <value> (string/no unit)* *drm_active_on_wednesday: <value> (string/no unit)* *drm_active_on_thursday: <value> (string/no unit)* *drm_active_on_friday: <value> (string/no unit)* *drm_active_on_saturday: <value> (string/no unit)*
0x69	Seconds per Core *Tick* (Inactive Mode)	4 B	• *Tick* value for periodic events during inactive mode (1 sec / LSB) • Acceptable values: 0, 10, 11, …, 86400 • 0: Disables all periodic transmissions during inactive mode • Other values: Invalid and ignored	*seconds_per_core_tick_inactive: <value> (unsigned/sec)*
0x6A	CO_2 Sampling Parameters (Inactive Mode)	3 B	• Bits 8-23: Sample period of the CO_2 transducer during inactive mode (1 sec / LSB)	*co2_sample_period_inactive: <value> (unsigned/sec)*

Address	Name	Size	Description	JSON Variable (Type/Unit)
			• Acceptable values: 0, 10, 11, …, 65535 • 0: Disables the CO_2 sensing element • 1-9: Invalid and ignored • Bits 0-7: Number of subsamples integrated per reported measurement during inactive mode • Acceptable values: 1, 2, …, 255 • 0: Invalid and ignored • Sample period must be greater than number of subsamples multiplied by 0.2	*co2_num_subsamples_inactive: <value> (unsigned/no unit)*

4.2.10.1 Dynamic Reporting Mode Enabled

The Dynamic Reporting Mode Enabled register enables and disables the use of both active and inactive reporting modes of the Sensor. If disabled, the Sensor defaults to Active Mode configurations for the Seconds per Core *Tick* and CO_2 Sampling Parameters registers (i.e., exclusively uses registers 0x20 and 0x30). The Sensor will not send timestamp requests or track the current date and time if dynamic reporting mode is disabled.

The value of this register will be set to 0 if the Sensor does not receive a timestamp after 15 minutes of sending its first timestamp request UL. Re-enabling this register will cause the Sensor to try and obtain a time reference for 15 minutes once again.

See Sections 1.2 and 3 for more details.

4.2.10.2 Timestamp Update Period

The frequency in which the Sensor updates its timing reference and the maximum number of attempts per update is determined by the Timestamp Update Period register. Bits 4-7 are used to set the frequency of timestamp update requests. A value between 1 and 15 will set the number of days between timestamp update requests, while a value of 0 (zero) will stop the Sensor from sending timestamp update requests. Bits 0-3 determine the maximum number of timestamp update requests that can be sent during each update period. Acceptable values are from 1 to 15, while 0 (zero) is invalid and ignored.

Timestamp update requests are always sent at 3:00 AM[9] every number of days determined by the configured timestamp update request period. This update period is with respect to 3:00 AM the day after the Sensor acquired its initial time reference. The Sensor will send timestamp requests every 4 minutes until it has either

[9] Each Sensor adds a random delay of 0-5 minutes to this time in order to prevent network congestion in cases where many Sensors wish to update their timestamps.

received a response, or it has sent the configured maximum number of timestamp update requests per update period. It is recommended that users allow the Sensor to periodically transmit timestamp update requests in order to maintain an accurate time reference.

4.2.10.3 Active Mode Options

The Active Mode Options register is used to set the Active mode time interval and days of the week in which the Sensor will go into Active mode. The start of the Active mode time interval can be set using Bits 16-23, while Bits 8-15 are used to set the end of the Active mode time interval. The start time (in 24-hour format) can be set to a value between 0 and 23, and other values are invalid and ignored. The end time can be set to a value between 1 and 24, where other values are invalid and ignored, so long as the end time is not greater than the start time. Finally, Bits 0-6 can be individually toggled to enable Active mode reporting on select days of the week during the configured Active mode time interval.

If the bit corresponding to a day of the week is set to 0, the Sensor will be in Inactive mode for the entire day. If the bit corresponding to a day of the week is set to 1, the Sensor will be in Active mode during the set time interval, and in Inactive mode for hours outside said interval.

4.2.10.4 Seconds per Core Tick (Inactive Mode)

If Dynamic Reporting Mode is enabled, this register determines the seconds per *tick* while the Sensor is in Inactive Mode. While in Inactive Mode, the Ticks per <transducer> registers shown in Table 4-5 are synchronized to this Core Tick register. This register is otherwise identical to register 0x20 as it is described in Section 4.2.2.1.

4.2.10.5 CO_2 Sampling Parameters (Inactive Mode)

If Dynamic Reporting Mode is enabled, this register determines the CO_2 sampling parameters while the Sensor is in Inactive Mode. This register is otherwise identical to register 0x30 as it is described in Section 4.2.4.1.

4.2.10.6 Default Configuration

Table 4-22 shows the default values for the Dynamic Reporting Mode configuration registers.

Table 4-22: Default Values of Dynamic Reporting Mode Configuration Registers

Dynamic Reporting Mode Enable	Dynamic Reporting Mode disabled
Timestamp Update Period	• Timestamp update period of 1 day • Maximum 3 timestamp update requests per update period
Active Mode Options	• Start of Active Mode set to 9:00 (9:00 AM) • End of Active Mode set to 17:00 (5:00 PM) • Active mode hours apply on Monday, Tuesday, Wednesday, Thursday, and Friday
Seconds per Core *Tick* (Inactive Mode)	3600 (1 hour)

CO2 Sampling Parameters (Inactive Mode)	• Sample period of 3600 sec (1 hour) • 32 subsamples

Examples:

- Set Timestamp Update Period:
  - DL payload: {0x **E7** 34}
    - Register 0x67 with write bit set to true
    - Timestamp update period set to 3 days
    - Maximum number of timestamp requests sent per update to 4
- Enable Dynamic Reporting Mode and set Active Mode hours and days of the week:
  - DL payload: {0x **E6** 01 **E8** 07 13 2A}
    - Registers 0x66 and 0x68 with write bits set to true
    - Dynamic Reporting Mode enabled
    - Start of Active Mode set to 7:00 AM
    - End of Active Mode set to 7:00 PM
    - Active mode determined to be during above times on Monday, Wednesday, and Friday
- Set Seconds per Core *Tick* and CO_2 Sampling Parameters for both Active and Inactive modes:
  - DL payload: {0x **A0** 00 00 02 58 **E9** 00 00 1C 20 **C0** 01 2C 10 **EA** 0E 10 20}
    - Registers 0x20, 0x69, 0x30, and 0x6A with write bits set to true
    - Active Mode: Seconds per Core *Tick* set to 600 sec (10 mins)
    - Inactive Mode: Seconds per Core *Tick* set to 7200 sec (2 hours)
    - Active Mode: CO_2 sampling period set to 300 sec (5 mins) and 16 subsamples
    - Inactive Mode: CO_2 sampling period set to 3600 sec (1 hour) and 32 subsamples

4.2.11 Response to DL Commands Configuration

The Breeze/Breeze-V includes the ability for the user to select the format of UL responses to DL commands. Details on the response formats can be found in Section 4.1. Table 4-23 shows the response to DL commands register. This register has R/W access.

Table 4-23: Response to DL Command Configuration Register

Address	Name	Size	Description	JSON Variable (Type/Unit)
0x6F	Format Option	1 B	• Bit 0: 0: Invalid-write response format 1: 4-byte CRC • Bits 1-7: Ignored	*resp_to_dl_command_format: <value>* *(string/no unit)*

4.2.11.1 Format Option

The value of the Format Option register determines how the Sensor responds to DL commands. Setting Bit 0 to 0 (zero) selects the invalid-write response format, while a value of 1 (one) selects the 4-byte CRC method. Please refer to Section 4.1 for more details.

4.2.11.2 Default Configuration

Table 4-24 shows the default value for the response to DL commands configuration register.

Table 4-24: Default Value of Response to DL Commands Configuration Register

Format Option	Invalid-write response format selected

4.2.12 Command and Control

Configuration changes are not retained after a power cycle unless they are saved in the Flash memory. Table 4-25 shows the structure of the Command & Control Register.

Table 4-25: Sensor Command & Control Register

Address	Access	Name	Size	Description	JSON Variable (Type/Unit)
0x70	WO	Flash Write Command	2 B	• Bit 14: 0/1 = Do not write/Write LoRaMAC Config • Bit 13: 0/1 = Do not write/Write App Config • Bit 0: 0/1 = Do not restart/Restart Sensor • Bits 1-12, 15: Ignored	*write_to_flash_app_config: <value> (string/no unit)* *write_to_flash_lora_config: <value> (string/no unit)* *restart_sensor: <value> (string/no unit)*
0x71	RO	FW Version	7 B	• Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRaMAC version major • Bits 16-23: LoRaMAC version minor • Bits 8-15: LoRaMAC version revision • Bits 0-7: LoRaMAC region ID (see Section 4.2.12.1)	*app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value> (unsigned/no unit)* *app_ver_revision: <value> (unsigned/no unit)* *loramac_ver_major: <value> (unsigned/no unit)* *loramac_ver_minor: <value>*

Address	Access	Name	Size	Description	JSON Variable (Type/Unit)
					(unsigned/no unit) *loramac_ver_revision: <value>* *(unsigned/no unit)* *loramac_region_id: <value>* *(string/no unit)*
0x72	WO	Reset Config Registers to Factory Defaults[10]	1 B	• 0x0A: Reset App Config • 0xB0: Reset LoRa Config • 0xBA: Reset both App and LoRa Configs • Any other value: Invalid and ignored	*factory_reset_config: <value>* *(string/no unit)*

Note: The Command & Control Register is always executed after the full DL configuration message has been decoded. The reset command should always be sent as an "unconfirmed" DL message. Failure to do so may cause a poorly designed NS to continually reboot the Sensor.

4.2.12.1 LoRaMAC Region ID

The LoRaMAC region ID is indicated by the value of Bits 0-7 in the FW Version register (register 0x71). Current LoRaWAN regions and corresponding region IDs are listed in Table 4-26.

Table 4-26: LoRaMAC Regions and Region IDs [1]

LoRaMAC Region	LoRaMAC Region ID
EU868	0
US915	1
AS923	2
AU915	3
IN865	4
KR920	6
RU864	7

Examples:

- Write Application Configuration to Flash memory:
  - DL payload: { 0x **F0** 20 00 }

[10] After sending the reset-to-factory-defaults command, the Sensor is automatically reset with corresponding default configuration values.

- Write Application and LoRa Configurations to Flash memory:
    - DL payload: { 0x **F0** 60 00 }
- Reboot Device:
    - DL payload: { 0x **F0** 00 01 }
- Get FW version, and reset App Config to factory defaults:
    - DL payload: { 0x **71 F2** 0A}

References

[1] LoRa Alliance, "LoRaWAN Regional Parameters," ver 1.0.2rB, Feb. 2017.

[2] LoRa Alliance, "LoRaWAN Specification," ver. 1.0.2, Jul 2016.

[3] Senseair AB and Asahi Kasei Microdevices Corporation, "Senseair Sunrise Customer Integration Guidelines," TDE7318 Rev 9, 2021.

[4] Asahi Kasei Microdevices Corporation, "FAQ - CO2 Sensors," [Online]. Available: https://www.akm.com/global/en/products/co2-sensor/design-support/faq-co2-sensor/. [Accessed 3 May 2022].