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Respiratory Sensor

Technical Reference Manual

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Acronyms and Glossary

ABP .... activation by personalization
ADR .... adaptive data rate
AF .... activity factor
App SW .... Respiratory Sensor application SW
B .... byte
bpm .... breath(s) per min, beat(s) per min
BT .... body temperature
CE .... chest expansion
CRC .... cyclic redundancy check
DL .... downlink
DR .... data rate
EIRP .... effective isotropically radiated power
FEA .... front-end application
flash .... non-volatile memory of the MCU, containing the sensor configuration
FW .... firmware
g .... gravity (unit of acceleration ≈ 9.8 m/s^2)
HR .... heart rate
HRM .... HR monitor
ID .... identity/identifier
IoT .... Internet of things
JSON .... JavaScript object notation
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
mg .... milli-*g*
min .... minute(s)
MSb .... most significant bit
MSB .... most significant byte
NA .... North American
NS .... network server
OTA .... over-the-air
OTAA .... OTA activation
POST .... power-on self-test
RAM .... random-access memory
RBT .... respiratory belt transducer

RF .... radio frequency
RR .... respiratory rate
R/W .... read/write
Rx .... receiver
sec .... second(s)
SW .... software
TBD .... to be defined
transducer .... a sensing element in the Respiratory Sensor, such as the accelerometer
TRM .... technical reference manual (this document)
Tx .... transmitter
UA .... urgent attention
UL .... uplink
ver. .... version

1 Introduction

This document describes the SW functionality, LoRa IoT UL (uplink) and DL (downlink) payloads, and configuration settings supported by the Respiratory Sensor, which is developed by TEKTELIC Communications Inc. This document assumes an understanding of the NS (network sensor) and its command interfaces. The Respiratory Sensor UL data are finally accessed and presented to the end user by a FEA (front-end application). The end user can also use the FEA to send DL commands to the Respiratory Sensor. This document also describes the interface between the Respiratory Sensor and the FEA.

The Respiratory Sensor is a light and small, battery powered LoRaWAN sensor that is worn around the chest (upper torso), and monitors and periodically reports several health signs of the person, including the BT (body temperature), RR (respiratory rate), CE (chest expansion), position, HR (heart rate), and activity status, which can potentially help at (early) detection of a health issue. The Respiratory Sensor also measures and periodically reports the remaining battery lifetime.

The Respiratory Sensor has two red and green LEDs, which show system activities or states. It also has an adjustable strap for different chest sizes. The strap is supposed to be worn comfortably, but not too loose at deep exhalation.

The Respiratory Sensor is also equipped with an accelerometer that is used to measure the body position or detect a surge in physical activity.

Table 1-1 shows the HW variant available for the Respiratory Sensor. Table 1-2 lists the Respiratory Sensor variants for the different RF regions identified by the LoRa Alliance [1]—also see [1] for the Tx and Rx bands in each LoRaWAN region. As shown in Table 1-2, the different RF variants use the same HW; they are distinguished through different, specialized FW.

Table 1-1: Respiratory Sensor HW Model

Product Code	Description
T0006923	Respiratory Sensor Module

Table 1-2: Respiratory Sensor Region Specific Variants

LoRaWAN RF Variant	Order Code
EU868	XXXXXEU868
US915	XXXXXUS915
AS923	XXXXXAS923
AU915	XXXXXAU915
IN865	XXXXXIN865
KR920	XXXXXKR920
RU864	XXXXXRU864

2 Operational Description

2.1 Overview

The Respiratory Sensor measures the **remaining battery lifetime**, **BT (body temperature)**, **RR (respiratory rate)**, **CE (chest expansion)**, **position** (body angle), and **HR (heart rate)**, and **AF (activity factor)**. Here is the measuring and reporting pattern of the Respiratory Sensor in the **normal mode**:

1. **Remaining Battery Lifetime:** Measured and reported every `norm_report_period` min.
2. **BT:** Measured every min, an average is reported every `norm_report_period` min.
3. **RR:** Measured every min, an average is reported every `norm_report_period` min.
4. **CE:** Measured every min, an average is reported every `norm_report_period` min.
5. **Position:** Measured and reported every `norm_report_period` min.
6. **HR:** Measured and reported every `norm_report_period` min.
7. **AF:** Measured since last report, and reported every `norm_report_period` min.

`norm_report_period` is the normal mode report period (Section 4.2.2).

The **BT** is the body temperatures measured from the thermistor attached to the body.

The **AF** is an indication for the intensity of the physical activity, in units of *g* (gravity), the person has had since the last report. The FEA can map **AF** to three levels of physical activity, Low, Med, High, based on some predefined thresholds.

The Respiratory Sensor goes into the **UA (urgent attention) mode** after receiving a command from the FEA to do so. Here is the measuring and reporting pattern of the Respiratory Sensor in the UA mode:

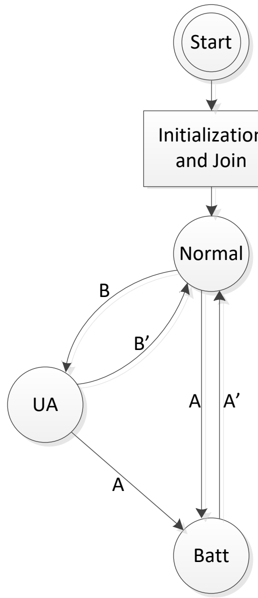
1. **Remaining Battery Lifetime:** Measured and reported every `ua_report_period` min.
2. **BT:** Measured every min, an average is reported every `ua_report_period` min.
3. **RR:** Measured every min, an average is reported every `ua_report_period` min.
4. **CE:** Measured every min, an average is reported every `ua_report_period` min.
5. **Position:** Measured and reported every `ua_report_period` min.
6. **HR:** Measured and reported every `ua_report_period` min.
7. **AF:** Measured since last report, and reported every `ua_report_period` min.

`ua_report_period` is the UA mode report period (Section 4.2.2).

Both the sensor user and FEA user can cancel the UA mode. When the UA mode is cancelled, the sensor goes into the normal mode. The FEA user can cancel UA by sending a command from the FEA to put the sensor into the normal mode.

The temperature **BT** is *always* measured every min. If a temperature measurement **BT** lies outside the operational range 30°C to 42°C, the Respiratory Sensor goes into the **battery saving mode**, where nothing is reported, and except for the temperature **BT**, nothing is measured either. As soon as a temperature measurements **BT** lies inside the operational range, the Respiratory Sensor goes into the **normal mode**.

Figure 2-1 Illustrates the state machine of the Respiratory Sensor.



Glossary:

Normal: Normal Mode
UA: Urgent Attention Mode
Batt: Battery Saving Mode
A: BT outside 30°C-42°C
A': BT inside 30°C-42°C
B: Go-to-UA push button event on Sensor or Go-to-UA command from FEA
B': Out-of-UA push button event on Sensor or Go-to-Normal command from FEA

Figure 2-1: State machine of the Respiratory Sensor.

The UL and DL information streams supported by the SW have been summarized in Table 2-1.

Table 2-1: Respiratory Sensor Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port
UL (Sensor to NS)	Periodic Report of Battery and Health Signs	**10**
	Periodic Report of Metadata	**100**
	Response to Configuration and Control Commands	**100**
DL (NS to Sensor)	Change the Sensor Mode of Reporting	**10**
	Configuration and Control Commands	**100**

2.2 Respiratory Sensor Battery Operation

The Respiratory Sensor is equipped with a replaceable CR2477 coin-cell battery with a nominal capacity of 1000 mAh. The Respiratory Sensor estimated lifetime is 3 months in the **normal mode**. An estimate for the remaining battery lifetime in percentage is included in every sensor report. When the remaining battery capacity estimate reaches 5% or less, a red LED pattern is activated to indicate this to the sensor user.

2.3 LED Patterns

The Respiratory Sensor has a red and a green LED. Table 2-2 specifies LED patterns for different events.

Table 2-2: Respiratory Sensor LED Patterns

Function	LED Pattern
App SW Activities	1. Both LEDs are turned off when the sensor is powered on, then they get turned on when the POST (power-on self-test) begins.

	2. When the POST ends, if the POST passed/failed, the green/red LED flashes ON-OFF-ON-OFF-ON-OFF-ON-OFF-ON-OFF (i.e. 5 times), with each ON or OFF being 50 ms. Both LEDs stay turned OFF after this until the joining procedure starts. 3. Joining: a) Green LED is toggled ON and OFF every 50 ms for the first hour. Then it flashes ON-OFF-ON-OFF (i.e. twice) with each ON or OFF being 50 ms, every 10 sec. b) Red LED flashes once for 25 ms right after transmitting a JOIN REQUEST, but for 100 ms right after receiving a JOIN ACCEPT. 4. Joined: Red LED flashes once for 25 ms right after transmitting an UL. Green LED flashes once for 25 ms right after receiving a DL.
Low Battery Indication	Red LED flashes 0.6 sec with 20ms-ON-80ms-OFF pattern, every 6 sec for 6-10% battery. Red LED flashes 0.6 sec with 20ms-ON-80ms-OFF pattern, every 3 sec for 1-5% battery.

3 UL Payload Formats

The UL streams (from the Respiratory Sensor to the NS) supported by the App SW are shown in Table 3-1, and are explained in Sections 3.1–3.3.

Table 3-1: UL Information Streams

Data Type	Sent on LoRaWAN Port
Periodic Report of Battery and Health Signs	**10**
Periodic Report of Metadata	**100**
Response to Configuration and Control Commands	**100**

3.1 Periodic Report of Battery and Health Signs

For simplicity and power efficiency, a fixed and short payload format, as shown in Figure 3-1, is considered for the reports. The reports are sent on ***LoRaWAN port 10***.

Encoding the UL (how the sensor SW builds an uplink): As shown in Figure 3-1, the following is how the uplink report is built by the SW:

1. The Battery Status byte is the remaining battery capacity, with 1 to 254 showing 1% to 100%. In fact, the remaining battery capacity of C in percentage is converted to $\left[\frac{253}{99}(C-1)+1\right]$, where $[.]$ is the round to the nearest integer function. If no valid measurement is available, the Battery Status byte is set to 0xFF.
2. The BT byte is obtained as $\max\left([20 \times (T-30)], 0\right)$, where $[.]$ is the round to the nearest integer function, and where T is the temperature measured from thermistor 1 in °C. If no valid measurement is available, the BT byte is set to 0xFF. A valid T is a temperature between `bt_limits.low` and `bt_limits.high`, inclusive (see Section 4.2.2.1).
3. The RR byte is the measured RR in bpm (1 LSb/bpm). If no valid measurement is available, the RR byte is set to 0xFF.
4. The status of the UA mode is encoded in the UA Bit (0/1 = mode inactive/active).
5. The 6-bit CE is the measured CE in percentage (1 LSb/0.2%), clipped from above at 12%. If no valid measurement is available, the 6-bit CE is set to 0x3F.
6. The 7-bit Position is an unsigned angle from 0° to 90°, with 0° corresponding to the sensor user lying down. If no valid measurement is available, the 7-bit Position is set to 0x7F.
7. The HR byte is the measured HR in bpm. If no valid measurement is available, the HR byte is set to 0xFF.
8. The AF byte shows the intensity of the physical activity since the last report (1 LSb/0.01 g), clipped from above at 2.5 g. If no valid measurement is available, the AF byte is set to 0xFF.

Battery Capacity	BT	RR	UA Bit	RFU Bit	CE	RFU	RFU Bit	Position	HR	RFU	AF
1 byte	1 byte	1 byte			6 bits	1 byte		7 bits	1 byte	1 byte	1 byte

Figure 3-1: The uplink payload format.

Table 3-2 shows a summary of the UL payload fields.

Table 3-2: UL Payload Fields

Field	Size	Data Format	JSON Variable (Type, Unit)
Battery Status	1 B	• $= \left[\frac{253}{99}(C-1)+1\right]$, $C =$ remaining battery capacity in % • $= 255$ if no measurement available	`remaining_battery_capacity` (unsigned, %)
BT	1 B	• $= \max([20 \times (T-30)], 0)$, $T_1 =$ Body temperature from thermistor 1 in °C • $= 255$ if no valid T available	`bt` (unsigned, °C)
RR	1 B	• $=$ RR in bpm • $= 255$ if no RR is available	`rr` (unsigned, bpm)
UA Mode Status	1 b	• 0 = UA mode inactive • 1 = UA mode active	`ua` (unsigned, no unit)
CE	6 b	• $= [5 \times \min(\mathrm{CE}, 12)]$, CE = chest expansion in % • $= 63$ if no valid CE available	`ce` (unsigned, %)
Position	7 b	• $=$ Position in ° (deg) • $= 127$ if no position available	`position` (unsigned, °)
HR	1 B	• $=$ HR in bpm • $= 255$ if no HR available	`hr` (unsigned, bpm)
AF	1 B	• $= [100 \times \min(A, 2.5)]$, $A =$ Activity intensity in *g* • $= 255$ if no A available	`af` (unsigned, *g*)

Example: Normal mode of reporting, remaining battery capacity = 92%, BT = 37.216°C, RR = 12 bpm, CE = 1%, position = 85°, HR = 72 bpm, activity intensity = 0.253 *g* is encoded as 0x EA 90 0C 05 FF 55 48 FF 19.

Decoding the UL (how the received uplink is decoded): Considering Figure 3-1, the following is how the received uplink on port 10 is decoded:

1. The remaining battery capacity in percentage is obtained as $\left[\frac{99}{253}(B-1)+1\right]$, where B is the unsigned integer value of the "Battery Status" byte, and where $[.]$ is the round to the nearest integer function. A value of $B = 255$ means no valid battery status is available.
2. The BT in °C, with two decimal digits, is obtained as $t/20 + 30$, where t is the unsigned integer value of the 8-bit BT. A value of $t = 255$ means no valid BT is available.
3. The RR in bpm is obtained as the unsigned integer value of the 8-bit RR. A value of 255 means no valid RR is available.
4. The UA Bit shows the UA mode status: 0/1 = mode inactive/active.
5. The CE in percentage is obtained as the unsigned integer value of the 6-bit CE divided by 5. A value of 63 means no valid CE is available.

6. The body position in degrees is obtained as the unsigned integer value of the 7-bit Position. A value of 127 means no valid body position is available.
7. The HR in bpm is obtained as the unsigned integer value of the 8-bit HR. A value of 255 means no valid HR is available.
8. The physical activity intensity in m*g*, with two decimal digits, is obtained as $10\times \mathrm{AF}_2$, where AF_2 is the unsigned integer value of the 8-bit AF_2. A value of $\mathrm{AF}_2 = 255$ means no AF_2 is available.

Example: Base64 tp8PI/8IN/8D or hex B6 9F 0F 97 FF 08 37 FF 03 is decoded as UA mode of reporting, remaining battery capacity = 72%, BT = 37.95°C, RR = 15 bpm, CE = 4.6%, position = 8°, HR = 55 bpm, activity intensity = 30 m*g*.

3.2 Periodic Report of Metadata

The Respiratory Sensor periodically reports some metadata to make it available to the FEA for display purposes. Currently, this metadata includes the value of register 0x71, which is the Respiratory Sensor FW version and LoRaWAN region number (see Section 4.2.2.14.2.7). As this information is the value of a Respiratory Sensor register, it is reported on ***LoRaWAN port 100***. The report format is the same as reporting the value of any other register (see Section 3.3). The frame payload has 5 bytes in the following format:

0x 71 XX XX XX YY

where "XX XX XX" is the Respiratory Sensor App SW version, and "YY" is the LoRaMAC region number, as specified in Section 4.2.7.

3.3 Response to Configuration and Control Commands

The Respiratory Sensor responses to DL configuration and control commands (which are sent on LoRaWAN port 100) are sent in the UL on ***LoRaWAN port 100***. These responses include,

- returning the value of a configuration register in response to a DL inquiry; and
- writing to a configuration register.

In the former case, the sensor responds by the address and value of each of the registers under inquiry (this can be in one or more consecutive UL packets depending on the maximum frame payload size allowed). In the latter case, the sensor responds with a CRC32 of the entire DL payload (which may be a combination of read and write commands) as the first 4 bytes of the UL frame. If the DL payload has also had read commands, the 4 CRC32 bytes are followed by the address and value of each of the registers under inquiry (like the sensor response in the former case).

4 DL Payload Formats

The DL streams (from the NS to the Respiratory Sensor) supported by the App SW are shown in Table 4-1, and are explained in Sections 4.1 and 4.2.

Table 4-1: DL Information Streams

Data Type	Sent on LoRaWAN Port
Change the Sensor Mode of Reporting	**10**
Configuration and Control Commands	**100**

4.1 Change the Sensor Mode of Reporting

There are DL commands sent to the sensor that instructs the sensor to go to the normal mode of reporting or to the UA mode of reporting. These commands are sent on ***LoRaWAN port 10***:

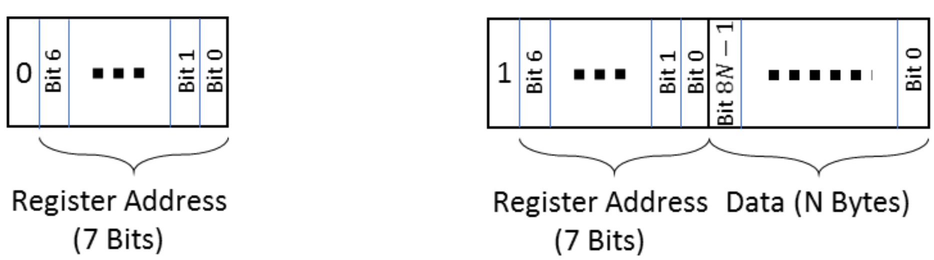
1. 0x 00 01 00: Go to the normal mode
2. 0x 00 01 FF: Go to the UA mode

4.2 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 and 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.



(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 Respiratory Sensor, the Respiratory Sensor immediately responds with a CRC32 of the entire DL payload as the first 4 bytes of the UL frame on ***LoRaWAN port 100*** (also see Section 3.3).

DL Configuration and Control Commands fall into one of the following categories and are discussed in Sections 4.2.1–4.2.7:

- LoRaMAC Configuration
- Periodic Tx Configuration
- BT Configuration
- RR and CE Configuration
- Accelerometer Configuration
- HR 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 Respiratory Sensor loads on start-up. They can also change certain run-time parameters. Table 4-2 shows the LoRaMAC configuration registers. All the registers have R/W (read/write) access. In this table, the bit indexing scheme is as shown in Figure 4-1.

Table 4-2: LoRaMAC Configuration Registers

Address	Value	Size	Description	JSON Variable (Type, Unit)	Default Value
0x10	Join Mode	2 B	• Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored	`loramac_join_mode: <value>` `(unsigned, no unit)`	0x 80 00

0x11	Options	2 B	• Bit 0:
			0/1 = Unconfirmed/Confirmed UL
			• Bit 1 = 1 (read-only):
			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_opts {`
				`confirm_mode: <value>,`
				`(unsigned, no unit)`
				
				`sync_word: <value>,`
				`(unsigned, no unit)`
				
				`duty_cycle: <value>,`
				`(unsigned, no unit)`
				
				`adr: <value>`
				`(unsigned, no unit)`
				`}`
					0x 00 0E

0x12	DR and Tx Power[1]	2 B	• Bits 8-11: Default DR number
			• Bits 0-3: Default Tx power number
			• Bits 4-7, 12-15: Ignored
				loramac_dr_tx {
				dr_number: <value>,
				(unsigned, no unit)
				
				tx_power_number: <value>
				(unsigned, no unit)
				}
					0x 00 00 (Tx Power 0 means max power, as per Table 4-3)

0x13	Rx2 Window	5 B	• Bits 8-39: Channel frequency in Hz for Rx2
			• Bits 0-7: DR for Rx2
				loramac_rx2 {
				frequency: <value>,
				(unsigned, Hz)
				
				dr_number: <value>
				(unsigned, no unit)
				}
					As per Table 4-4

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

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

RF 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 Regions

RF Region	Channel Frequency [Hz]	DR Number
EU868	869525000	0
US915	923300000	8
AS923	923200000	2
AU915	923300000	8
IN865	866550000	2
KR920	921900000	0
RU864	869100000	0

Examples:

- Enable ADR, disable Duty Cycle, make UL confirmed:
    - DL payload: 0x 91 00 0B
- Set default DR number to 3, default Tx power number to 4:

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

- DL payload: 0x 92 03 04

4.2.2 Periodic Tx Configuration

Table 4-5 shows the configuration registers for the Respiratory Sensor periodic Tx operation. This includes periodic transmissions in the normal mode, UA mode, and rest mode (Sections 2.1 and 3.1), as well as periodic transmission of metadata (Section 3.2). All registers have R/W access.

Table 4-5: Periodic Tx Configuration Registers

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value
0x20	Normal Mode Report Period	1 B	• Report period in the normal mode (1 min/LSb) • Acceptable values: > 0 • 0: Invalid and ignored	`norm_report_period: <value>` `(unsigned, min)`	0x 05
0x21	UA Mode Report Period	1 B	• Report period in the UA mode (1 min/LSb) • Acceptable values: > 0 • 0: Invalid and ignored	`ua_report_period: <value>` `(unsigned, min)`	0x 01
0x23	Metadata Report Period	2 B	• Report period of metadata (1 min/LSb) • Acceptable values: Everything • 0: Disables metadata periodic report	`meta_report_period: <value>` `(unsigned, min)`	0x 05 A0

4.2.2.1 Dependencies and Constraints

Not all Respiratory Sensor App SW configuration combinations are possible. This is to keep the sensor sanity in doing what it is supposed to do. The following constraint is applied:

1. `ua_report_period` ≤ `norm_report_period`

An attempt to change the configuration parameters in violation of the above constraints is ignored by the App SW.

4.2.3 BT (Body Temperature) Configuration

Table 4-6 shows the configuration registers for measuring BT. All the registers have R/W access.

The coefficients A0, A1, A2 shown in Table 4-6 are used in the conversion formula, from the ADC reading to the BT.

`bt_count_threshold` shows the number of consecutive temperature readings BT outside or inside the temperature limits `bt_limits.low` and `bt_limits.high` needed for a transition to the battery saving or normal mode to occur. Recall that the temperature is always measured every minute by the sensor (see Section 2.1).

A value of 0 for bt_count_threshold will disable the battery saving mode, meaning that the sensor will never transition to this mode.

The OTA reported body temperatures are actually the output of a moving average filter of length bt_ma_win_len. The filter is applied on per-minute temperature samples (as the temperature samples are always taken every minute), only for the purpose of reporting temperatures OTA; the filter is not applied on the samples used to decide transition into or out of the battery saving mode (as controlled by the parameters bt_count_threshold, bt_limits.low, and bt_limits.high explained above).

Table 4-6: BT Configuration Registers

Address	Name	Size	Format	JSON Variable (Type, Unit)	Default Value
0x34	A0 Coefficient	8 B	• Double-precision floating-point	bt_a0: <value> (unsigned, °C)	86.6
0x35	A1 Coefficient	8 B	• Double-precision floating-point	bt_a1: <value> (unsigned, °C)	-121.39
0x36	A2 Coefficient	8 B	• Double-precision floating-point	bt_a2: <value> (unsigned, °C)	32.916
0x37	Temperature Count Threshold	1 B	• 1-255: Number of consecutive temperatures to check to go into/out of battery saving mode • 0: Disables battery saving mode	bt_count_threshold (unsigned, no unit)	1

0x38	Temperature Limits	2 B	• Bits 8-15: High temperature limit (unsigned, 1°C/LSb)
			• Bits 0-7: Low temperature limit (unsigned, 1°C/LSb)
			• High limit ≤ Low limit: Invalid and ignored
				bt_limits {
				high: <value>, (unsigned, °C)
				
				low: <value> (unsigned, °C)
				}
					0x 2A 1E

0x39	Temperature Moving Average Window Length	1 B	• Temperature moving average window length in number of samples (minutes) • 0: Invalid and ignored	bt_ma_win_len: <value> (unsigned, no unit)	0x 1E

4.2.4 RR (Respiratory Rate) and CE (Chest Expansion) Configuration

The RBT is sampled at a fixed rate of 4 Hz. The samples collected over 1 min are analyzed to derive a per-min RR. The final RR is obtained by averaging over valid per-min RRs of the last rbt_window_size min. A valid per-min RR is the one that lies between rr_limits.low and rr_limits.high, inclusive.

The CE is also derived from the RBT samples by first calculating a per-minute CE from a valid per-min RR, conversion factor ce_conversion_factor, and statistical function ce_stat_function. The final CE value is calculated by averaging over valid per-min CEs over the last rbt_window_size minutes.

Table 4-7 shows the RR and CE configuration registers. These registers have R/W access.

Table 4-7: RR and CE Configuration Registers

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value
0x3B	RR Window Size	1 B	• Size of the RR window (1 sample/LSb) • Acceptable values: 1-10 • Other values: Invalid and ignored	`rr_window_size: <value>` `(unsigned, no unit)`	3

0x3C	RR Limits	2 B	• Bits 8-15: Max RR (unsigned, 1 bpm/LSb)
			• Bits 0-7: Min RR (unsigned, 1 bpm/LSb)
			• Max RR ≤ Min RR: Invalid and ignored
				`rr_limits {`
				`high: <value>,`
				`(unsigned, bpm)`
				
				`low: <value>`
				`(unsigned, bpm)`
				`}`
					0x 3C 07

0x3D	CE Conversion Factor	8 B	• Double-precision floating-point	`ce_conversion_factor:`
				`<value>`
				`(unsigned, %/V)`
					30.85

0x3E	CE Statistical Function	1 B	• 0 = Average
			• 1 = Min
			• 2 = Max
				`ce_stat_function:`
				`<value>`
				`(unsigned, no unit)`
					0

4.2.5 Accelerometer Configuration

The accelerometer transducer in the Respiratory Sensor is used to determine the position and activity intensity of the sensor user.

The accelerometer is always turned on in the Low-power mode with all the axes (X, Y, Z) enabled, except in the battery saving mode, where it is put into the power-down mode.

Table 4-8 shows the accelerometer configuration register. This register has R/W access. In this table, the bit indexing scheme is as shown in Figure 4-1.

Table 4-8: Accelerometer Configuration Register

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value

0x40	Accelerometer Sensitivity	1 B	• Bits 0-2 (Sample Rate):
			0: Invalid and ignored
			1/**2**/3/4/5/6/7 = 1/**10**/25/50/100/200/400 Hz
			• Bits 4-5 (Measurement Range):
			0/**1**/2/3 = ±2/**±4**/±8/±16 *g*
			• Bit 3/6/7: Ignored
				`accelerometer_sensitivity`
				`{`
				`sample_rate: <value>,`
				`(unsigned, Hz)`
				
				`measurement_range:`
				`<value>`
				`(unsigned, g)`
				`}`
					0x 12

4.2.5.1 Sensitivity

The Sensitivity register is used to set the sample rate and measurement range of the accelerometer.

When powered on, the accelerometer always samples the transducer element at a fixed sample rate. To capture an acceleration event, the physical event needs to last longer than the sample period. Larger sample rates have a shorter period and can therefore resolve shorter impacts. However, sampling the transducer at a larger rate increases the power usage, impacting the battery life. This is both because of the more accelerometer current draw for a larger sample rate, and because at a larger sample rate, the MCU needs to wake up more often and process more samples coming out of the accelerometer.

The measurement range or full scale shows the dynamic range of accelerations that can be monitored on any axis. When active, the accelerometer is always put into the Low-power mode, which means that the output acceleration values on any given axis (X, Y, Z), is an 8-bit signed number. This means that the measurement ranges ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* becomes corresponding to typical transducer output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively[2].

4.2.6 HR (Heart Rate) Configuration

The HR reading is obtained from the HRM (HR monitor) transducer, by averaging over valid per-min HRs (those between 50 and 200 bpm) of the last `hr_window_size` min.

Table 4-9 shows the HR configuration registers. All the registers have R/W access. In this table, the bit indexing scheme is as shown in Figure 4-1.

Table 4-9: HR Configuration Registers

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value
0x50	R to R Window Averaging	1 B	• Bits 0-3: Acceptable values: 0, 1, …, 11 Other values: Invalid and ignored • Bits 4-7: Ignored	`rtor_wndw: <value>` (unsigned, no unit)	2
0x51	R to R Gain	1 B	• Bits 0-3: Acceptable values: 0, 1, …, 15 • Bits 4-7: Ignored	`rtor_gain: <value>` (unsigned, no unit)	6
0x52	R to R Peak Averaging Weight Factor	1 B	• Bits 0-1: Acceptable values: 0, 1, 2, 3 • Bits 2-7: Ignored	`rtor_pavg: <value>` (unsigned, no unit)	1
0x53	R to R Peak Threshold Scaling Factor	1 B	• Bits 0-3: Acceptable values: 0, 1, …, 15 • Bits 4-7: Ignored	`rtor_ptsf: <value>` (unsigned, no unit)	1

[2] In the case of ±16 *g*, the measurement range is actually about ±24 *g*, with lower accuracy for values outside the ±16 *g* range.

0x54	R to R Minimum Hold Off	1 B	• Bits 0-5 Acceptable values: 0, 1, …, 63 • Bits 6-7: Ignored	`rtor_hoff: <value>` `(unsigned, no unit)`	30
0x55	R to R Interval Averaging Weight Factor	1 B	• Bits 0-1: Acceptable values: 0, 1, 2, 3 • Bits 2-7: Ignored	`rtor_ravg: <value>` `(unsigned, no unit)`	2
0x56	R to R Interval Hold Off Scaling Factor	1 B	• Bits 0-2: Acceptable values: 0, 1, …, 7 • Bits 3-7: Ignored	`rtor_rhsf: <value>` `(unsigned, no unit)`	0

0x57	HR Window Size	1 B	• Size of the HR window (1 sample/LSb)
			• Acceptable values:
			1-10
			• Other values:
			Invalid and ignored
				`hr_window_size:`
				`<value>`
				`(unsigned, no unit)`
					3

0x58	HR Step Limit	2 B	• Bits 8-15:
			Parameter *m*
			Acceptable values:
			1, …, 15
			Other values:
			Invalid and ignored
			• Bits 0-7:
			Parameter *s*
			• Acceptable values:
			0, 1, …, 255
				`hr_step_limit {`
				`m: <value>,`
				`(unsigned, no unit)`
				
				`s: <value>,`
				`(unsigned, no unit)`
				`}`
					0x 04 1E

4.2.7 Command and Control

Configuration changes are not retained after a power cycle unless they are saved in the flash. Table 4-10 shows the structure of the Command-and-Control registers. In this table, the bit indexing scheme is as shown in Figure 4-1.

Table 4-10: Command-and-Control Registers

Address	Access	Name	Size	Description	JSON Variable (Type, Unit)

0x70	W	Flash Write Command	2 B	• Bit 14:
				• 0/1 = Do not write/Write LoRaMAC Configuration
				• Bit 13:
					`write_to_flash {`
					`app_config: <value>,`
					`(unsigned, no unit)`
					
					`lora_config: <value>,`
					`(unsigned, no unit)`

				• 0/1 = Do not write/Write App SW Configuration
				• Bit 0:
				• 0/1 = Do not restart/Restart Tracker
				• Bits 1-12, 15: Ignored
					`restart_sensor: <value>`
					`(unsigned, no unit)`
					`}`

0x71	R	Metadata	4 B	• Bits 24-31: App SW version major
				• Bits 16-23: App SW version minor
				• Bits 8-15: App SW version revision
				• Bits 0-7: LoRaWAN region number (see Section 4.2.7.1)
					`metadata {`
					`app_ver_major: <value>,`
					`(unsigned, no unit)`
					
					`app_ver_minor: <value>,`
					`(unsigned, no unit)`
					
					`app_ver_revision: <value>,`
					`(unsigned, no unit)`
					
					`lorawan_region: <value>`
					`(unsigned, no unit)`
					`}`

0x72	W	Reset Configuration Registers to Factory Defaults[3]	1 B	• 0x0A = Reset App SW Configuration
				• 0xB0 = Reset LoRaMAC Configuration
				• 0xBA = Reset both App SW and LoRaMAC Configurations
				• Any other value: Invalid and ignored
					`config_factory_reset {`
					`app_config: <value>,`
					`(unsigned, no unit)`
					
					`loramac_config: <value>`
					`(unsigned, no unit)`
					`}`

Note: The Command and Control registers are always executed after the full DL configuration message has been decoded. The reset commands should always be sent as an unconfirmed DL message. Failure to do so may cause a poorly designed NS to continually reboot the Respiratory Sensor.

4.2.7.1 LoRaWAN Region

The LoRaWAN region number is the last byte of the Metadata register (Register 0x71). Current LoRaWAN regions and corresponding region numbers for the Respiratory Sensor are listed in Table 4-11.

Table 4-11: LoRaWAN Regions and Region Numbers

LoRaWAN Region	Region Number
EU868	0
US915	1
AS923	2

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

AU915	3
IN865	4
KR920	6
RU864	7

Examples:

- Write the App SW configuration to the flash
  - DL payload: 0x F0 20 00
- Write the App SW and LoRaMAC configurations to the flash
  - DL payload: 0x F0 60 00
- Reboot the sensor
  - DL payload: 0x F0 00 01
- Get the FW version and LoRaWAN region number, then reset the App SW configuration to factory defaults
  - DL payload: 0x 71 F2 0A

5 Respiratory Sensor and FEA Interface

5.1 UL Direction

This includes the following:

1. Periodic reports of the battery and health signs on ***LoRaWAN port 10***. The format of these reports and their decoding have been fully explained in Section 3.1.
2. Periodic report of metadata. This includes receiving App SW version and LoRaWAN region number information in the form of payloads 0x 71 XX XX XX YY on ***LoRaWAN port 100***, as described in Sections 3.2 and 4.2.7. For example, payload 71 01 00 00 01 in hex, or cQEAAAE= in base64, means that the sensor App SW version is 1.0.0 and the sensor LoRaWAN region number is 1 (indicating the US region).

5.2 DL Direction

The DL direction includes the configuration and control commands sent from the FEA to the sensor. As the sensor is a LoRaWAN Class A end device, these commands are only received by the sensor upon the sensor uplinking something. These configuration and control commands includes the following:

1. Control command to change the sensor mode of reporting, sent on ***LoRaWAN port 10***. The use and format of this command has been specified in Section 4.1.
2. Configuration and control commands sent on ***LoRaWAN port 100*** to,
    a. change the configuration of the sensor
    b. save the current sensor configuration to its flash
    c. simply reboot the sensor, or, reboot the sensor to its factory defaults.

References

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

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