TEKTELIC COMMUNICATIONS INC.

LoRa IoT Smart Room Sensor

Technical Reference Manual

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Revision History

Version	Date	Editor	Comments
0.1	Jun 10, 2019	Reza Nikjah	Initial draft for LoRa IoT Smart Room Sensors (Gen 3 Home Sensors).
0.2	Jun 13, 2019	Reza Nikjah	Modified based on Cesar's feedbacks. These include, • typos and oversights; • 2 bytes instead of 1 byte for analog input threshold; • moving Accelerometer Configuration section ahead of Threshold Configuration section, so the register addresses appear in a reasonable order; • change of "Sample Rate & Measurement Range" for the Accelerometer to "Sensitivity" • change of register name "Threshold" to "Threshold Control" for Light; • change of bitmapping of the Light "Threshold Control" register; • change of bitmapping of the PIR "Mode" register.
0.3	Jun 19, 2019	Reza Nikjah	• Minor edits: ○ Categorized accelerometer events into "acceleration events" and "impact alarm events" ○ Corrected description of the accelerometer events debounce time ○ Corrected possible light threshold values and number of bits devoted to the light threshold ○ Corrected Rx2 frequency for DN915 ○ Removed the default register value for configuration registers, and instead, *described* the default values
0.4	Jul 10, 2019	Reza Nikjah	• Edits based on feedbacks from DISH, mainly: ○ Clarified the grouping in Table 2-1 ○ Clarified the External Connector configuration ○ Clarified Accelerometer configuration ○ showed current draws for different accelerometer sample rates and moisture sample periods
0.5	Jul 15, 2019	Reza Nikjah	• Corrected typos • Edits based on Cesar's feedbacks, mainly: ○ Added register 0x11 Sync Word bit ○ Corrected Acceleration Event Debounce Time description ○ Explained limits on the Sample Periods
0.6	Oct 16, 2019	Reza Nikjah	• Minor edits (Table 2-1) • Clarified that moisture detection is specific to Base

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Acronyms and Glossary

ABP............................ activation by personalization
ADC .... analog-to-digital converter
ADR .... adaptive data rate
CRC............................ cyclic redundancy check
DL .... downlink
DR.............................. data rate
EIRP .... effective isotropic radiated power
Flash memory .... Non-volatile memory located on the Home Sensor, which contains application and configuration settings.
g .... gravity (unit of acceleration ≈ 9.8 m/s^2)
ID .... identity
IoT .... Internet of things
LoRa .... a patented "long-range" IoT technology acquired by Semtech
LoRAMAC.................. LoRaWAN MAC
LoRaWAN.................. LoRa wide area network (a network protocol based on LoRa)
LoRaWAN Commissioning
.... The unique device identifiers and encryption keys used for LoRaWAN communication (see LoRaWAN Specification [1] for more details).
LSB............................. least significant bit
MAC........................... medium access control
MCU .... microcontroller unit
MSB .... most significant bit
NS .... network server
OTA .... over-the-air
OTAA .... OTA activation
PIR .... passive infrared
RH .... relative humidity
RO .... read-only
Room Sensor .... a LoRa IoT Smart Room Sensor module
R/W .... read/write
Rx .... receiver
Sensor .... Room Sensor
transducer................. the sensing element attached to the Room Sensor, e.g. PIR transducer, temperature transducer.
TRM........................... technical reference manual (this document)
Tx .... transmitter
UL .... uplink
WO .... write-only

1 Overview

This TRM describes the user accessible configuration settings (pseudo registers) supported by the Lora IoT Smart Room Sensor (or Generation 3 of All-in-One LoRa IoT Home Sensors), referred to as the Room Sensor or the Sensor henceforth. This document is intended for a technical audience, such as application developers, with an understanding of the NS and its command interfaces.

The Room Sensor is a multi-purpose LoRaWAN IoT sensor packed into a very small form factor. The Room Sensor is ideal for monitoring and reporting temperature (ambient, remote through a probe, or MCU), humidity, light, shock, and open/closed doors and windows in the home environment. Additional sensing features such as leak and motion detection, as well as counting pulses from an external device are also supported with the appropriate Room Sensor model. Table 1-1 presents the current generation of the Room Sensor family. Also, Table 1-2 shows the LoRa RF region and Tx and Rx bands for the different models (variants).

Table 1-1: Room Sensor Models

Part Number and Revision			Description
Level 1	Level 2	Level 3	
T0006115 A			Room Sensor Module, NA Base
T0006116 A			Room Sensor Module, NA PIR
T0006117 A			Room Sensor Module, EU Base
T0006118 A			Room Sensor Module, EU PIR
T0006161 A			Room Sensor Module, CN Base
T0006162 A			Room Sensor Module, CN PIR
T0006163 A			Room Sensor Module, DN Base
T0006164 A			Room Sensor Module, DN PIR
	T0006003 A		Room Sensor Bottom, LoRa IoT
	T0006107 A		Room Sensor Top, LoRa IoT, Base
	T0006149 A		Room Sensor Top, LoRa IoT, PIR
	T0006132 A1		Room Sensor PCBA, NA Base
	T0006133 A1		Room Sensor PCBA, NA PIR
	T0006151 A1		Room Sensor PCBA, EU Base
	T0006152 A1		Room Sensor PCBA, EU PIR
	T0006156 A1		Room Sensor PCBA, CN Base
	T0006157 A1		Room Sensor PCBA, CN PIR
	T0006154 A1		Room Sensor PCBA, DN Base
	T0006155 A1		Room Sensor PCBA, DN PIR
		T0006131 A	Room Sensor PCB

Table 1-2: Room Sensor LoRa RF Region and Tx and Rx Bands

Variant	RF Region	Tx Band (MHz)	Rx Band (MHz)
NA	US915	902.3–914.9	923.3–927.5
EU	EU868	863–870	
CN	CN470	470.3–489.3	500.3–509.7
DN	DN	902.3–914.9	722-728

In regard to communication direction (UL or DL) and LoRaWAN ports, all information streams currently supported by the SW are as follows:

- Readings obtained from on-board transducers (***sent in UL, LoRaWAN port 10***)
- Configuration and control commands from the NS used to change the Sensor's behavior or inquire the Sensor for the values of registers (***sent in DL, LoRaWAN port 100***)
- Response to configuration and control commands from the NS (***sent in UL, LoRaWAN port 100***)

The default configuration of the Sensor for reporting transducer readings includes the following:

- Report the battery voltage every hour.
- Report the ambient temperature every hour.
- Report the ambient RH every hour.
- Report actuation (an open-to-close or close-to-open event) of the reed switch every 1 (one) actuation
- Report actuation (an open-to-close or close-to-open event) of the digital input every 1 (one) actuation
- Report motion after one PIR event (PIR model only)
- Clear motion after 5 minutes of no motions (PIR model only)

In the following sections, the UL (departing from the Sensor) and DL (destined to the Sensor) payload formats are explained. Refer to the *Smart Room Sensor Uplink and Downlink Frame Payloads* spreadsheet [2] for a thorough tool to build any UL or DL frame payload by varying parameter values, toggling read/write actions, and enabling/disabling different fields as desired.

2 UL Payload Formats

The UL streams (from the Sensor to the NS) include,

- the readings obtained from on-board transducers (***sent on LoRaWAN port 10***);
- response to configuration and control commands from the NS (***sent on LoRaWAN port 100***)

and are explained in Sections 2.1 and 2.2, respectively.

2.1 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 first) is always followed.

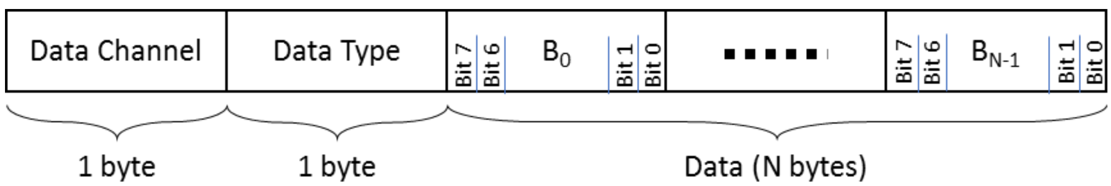

Figure 2-1: The UL frame payload format.

A Sensor message payload can include multiple transducer data frames. The ordering of frames is not guaranteed (they can be in any order). A single payload may include data from any given transducer. The Room Sensor payload frame values are shown in Table 2-1. In this table, B_i refers to data byte indexed *i* as shown in Figure 2-1. Payload frame values in Table 2-1 has been grouped by bolded boundaries. This grouping is only to indicate which payloads are related to the same physical transducer. The grouping *does not imply* that the payloads within the same group are uplinked together.

Transducer data in the UL are sent through ***LoRaWAN port 10***.

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

Type Information	Data Channel ID	Data Type ID	Bytes	Data Type	Data Format
Battery Voltage	0x00	0xFF	2	Analog	10 mV / LSB (signed)
Reed Switch State	0x01	0x00	1	Digital	0x00 = Low—magnet present 0xFF = High—magnet absent
Reed Switch Count	0x08	0x04	2	Counter	Number
Impact Alarm	0x0C	0x00	1	Digital	0x00 = Impact alarm inactive 0xFF = Impact alarm active
Acceleration Magnitude	0x05	0x02	2	Analog	1 milli-g/LSB (unsigned)

Acceleration Vector	0x07	0x71	6	Acceleration	1 milli-g/LSB (signed) B_0-B_1: X-axis acceleration B_2-B_3: Y-axis acceleration B_4-B_5: Z-axis acceleration
External Connector: Digital Input State	0x0E	0x00	1	Digital	0x00 = Low—Connector short-circuited 0xFF = High—Connector open-circuited
External Connector: Digital Input Count	0x0F	0x04	2	Counter	Number
External Connector: Analog Input[1]	0x11	0x02	2	Analog	1 mV/LSB (signed)
MCU Temperature	0x0B	0x67	2	Temperature	0.1°C / LSB (signed)
Ambient Temperature	0x03	0x67	2	Temperature	0.1°C / LSB (signed)
Ambient RH	0x04	0x68	1	RH	0.5% / LSB
Ambient Light State	0x02	0x00	1	Digital	0x00 = Dark 0xFF = Bright
Ambient Light Intensity	0x10	0x02	1	Analog	The uncalibrated digitized light intensity, a value between 0 and 64, inclusive
Motion (PIR) Event State	0x0A	0x00	1	Digital	0x00 = No motion 0xFF = Motion detected
Motion (PIR) Event Count	0x0D	0x04	2	Counter	Number
Moisture	0x09	0x00	1	Digital	0x00 = Dry 0xFF = Wet

2.1.1 Example Uplink Payloads

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

- 0x **03 67** 00 0A **04 68** 28
  - $0\text{x}\ \mathbf{03\ 67}\ (\text{Ambient Temperature}) = (0\text{x}\ 00\ 0\text{A}) \times 0.1°\text{C} = 1°\text{C}$
  - $0\text{x}\ \mathbf{04\ 68}\ (\text{Ambient RH}) = (0\text{x}\ 28) \times 0.5\% = 20\%$
- 0x **04 68** 14 **01 00** FF **08 04** 00 05
  - $0\text{x}\ \mathbf{04\ 68}\ (\text{Ambient RH}) = (0\text{x}\ 14) \times 0.5\% = 10\%$

[1] Voltage value, to be converted to temperature for a remote temperature probe using a conversion table or formula.

- $0x\ \mathbf{01\ 00}$ (Reed Switch State) $= 0x\ FF =$ Magnet absent
- $0x\ \mathbf{08\ 04}$ (Reed Switch Count) $= 0x\ 00\ 05 = 5$ switch triggers

- 0x **04 68** 2A **03 67** FF FF **00 FF** 01 2C
  - $0x\ \mathbf{04\ 68}$ (Ambient RH) $= (0x\ 2A) \times 0.5\% = 21\%$
  - $0x\ \mathbf{03\ 67}$ (Ambient Temperature) $= (0x\ FF\ FF) \times 0.1°C = -0.1°C$
  - $0x\ \mathbf{00\ FF}$ (Battery Voltage) $= (0x\ 01\ 2C) \times 0.01\ V = 3.00\ V$
- 0x **02 00** FF **07 71** 00 3A 00 07 00 53 **0E 00** 00
  - $0x\ \mathbf{02\ 00}$ (Light State) $= 0x\ FF =$ Bright
  - $0x\ \mathbf{07\ 71}$ (Acceleration Vector) $=$ [X axis: $(0x\ 02\ 44) \times 0.001g$, Y axis: $(0x\ 00\ 46) \times 0.001g$, Z axis: $(0x\ 03\ 3E) \times 0.001g$] $=$ [X axis: $0.58g$, Y axis: $0.07g$, Z axis: $0.83g$]
  - $0x\ \mathbf{0E\ 00}$ (Digital Input State) $= 0x\ 00 =$ Connector short–circuited
- 0x **0D 04** 00 02
  - $0x\ \mathbf{0D\ 04}$ (Motion Event Count) $= 0x\ 00\ 02 = 2$ motion events

2.2 Response to Configuration and Control Commands

Sensor responses to DL configuration and control commands (which are sent on ***LoRaWAN port 100***; see Section 3) are sent in the UL on ***LoRaWAN port 100***. These responses include,

- returning the value of a configuration register in response to an inquiry from the NS, 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 (similar to the Sensor response in the former case).

3 DL Payload Formats

The only DL message (from the NS to the Sensor) supported by the SW includes,

- configuration and control commands used to change the Sensor's behavior or inquire the Sensor for the values of registers (***sent on LoRaWAN port 100***);

A single DL configuration and control message can contain multiple command blocks, with a possible mix of read and write commands. Each message block is formatted as shown in Figure 3-1. A big-endian format (MSB first) is always followed.

The Command Field has a "register" address that is used to access various configuration parameters. These addresses are bound between 0x00 and 0x7F.

Bit 7 of the Command Field determines whether a read or write action is being performed. To write to a register, this bit must be set to 1 (one), but to read a register, it must be set to 0 (zero). 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.

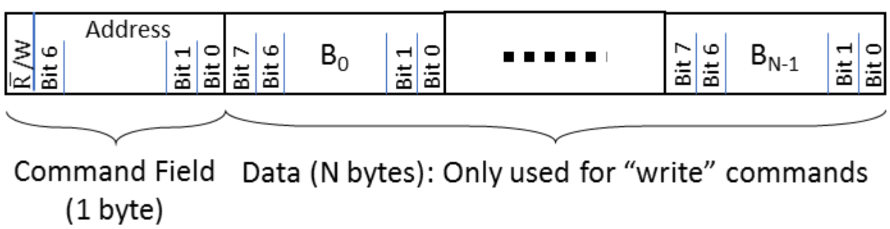

Figure 3-1: The format of a DL configuration and control message block.

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

Examples:

In the following examples, the Command Field is boldfaced:

- Read registers 0x00, 0x01, and 0x02:
  - DL command: { 0x **00 01 02** }
- Read register 0x05 and write value 0x8000 to register 0x10:
  - DL command: { 0x **05 90** 80 00 }

When a write command is sent to the Sensor, the 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 2.2).

DL configuration and control commands fall into one of the following four categories and are discussed in Sections 3.1, 3.2, 3.3, and 3.4, respectively:

- LoRaWAN Commissioning
- LoRaMAC Configuration
- Application Configuration
- Command and Control

3.1 LoRaWAN Commissioning

LoRaWAN commissioning values can be read back from the Sensor using DL commands. These registers are RO. See LoRaWAN 1.0.2 specification [1] for description of values. Table 3-1 shows a list of these registers.

Table 3-1: LoRaWAN Commissioning Registers

Address	Access	Value	Bytes
0x00	R	DevEUI	8
0x01	R	AppEUI	8
0x02	R	AppKey	16
0x03	R	DevAddr	4
0x04	R	NwkSKey	16
0x05	R	AppSKey	16

Note 1: Commissioning values need to be kept secure at all times.

Note 2: Registers 0x02, 0x04, and 0x05 cannot be read back in some regions if the DR number is too small. For example, in the NA region, the maximum payload size with DR0 is 11 bytes.

3.2 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 3-2 shows the MAC configuration registers. In this table, B_i refers to data byte indexed *i* as defined Figure 3-1.

Table 3-2: LoRaMAC Configuration Registers

Address	Access	Value	Bytes	Description
0x10	R/W	Join Mode	2	• B_0-bits 0-6, B_1: Ignored • B_0-bit 7: 0 = ABP 1 = OTAA
0x11	R/W	• Unconfirmed/Confirmed UL • Disable/Enable Duty Cycle • Disable/Enable ADR	2	• B_0: Ignored • B_1-bit 0: 0 = Unconfirmed UL 1 = Confirmed UL • B_1-bit 1 equals 1 always (RO): 0 = Sync Word disabled

				1 = Sync Word enabled • B_1-bit 2: 0 = Disable duty cycle 1 = Enable duty cycle • B_1-bit 3: 0 = Disable ADR 1 = Enable ADR • B_1-bits 1, 4-7: Ignored
0x12	R/W	• Default DR number • Default Tx Power number	2	• B_0-bits 0-3: Default DR number • B_1-bits 0-3: Default Tx power number
0x13	R/W	• Rx2 window channel frequency • Rx2 window DR number	5	• B_0-B_1-B_2-B_3: Channel frequency in Hz for Rx2 • B_4: DR for Rx2
0x19	R/W	Net ID MSBs	2	Bytes B_0-B_1 in the Net ID (B_0-B_1-B_2-B_3)
0x1A	R/W	Net ID LSBs	2	Bytes B_2-B_3 in the Net ID (B_0-B_1-B_2-B_3)

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. Modifying configuration parameters in the NS is outside the scope of this document.

Examples:

In the following example payloads, the Command Field is boldfaced:

- 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 09 }
- Set default DR number to 1 and default Tx power number to 2:
  - DL payload: { 0x **92** 01 02 }

3.2.1 Default Configuration

Table 3-3 and Table 3-5 show the default values for the LoRaMAC configuration registers (cf. [1], [3]).

Table 3-3: Default Values of LoRaMAC Configuration Registers

Address	Default Value
0x10	OTAA mode
0x11	• Unconfirmed UL • Enabled duty cycle[2]

[2] In the LoRa RF regions where there is no duty cycle limitation, such as US915 and DN915, the “enabled duty cycle” configuration of the Sensor is ignored.

	• Enabled ADR
0x12	• DR0 • Tx Power 0—max power, see Table 3-4
0x13	As per Table 3-5
0x19	0
0x1A	0

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

RF Region	Max Tx EIRP [dBm]
EU868	16
US915	30
AS923	16
AU915	30
IN865	30
CN470	19.15
KR920	14
RU864	16
DN915	30

Table 3-5: 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
CN470	505300000	0
KR920	921900000	0
RU864	869100000	0
DN915	725900000	8

3.3 Application Configuration

This section lists all possible application configurations (as part of DL configuration and control commands), including periodic Tx configuration and configurations of the different transducers.

3.3.1 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 3-6.

Note: Certain transducer types, such as accelerometer and light, need to be enabled for periodic reporting. Details are available in each transducer's respective section.

Table 3-6: Periodic Transmission Configuration Registers

Address	Access	Value	Bytes	Description
0x20	R/W	Seconds per Core *Tick*	4	Sets the core *tick* for periodic events. A value of 0 disables all periodic transmissions.
0x21	R/W	*Ticks* per Battery	2	*Ticks* between battery voltage reports. A value of 0 disables periodic battery voltage reports.
0x22	R/W	*Ticks* per Ambient Temperature	2	*Ticks* between ambient temperature reports. A value of 0 disables periodic ambient temperature reports.
0x23	R/W	*Ticks* per Ambient RH	2	*Ticks* between ambient RH reports. A value of 0 disables periodic ambient RH reports.
0x24	R/W	*Ticks* per Reed Switch	2	*Ticks* between reed switch reports. A value of 0 disables periodic reed switch reports.
0x25	R/W	*Ticks* per Ambient Light	2	*Ticks* between ambient light reports. A value of 0 disables periodic ambient light reports.
0x26	R/W	*Ticks* per Accelerometer (both Acceleration and Impact Alarm)	2	*Ticks* between accelerometer reports. A value of 0 disables periodic accelerometer reports.
0x27	R/W	*Ticks* per MCU Temperature	2	*Ticks* between MCU temperature reports. A value of 0 disables periodic MCU temperature reports.
0x28	R/W	*Ticks* per Motion (PIR)/ *Ticks* per Moisture	2	*Ticks* between motion (PIR)/moisture reports. A value of 0 disables periodic motion (PIR)/moisture reports.
0x29	R/W	*Ticks* per External Connector (Digital/Analog Input)	2	*Ticks* between external connector (digital/analog input) reports. A value of 0 disables periodic digital/analog input reports.

3.3.1.1 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 60 seconds, and the maximum is 86,400 seconds (one day). Values from 1 second to 59 seconds and values above 86,400 seconds are invalid and ignored. A value of 0 (zero) disables all periodic reporting.

3.3.1.2 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.

3.3.1.3 Default Configuration

Table 3-7 shows the default values for the periodic transmission configuration registers.

Table 3-7: Default Values of Periodic Transmission Configuration Registers

Seconds per Core *tick*	3600 (1 hour)
***Ticks* per Battery**	1 (thus 1-hour period)
***Ticks* per Ambient Temperature**	1 (thus 1-hour period)
***Ticks* per Ambient RH**	1 (thus 1-hour period)
***Ticks* per Reed Switch**	0 (periodic Tx disabled)
***Ticks* per Ambient Light**	0 (periodic Tx disabled)
***Ticks* per Accelerometer**	0 (periodic Tx disabled)
***Ticks* per MCU Temperature**	0 (periodic Tx disabled)
***Ticks* per PIR/Moisture**	0 (periodic Tx disabled)
***Ticks* per Digital/Analog Input**	0 (periodic Tx disabled)

3.3.1.4 Example DL Messages

In the following example payloads, the Command Field is boldfaced:

- 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)

3.3.1.5 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 week, 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).

3.3.2 Reed Switch Configuration

Table 3-8 shows a list of Reed Switch configuration registers.

Table 3-8: Reed Switch Configuration Registers

Address	Access	Value	Bytes	Description
0x2A	R/W	Mode	1	• Bit 0: 0 = Rising edge disable 1 = Rising edge enabled • Bit 1: 0 = Falling edge disabled 1 = Falling edge enabled • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-7: Ignored
0x2B	R/W	Count Threshold	2	Number of triggers for event transmission. A value of 0 disables event transmission.
0x2C	R/W	Value to Tx	1	• Bit 0: 0 = Input state not reported 1 = Input state reported • Bit 1: 0 = Counter value not reported 1 = Counter value reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-7: Ignored

3.3.2.1 Mode

The Reed Switch is edge-triggered and can be set to trigger to rising-edge trigger (Low or Closed to High or Open), falling-edge triggered (High or Open to Closed or Low) or both. An attempt to set the Mode to 0x00 (i.e. to disable both rising and falling edges) is ignored by the Sensor.

Application Example:

Door Open/Close detection would use both rising and falling triggers to detect when the door was opened and when it was closed.

3.3.2.2 Count Threshold

The Count Threshold determines when the Sensor transmits after seeing an event on the Reed Switch. A value of 0 (zero) disables the event driven transmission, while a value of 1 (one) or greater triggers an event-based transmission after the configured number of events has occurred, which is when the event "counter" reaches the value of the Count Threshold. Whenever such event-based transmission occurs, the event counter is automatically reset to 0 and starts incrementing as events occur until the counter reaches the threshold again and another event-based transmission occurs.

Application Examples:

If a sensor is intended to monitor room utilization, it may be configured either to disable event-based transmission in favor of getting hourly reports from the sensor, or to only transmit after 50 "events" logged in the room. The latter may be useful for alerting cleaning staff that room requires attention.

3.3.2.3 Value to Tx

The Value to Tx determines what information is transmitted whenever an event or periodic digital transmission is required. If the value is "Counter Value", the transmission contains the number of times the Reed Switch was triggered since the last transmission, while the value of "Input State" causes a transmission of the current input state of the switch (i.e. Open or Closed).

3.3.2.4 Default Configuration

Table 3-9 shows the default values for the Reed Switch configuration registers.

Table 3-9: Default Values of Reed Switch Configuration Registers

Mode	Rising and falling edges enabled
Threshold	1 (one)
Value to Tx	State and count reported

3.3.2.5 Example DL Messages

In the following example payloads, the Command Field is boldfaced:

- Have Reed Switch be triggered only on rising edges:
  - DL payload: { 0x **AA** 01 }
    - Register 0x2A with write bit set to true
    - "Rising Edge" enabled, "Falling Edge" disabled
- Read current value of Count Threshold:
  - DL payload: { 0x **2B** }
    - Register 0x2B with write bit set to false
- Transmit the Reed Switch "state" as soon as the Reed Switch is tripped 10 times:
  - DL payload: { 0x **AB** 00 0A **AC** 01 }
    - Registers 0x2B and 0x2C with their write bits set to true
    - Count Threshold set to 10
    - Value to Tx set to "Input State"
- Disable the Reed Switch event-driven transmission, but report the number of times the Reed Switch has been triggered whenever a report is inquired (i.e. in the case of periodic reporting):
  - DL payload: { 0x **AB** 00 00 **AC** 02 }
    - Count Threshold set to 0 (zero)
    - Value to Tx set to "Counter Value"

3.3.3 External Connector Configuration

Only the Base variant of the Room Sensor is equipped with an external connector. This connector can be configured as either a digital input (having only two values or states of "open" and "closed"), or analog input. The input mode (digital or analog) is determined by bit 7 of register 0x2D (see Table 3-10). The input mode is digital by default.

In the digital input mode, the external connector has only two values or states: open (open-circuited) with a value of 0xFF, and closed (short-circuited) with a value of 0x00. For example, in this mode of operation, the external connector can be used for leak detection. This mode of operation supports periodic (Section 3.3.1) and event-based (edge triggered) reporting (see the following subsections).

In the analog input mode, one pin is grounded, and the other pin is pulled up to VMCU (1.8 V) by a 68.1-*k*Ω resistor. The analog input has values in units of mV from 0 to VMCU (the resolution is 1 mV[3]), and is suitable for connection to a thermistor (recommended 10-*k*Ω) as a

[3] The actual ADC output has a resolution of 0.61 mV.

remote temperature probe. The actual temperature can be obtained from the value of the analog input and a provided conversion table or formula. This mode of operation supports periodic (Section 3.3.1) and threshold-based reporting (Section 3.3.5).

Table 3-10 shows a list of External Connector configuration registers.

Table 3-10: External Connector Configuration Registers

Address	Access	Value	Bytes	Description
0x2D	R/W	Mode	1	• Bit 0: 0 = Rising edge disable 1 = Rising edge enabled • Bit 1: 0 = Falling edge disabled 1 = Falling edge enabled • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-6: Ignored. • Bit 7: 0 = Digital Input mode 1 = Analog Input mode
0x2E	R/W	Count Threshold	2	Number of triggers for event transmission. A value of 0 disables event transmission.
0x2F	R/W	Value to Tx	1	• Bit 0: 0 = Digital Input state not reported 1 = Digital Input state reported • Bit 1: 0 = Digital Input count not reported 1 = Digital Input count reported • Both bits 0 and 1 set to 0: Invalid and ignored Bits 2-7: Ignored

3.3.3.1 Mode

In the Digital Input mode (bit 7 = 0), the input is edge-triggered and can be set to be triggered by the rising edge (Low or Closed to High or Open), falling edge (High or Open to Closed or Low), or both. An attempt to set the Mode to 0x00 (i.e. to disable both rising and falling edges) is ignored by the Sensor.

In the Analog Input mode (bit 7 = 1), bits 0-6 of register 0x2D, and the entire registers 0x2E and 0x2F are irrelevant and ignored. The configuration registers in the Analog Input mode only include 0x29 (see Section 3.3.1), 0x44, 0x45, 0x46, and 0x4A (see Section 3.3.4).

Application Examples for Digital Input Mode:

- Door Open/Close detection would use both rising and falling triggers to detect when the door was opened and when it was closed.
- Pulse counting from a water meter would use a single edge trigger, depending on the resting state of the connected device (positive pulse would use rising edge, negative pulse would use falling edge).

3.3.3.2 Count Threshold

The Count Threshold is only applicable in the Digital Input mode, and determines when the Sensor transmits after seeing an event on Digital Input. A value of 0 (zero) disables the event driven transmission, while a value of 1 (one) or greater triggers an event-based transmission after the configured number of events has occurred, which is when the event "counter" reaches the value of the Count Threshold. Whenever such event-based transmission occurs, the event counter is automatically reset to 0 and starts incrementing as events occur until the counter reaches the threshold again and another event-based transmission occurs.

Application Examples:

If a sensor is intended to pulse count from a high-volume water meter, it may be configured to disable event-based transmission in favor of getting hourly reports from the sensor.

- If a sensor is intended to monitor room utilization it may be configured to only transmit after 100 "events" logged in the room. This may be useful for alerting cleaning staff that room requires attention.

3.3.3.3 Value to Tx

The Value to Tx is only applicable in the Digital Input mode, and determines what information is transmitted whenever a Digital Input event or periodic transmission is required. If the value is Digital Input state, the transmission contains the current Digital Input state of the switch (i.e. 0xFF for open or 0x00 for closed). If the value is the Digital Input count, the transmission contains the number of times that the Digital Input was triggered since the last transmission.

3.3.3.4 Default Configuration

Table 3-11 shows the default values for the External Connector configuration registers.

Table 3-11: Default Values of External Connector Configuration Registers

Mode	Digital Input mode with rising and falling edges enabled
Threshold	1 (one)
Value to Tx	State and count reported for Digital Input

3.3.3.5 Example DL Messages

In the following example payloads, the Command Field is boldfaced:

- Have Digital Input be triggered only on falling edges:
  - DL payload: { 0x **AD** 02 }
    - Register 0x2D with write bit set to true
    - “Rising Edge” disabled, “Falling Edge” enabled
- Read current value of Count Threshold:
  - DL payload: { 0x **2E** }
    - Register 0x2E with write bit set to false
- Transmit the Digital Input state as soon as the Digital Input is tripped 20 times:
  - DL payload: { 0x **AE** 00 14 **AF** 01 }
    - Registers 0x2E and 0x2F with their write bits set to true
    - Count Threshold set to 20
    - Value to Tx set to “Input State”
- Disable the Digital Input event-driven transmission, but report the number of times the Digital Input has been triggered whenever a report is inquired (i.e. in the case of periodic reporting):
  - DL payload: { 0x **AE** 00 00 **AF** 02 }
    - Count Threshold set to 0 (zero)
    - Value to Tx set to “Digital Input count”

3.3.4 Accelerometer Configuration

The accelerometer transducer offers a threshold for an “impact alarm event”[4], and a threshold for an “acceleration event”. It can also be polled periodically for applications where the Sensor orientation may be of interest. Table 3-12 shows a list of accelerometer configuration registers.

Some terminology in this section is as follows:

- Accelerometer (transducer) refers to the accelerometer transducer component.
- Impact alarm (event) refers to an accelerometer event based on exceeding an impact alarm event threshold. Impact alarm events are reported with an impact alarm.
- Acceleration (event) refers to an accelerometer event, independent of the impact alarm event, and based on exceeding an acceleration event threshold. Acceleration events are reported with the acceleration magnitude, acceleration vector, or both.

Table 3-12: Accelerometer Configuration Registers

Address	Access	Value	Bytes	Description
0x30	R/W	Impact Alarm Event Threshold	2	Unsigned, 1 milli-g/LSB

[4] Here “impact” generally refers to a Sensor motion event (i.e. not necessarily an *impact* to the Sensor).

0x31	R/W	Acceleration Event Threshold	2	Unsigned, 1 milli-g/LSB
0x32	R/W	Value to Tx	1	• Bit 0 (applicable to accelerometer periodic reporting only[5]): 0 = Impact alarm not reported 1 = Impact alarm reported • Bit 4 (applicable to both accelerometer periodic reporting and acceleration event reporting): 0 = Acceleration magnitude not reported 1 = Acceleration magnitude reported • Bit 5 (applicable to both accelerometer periodic reporting and acceleration event reporting): 0 = Acceleration vector not reported 1 = Acceleration vector reported • Bits 1-3, 6, 7: Ignored
0x33	R/W	Acceleration Event Debounce Time	2	Seconds to wait before possibly reporting an acceleration event again
0x34	R/W	Mode	1	• Bit 0: 0 = Impact alarm event threshold disabled 1 = Impact alarm event threshold enabled • Bit 1: 0 = Acceleration event threshold disabled 1 = Acceleration event threshold enabled • Bits 2, 3: Ignored • Bit 4: 0 = X-axis disabled 1 = X-axis enabled • Bit 5: 0 = Y-axis disabled 1 = Y-axis enabled • Bit 6: 0 = Z-axis disabled 1 = Z-axis enabled • Bit 7:

[5] This bit only controls whether the impact alarm status (i.e. raised or cleared) will be present in periodic reporting when such accelerometer periodic reporting is enabled (see Section 3.3.1). This bit does not control reporting of the impact alarm status for impact alarm events. If the impact alarm event threshold is enabled (register 0x34, bit 0), an impact alarm is always raised (reported) when the impact alarm event threshold (register 0x30) is exceeded, and is cleared after an impact alarm event grace period (register 0x36) elapses without any impact alarm events (see Section 3.3.4.7).

				0 = Accelerometer power off 1 = Accelerometer power on
0x35	R/W	Sensitivity	1	• Bits 0-2 (Sample Rate): 0: Invalid and ignored 1 = 1 Hz 2 = 10 Hz 3 = 25 Hz 4 = 50 Hz 5 = 100 Hz 6 = 200 Hz 7 = 400 Hz • Bits 4-5 (Measurement Range[6]): 0 = ±2 *g* 1 = ±4 *g* 2 = ±8 *g* 3 = ±16 *g* • Bits 3, 6, 7: Ignored
0x36	R/W	Impact Alarm Event Grace Period	2	Impact alarm grace period in seconds (time to pass after the last impact alarm before the alarm can be cleared)
0x37	R/W	Impact Alarm Event Threshold Count	2	Number of impact alarm events before an impact alarm is raised
0x38	R/W	Impact Alarm Event Threshold Period	2	Period in seconds over which impact alarm events are counted for threshold detection

3.3.4.1 Impact Alarm Event Threshold

This parameter is the g-threshold for an impact alarm event. Impact alarm events are reported only if,

- the impact alarm event threshold (bit 0 of register 0x34) is enabled; and
- the impact alarm event threshold is exceeded on at least one of the enabled axes (X, Y, Z) within a period (Impact Alarm Event Threshold Period—register 0x38) for more than a number of times (Impact Alarm Event Threshold Count—register 0x37).

[6] Measurement ranges ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical transducer output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively. Note that if a threshold configured in register 0x30 or register 0x31 is equal to or greater than the configured measurement full scale (2 *g*, 4 *g*, 8 *g*, 16 *g*), then the corresponding event (impact alarm or acceleration event) will never be triggered.

3.3.4.2 Acceleration Event Threshold

This parameter is the g-threshold for an acceleration event. Provided that the acceleration threshold is enabled (bit 1 of register 0x34), acceleration events are reported as soon as the Acceleration Event Threshold is exceeded on at least one of the enabled axes (X, Y, Z). However, acceleration event interrupts are totally ignored (not registered) for a time period equal to the Acceleration Event Debounce Time (register 0x33) after a registered (and thus reported) acceleration event.

3.3.4.3 Value to Tx

Determines what is reported (transmitted) in the case of an acceleration event or accelerometer periodic transmission. The parameters to report include the status of the impact alarm (alarm on/off), the acceleration magnitude $\|\langle x, y, z\rangle\| = \sqrt{x^2 + y^2 + z^2}$, and the acceleration vector $\langle x, y, z\rangle$.

3.3.4.4 Acceleration Event Debounce Time

Interrupts due to acceleration events are disabled for a configurable time frame, called the Acceleration Event Debounce Time, after an acceleration event is registered. This is done to prevent a single acceleration event from being transmitted as multiple events. The minimum debounce time is 1 (one) second. Value 0 is invalid and ignored.

3.3.4.5 Mode

When not being used in an end-user application, the accelerometer transducer can be put in the power-down mode to save battery life. Otherwise, the accelerometer is put in the low-power mode, which is an active and operational, but a low consumption, mode for the accelerometer.

Additionally, impact alarm and acceleration event thresholds can be enabled/disabled. Disabling a threshold prevents the Sensor from generating the corresponding event. It is also possible to enable/disable X, Y, Z axes independently. When an axis is disabled, it is not considered in monitoring impact alarm or acceleration events.

3.3.4.6 Sensitivity

When powered on, the accelerometer always samples the transducer element at a fixed rate, called the Sample Rate. To capture an impact alarm or 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. Table 3-13 shows how much continuous current draw is expectable to be drawn from a 3.2-V battery for the different sample rates when the accelerometer is powered on. For example, the sample rate of 1 Hz would translate to about 15 mAh/year battery usage, while a sample rate of 50 Hz would triple that usage.

Table 3-13: Typical Current Draws at 3.2 V for Different Accelerometer Sample Rates

Sample Rate [Hz]	1	10	25	50	100	200	400
Current Draw [μA]	1.6	2.3	3.1	4.7	7.8	14.1	28.1

Furthermore, the Sensitivity register sets the measurement range or full scale, which shows the dynamic range of accelerations that can be monitored on any enabled axis. Note that when active, the accelerometer is always put in its low power mode, which means the output acceleration values on any given axis (X, Y, or Z), is an 8-bit signed number. Therefore, a measurement range of ±2 *g* implies a precision of 4/256 *g*/LSB.

3.3.4.7 Impact Alarm Event Grace Period

The Grace Period determines how long the Room Sensor waits before the previously reported impact alarm event is considered clear. For example, a Grace Period of 5 (five) minutes results in the sensor transmitting “Impact Detected” when there is movement, and “Impact Alarm Cleared” 5 (five) minutes after the Sensor has been still.

The minimum acceptable value for this register is 15. Values smaller than 15 are invalid and ignored.

3.3.4.8 Impact Alarm Event Threshold Count

The accelerometer generates an impact alarm event each time it detects movement. Depending on the customer use case, it may be desirable to increase the threshold count to reduce sensitivity. This feature is to allow customers to filter out short impact events, while still allowing longer impact events to be reported.

The minimum acceptable value for this register is 1. Value 0 is invalid and ignored.

3.3.4.9 Impact Alarm Event Threshold Period

The Impact Alarm Event Threshold Period is the amount of time that impact alarm events are accumulated for threshold detection. For example, an Impact Alarm Event Threshold Period of 10 (ten) seconds accumulates impact alarm events over a 10 (ten)-second period from the time of first detection. If the Impact Alarm Event Threshold Count is reached before the time expires, the sensor reports “Impact Detected”, otherwise it does not report.

The minimum acceptable value for this register is 5. Values smaller than 5 are invalid and ignored.

3.3.4.10 Default Configuration

Table 3-14 shows the default values for the accelerometer configuration registers.

Table 3-14: Default Values of Accelerometer Configuration Registers

Impact Alarm Event Threshold	1500 milli-*g*
Acceleration Event Threshold	3000 milli-*g*
Value to Tx	Acceleration vector
Acceleration Event Debounce Time	2 seconds
Mode	• Impact alarm threshold disabled • Acceleration threshold disabled • X-axis, Y-axis, and Z-axis enabled • Accelerometer power off
Sensitivity	• Sample rate 1 Hz • Measurement range ±8 *g*
Impact Alarm Event Grace Period	300 seconds (5 minutes)
Impact Alarm Event Threshold Count	1
Impact Alarm Event Threshold Period	15 seconds

3.3.5 Temperature/RH/Analog Input Threshold Configuration

The Room Sensor supports threshold transmission on four different transducer values:

- Ambient temperature: Measured by the Temperature/RH transducer
- Ambient RH: Measured by the Temperature/RH transducer
- MCU Temperature: Measured by the MCU (with lower accuracy compared to the Ambient Temperature)
- Analog Input Voltage: When the External Connector is in the Analog Input mode.

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 3-15 shows a list of configuration registers for the temperature/RH/Analog Input threshold setting. In this table, B_i refers to data byte indexed *i* as defined Figure 3-1.

Table 3-15: Temperature/RH/Analog Input Threshold Configuration Registers

Address	Access	Value	Bytes	Description

[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.

0x39	R/W	Ambient Temperature/RH Sample Period: Idle	4	Sample period of Ambient Temperature/RH transducer: Idle state (seconds)
0x3A	R/W	Ambient Temperature/RH Sample Period: Active	4	Sample period of Ambient Temperature/RH transducer: Active state (seconds)
0x3B	R/W	Low/High Ambient Temperature Thresholds	2	• B_0: High temperature threshold (signed, 1°C / LSB) • B_1: Low temperature threshold (signed, 1°C / LSB)
0x3C	R/W	Ambient Temperature Thresholds Enabled	1	• Bit 0: 0 = Disabled 1 = Enabled • Bits 1-7: Ignored
0x3D	R/W	Low/High Ambient RH Thresholds	2	• B_0: High RH threshold (unsigned, 1% RH / LSB) • B_1: Low RH threshold (unsigned, 1% RH / LSB)
0x3E	R/W	Ambient RH Thresholds Enabled	1	• Bit 0: 0 = Disabled 1 = Enabled • Bits 1-7: Ignored
0x40	R/W	MCU Temperature Sample Period: Idle	4	Sample period of MCU temperature transducer: Idle state (seconds)
0x41	R/W	MCU Temperature Sample Period: Active	4	Sample period of MCU temperature transducer: Active state (seconds)
0x42	R/W	Low/High MCU Temperature Thresholds	2	• B_0: High MCU temperature threshold (signed, 1°C / LSB) • B_1: Low MCU temperature threshold (signed, 1°C / LSB)
0x43	R/W	MCU Temperature Thresholds Enabled	1	• Bit 0: 0 = Disabled 1 = Enabled • Bits 1-7: Ignored
0x44	R/W	Analog Input Sample Period: Idle	4	Sample period of analog input: Idle state (seconds)
0x45	R/W	Analog Input Sample Period: Active	4	Sample period of analog input: Active state (seconds)
0x46	R/W	Low/High Analog Input Thresholds	4	• B_0-B_1: High analog input threshold (unsigned, 1 mV/LSB) • B_2-B_3: Low analog input threshold (unsigned, 1 mV/LSB)

0x4A	R/W	Analog Input Thresholds Enabled	1	• Bit 0: 0 = Disabled 1 = Enabled • Bits 1-7: Ignored

3.3.5.1 Temperature/RH/Analog Input 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 30 seconds, and the maximum is 86,400 seconds (one day). Values smaller than 30 for this register are invalid and ignored.

3.3.5.2 Temperature/RH/Analog Input 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 30 seconds, and the maximum is 86,400 seconds (one day). Values smaller than 30 for this register are invalid and ignored.

3.3.5.3 Temperature/RH/Analog Input 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 or MCU 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. The Analog Input thresholds are also unsigned numbers, and have a precision of 1 mV per bit.

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

3.3.5.4 Temperature/RH/Analog Input 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.

3.3.5.5 Default Configuration

Table 3-16 shows the default values for the threshold configuration registers.

Table 3-16: Default Values of Threshold Configuration Registers

Ambient Temperature/RH Sample Period: Idle	60 seconds
Ambient Temperature/RH Sample Period: Active	30 seconds

Ambient Temperature Threshold: High	30°C
Ambient Temperature Threshold: Low	15°C
Ambient Temperature Thresholds Enabled	Disabled
Ambient RH Threshold: High	80%
Ambient RH Threshold: Low	15%
Ambient RH Thresholds Enabled	Disabled
MCU Temperature Sample Period: Idle	300 seconds
MCU Temperature Sample Period: Active	60 seconds
MCU Temperature Threshold: High	30°C
MCU Temperature Threshold: Low	15°C
MCU Temperature Thresholds Enabled	Disabled
Analog Input Sample Period: Idle	60 seconds
Analog Input Sample Period: Active	30 seconds
Analog Input Threshold: High	1200 mV
Analog Input Threshold: Low	600 mV
Analog Input Thresholds Enabled	Disabled

3.3.5.6 Example DL Messages

In the following example payloads, the Command Field is boldfaced:

- Set Ambient 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 Ambient Temperature/RH Sample Periods:
  - DL payload: { 0x **39 3A** }
    - Registers 0x39 and 0x3A with their write bits set to false
- Set and enable Ambient 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

3.3.6 Light Sensing Configuration

The Room Sensor light sensing allows for the detection of the presence or absent of light based on the built-in light sensing transducer. The sensing element light pipe is visible on the top surface of the Room Sensor. The orientation of the Room Sensor relative to the light source impacts the measured level of light intensity. The Room Sensor light sensing capability supports both periodic and threshold-based transmissions. Table 3-17 shows a list of light transducer configuration registers.

Table 3-17: Light Transducer Configuration Registers

Address	Access	Value	Bytes	Description
0x47	R/W	Sample Period	4	Sample period of the light transducer (seconds)
0x48	R/W	Threshold Control	1	• Bits 0-5: 0: Invalid and ignored 1-63: Threshold level (1: darkest, 63: brightest) • Bit 6: Ignored • Bit 7: 0 = Threshold-based reporting disabled 1 = Threshold-based reporting enabled
0x49	R/W	Value to Tx	1	• Bit 0: 0 = State (dark or bright) not reported 1 = State reported • Bit 1: 0 = Intensity (a value between 0 and 64, inclusive) not reported 1 = Intensity reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-7: Ignored

3.3.6.1 Sample Period

The light transducer is held turned 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. Shorter sample periods result in an improved detection time but result in additional battery usage.

Acceptable values for the sample period are 0, 30–86,400 seconds. Setting the sample period to 0 (zero) disables the light sensing element. Values 1 to 29 seconds or values greater than 86,400 seconds are invalid and ignored.

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.

3.3.6.2 Threshold Control

Bits 0-5 of the Threshold Control register is used to set the dark/bright transition point for the Sensor, and can be set to any value from 1 to 63. 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 (one) corresponds to the darkest threshold, and 63 to the brightest threshold. When first enabled, the Sensor begins in the "dark" state.

Bit 7 of the Threshold is used to enable or disable the threshold-based reporting. If the 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). If the threshold-based reporting is disabled, the threshold defined in bits 0-5 is only used to determine the "state" (dark or bright) in possible periodic transmissions.

3.3.6.3 Value to Tx

The Value to Tx determines the value that is reported in periodic or threshold-based transmissions. The light state is either dark or bright (based on a comparison of the light intensity value with the light threshold). The light intensity is a value between 0 and 64, inclusive.

3.3.6.4 Default Configuration

Table 3-18 shows the default values for the light transducer configuration registers.

Table 3-18: Default Values of Light Transducer Configuration Registers

Sample Period	Light transducer disabled
Threshold Control	• Threshold-based reporting enabled • Light threshold = 32; i.e. mid-range threshold
Value to Tx	Light state reported only

3.3.7 Motion Transducer Configuration

The motion transducer (detector) is *on PIR Room Sensor models only* and uses a PIR array sensor for the detection of human motion in a room. Due to the sensitive electronics used in the PIR motion detector, the Room Sensor is designed to behave as follows:

- For 2 (two) minutes after power is first applied to the device, the PIR motion detector is disabled. This is required for the PIR transducer output to stabilize and avoids false detections.
- For approximately 5 (five) seconds after a radio transmission or after sampling the temperature/RH transducer, the PIR motion detector is disabled. The operation of the

radio or the temperature/RH transducer causes the PIR transducer to produce false positives so a "cool down" period is required after each Tx.

The Room Sensor runs a simple state machine for reporting whether or not motion is detected. To conserve battery usage, the Room Sensor only reports motion 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 3.3.7.1) expires.

Table 3-19 shows a list of motion transducer configuration registers.

Table 3-19: Motion Transducer Configuration Registers

Address	Access	Value	Bytes	Description
0x50	R/W	Grace Period	2	Grace period in seconds (time before motion is no longer detected)
0x51	R/W	Threshold Count	2	Number of PIR events before motion is detected
0x52	R/W	Threshold Period	2	Period over which PIR events are counted for threshold detection
0x53	R/W	Mode	1	• Bit 0 (only applies to periodic Tx): 0 = No motion count reported 1 = Motion count reported • Bit 1 (only applies to periodic Tx): 0 = No motion state reported 1 = Motion state reported • Both bits 0 and 1 set to 0: Invalid and ignored • Bits 2-5: Ignored • Bit 6: 0 = PIR event-based transmission disabled 1 = PIR event-based transmission enabled • Bit 7: 0 = PIR transducer disabled 1 = PIR transducer enabled

3.3.7.1 Grace Period

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

3.3.7.2 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.

3.3.7.3 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) seconds accumulates motion detection events over a 10 (ten)-second 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.

3.3.7.4 Mode

The Mode register allows the customer to disable/enable the motion transducer, as well as change the type of data that is transmitted by the Room 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 the event-based reporting is enabled. Bit 0 (motion count) and bit 1 (motion state) bits determine what values are transmitted when periodic reporting is enabled.

3.3.7.5 Default Configuration

Table 3-20 shows the default values for the motion transducer configuration registers.

Table 3-20: Default Values of Motion Transducer Configuration Registers

Grace Period	300 seconds (5 minutes)
Threshold	1
Threshold Period	15 seconds
Mode	• PIR transducer enabled • Event-based transmission enabled • Motion count reported only, in the case of a periodic transmission

3.3.8 Moisture Configuration

The Base Room Sensor is equipped with a capacitance-based moisture detection system. *The moisture detection is not supported in the PIR Room Sensor.* This allows the Room Sensor to detect the pooling of water (water line leak, spills, etc.) and report moisture detection events. The moisture transducer (detector) is integrated into the Room Sensor enclosure base (screw side) and can sense moisture without making physical contact with the liquid. This transducer does not measure humidity in air. Table 3-21 shows a list of moisture transducer configuration registers.

Table 3-21: Moisture Transducer Configuration Registers

Address	Access	Value	Bytes	Description
0x5A	R/W	Sample Period	1	• Period of moisture measurement • Bits 0-2: 1 = 16 seconds 2 = 32 seconds 3 = 64 seconds 4 = 128 seconds 0, 5-7: Invalid and ignored • Bits 3-7: Ignored
0x5B	R/W	Threshold	1	Moisture detection threshold: • 0, 1, …, 49: Invalid and ignored
0x5C	R/W	Enable/Disable	1	• Bit 0: 0 = Moisture sensing disabled 1 = Moisture sensing enabled • Bits 1-7: Ignored
0x5D	WO	Calibrate Baseline	1	• Command to calibrate the transducer as “dry”: 0 = Do nothing 1-255 = Recalibrate the “dry” baseline

3.3.8.1 Sample Period

The moisture transducer is activated periodically to determine if water is present. A smaller sample period results in a faster response from the Sensor in the event of a leak, however it results in higher battery usage than a larger sample period.

Table 3-22 shows how much continuous current draw is expectable to be drawn from a 3.2-V battery for the different moisture sample periods when the moisture sensing is enabled. For example, the sample period of 16 seconds would translate to about 60 mAh/year battery usage, twice as much usage compared to a sample period of 128 seconds.

Table 3-22: Typical Current Draws at 3.2 V for Different Moisture Sample Periods

Sample Period [sec]	16	32	64	128
Current Draw [μA]	7	5	4	3.5

Note: For the updates to the Sample Period to take effect, the moisture transducer requires to be de-initialized and then initialized.

3.3.8.2 Threshold

The Threshold of the moisture transducer determines the tripping point for various conditions. Nominally, a 1/4" of water below the Room Sensor results in a shift of about 300 units from the dry measurement baseline. The Threshold is tunable to allow the customer to set the desired sensitivity level. However, note that changing the threshold may desensitize the moisture transducer or increase the likelihood of a false positive.

Any value less than 50 for the Threshold is ignored.

3.3.8.3 Enable/Disable

The Enable/Disable register sets whether the moisture transducer is initialized (enabled) or de-initialized (disabled). This register is used to determine the default state of the moisture transducer when first powered on.

3.3.8.4 Calibrate Baseline

Writing a non-zero value to this register forces the transducer to re-calibrate the dry baseline to the current value regardless of its actual state (wet or dry). It is recommended that this command is run when a Room Sensor is first deployed or relocated to ensure that the baseline is correctly set for the material under the Room Sensor. Any issued recalibration is performed as soon as the next moisture sample is taken. Therefore, as an example, if the sample period is 16 seconds, it may take up to 16 seconds for a recalibration command to be executed.

3.3.8.5 Default Configuration

Table 3-23 shows the default values for the moisture transducer configuration registers.

Table 3-23: Default Values of Moisture Transducer Configuration Registers

Sample Period	32 seconds
Threshold	100
Enable/Disable	Disabled (De-initialized)

3.3.8.6 Example DL Messages

In the following example payloads, the Command Field is boldfaced:

- Set the Sample Period to 64 seconds and read the Threshold
  - DL payload: { 0x **DA** 03 **5B** }
- Force the transducer to calibrate as being dry
  - DL payload: { 0x **DD** 01 }

3.3.8.7 Operation Algorithm

1. Whenever the moisture detector is enabled, it is recalibrated for a new dryness baseline.
2. In every sample, if the measured value goes up from the baseline by more than 10 counts (not user configurable), the moisture detector is recalibrated for a new dryness baseline.
3. In every sample, if the measured value goes down from the baseline by more than the Threshold (user configurable, see Section 3.3.8.2), the detector is tripped (signaling wetness).
4. Every 60 samples, if humidity changes by more than 10% (up or down–not user configurable), the moisture detector gets recalibrated for a new dryness baseline.

3.4 Command and Control

Configuration changes are not retained after a power cycle unless they are saved in the Flash memory. Table 3-24 shows the structure of the Command & Control Register. In this table, B_i refers to data byte indexed *i* as defined Figure 3-1.

Table 3-24: Sensor Command & Control Register

Address	Access	Name	Bytes	Description
0x70	W	Flash Write Command	2	• B_0-bit 5: 0 = Do not write App Config 1 = Write App Config • B_0-bit 6: 0 = Do not write LoRa Config 1 = Write LoRa Config • B_0-bits 0-4, 7: Ignored • B_1-bit 0: 0 = Do not restart Sensor 1 = Restart Sensor • B_1-bits 1-7: Ignored
0x71	R	FW Version	7	• B_0: App version major • B_1: App version minor • B_2: App version revision • B_3: LoRaMAC version major • B_4: LoRaMAC version minor • B_5: LoRaMAC version revision • B_6: LoRaMAC region number
0x72	W	Reset Config Registers to Factory Defaults[8]	1	• 0x0A = Reset App Config • 0xB0 = Reset LoRa Config • 0xBA = Reset both App and LoRa Configs • Any other value: Invalid and ignored

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.

[8] Resetting to factory defaults takes effect on the next power-cycle.

3.4.1 LoRaMAC Region

The LoRaMAC region is indicated by B_6 in the FW Version register (register 0x71). Current LoRaMAC regions and corresponding region numbers are listed in Table 3-25.

Table 3-25: LoRaMAC Regions and Region Numbers

LoRaMAC Region	Region Number
EU868	0
US915	1
AS923	2
AU915	3
IN865	4
CN470	5
KR920	6
RU864	7
DN915	8

3.4.2 Command Examples

In the following examples, the Command Field is boldfaced:

- Write Application Configuration to Flash memory
  - DL payload: { 0x **F0** 20 00 }
- 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 Specification," ver. 1.0.2, Jul 2016.

[2] TEKTELIC Communications Inc., "Smart Room Sensor Uplink and Downlink Frame Payloads," ver 0.1, Jun 2019---in-progress.

[3] LoRa Alliance, "LoRaWAN 1.1 Regional Parameters," ver. 1.1, rev. B, Jan 2018.