Terabee LoRa Level Monitoring XL

User manual

v1.0

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Introduction

The purpose of this document is to give guidelines for configuration, operation and maintenance of the Terabee LoRa Level Monitoring XL (further in text referred as Terabee device). The user manual also includes instructions for using the Terabee Configuration GUI.

Symbols explanation

The following symbols are used within the document:

This symbol indicates important messages or specific recommendations in order to operate the product in the intended manner

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About product

Terabee's solution is a self-powered, low-energy and wireless IoT device - providing users with remote data on remaining material levels inside silos, tanks and vats. It integrates an optical (LED) ToF sensor for distance measurements with up to 60 meter range, also providing a non-intrusive way of monitoring material levels. Data from the device is sent to the network at regular & configurable intervals, using the wireless LoRa protocol with kilometers of coverage area. For operations, the device uses an onboard (replaceable) battery which in combination with the low-energy LoRa protocol provides users with years of autonomy.

Device installation is possible inside or outside selected silos or tanks. Zero cabling for power or communication is needed, minimizing overall installation efforts and time. The product includes a free and easy-to-use Configuration GUI for quick tests and device parameter setup.

Contact the Terabee team at terabee-sales@terabee.com for more information.

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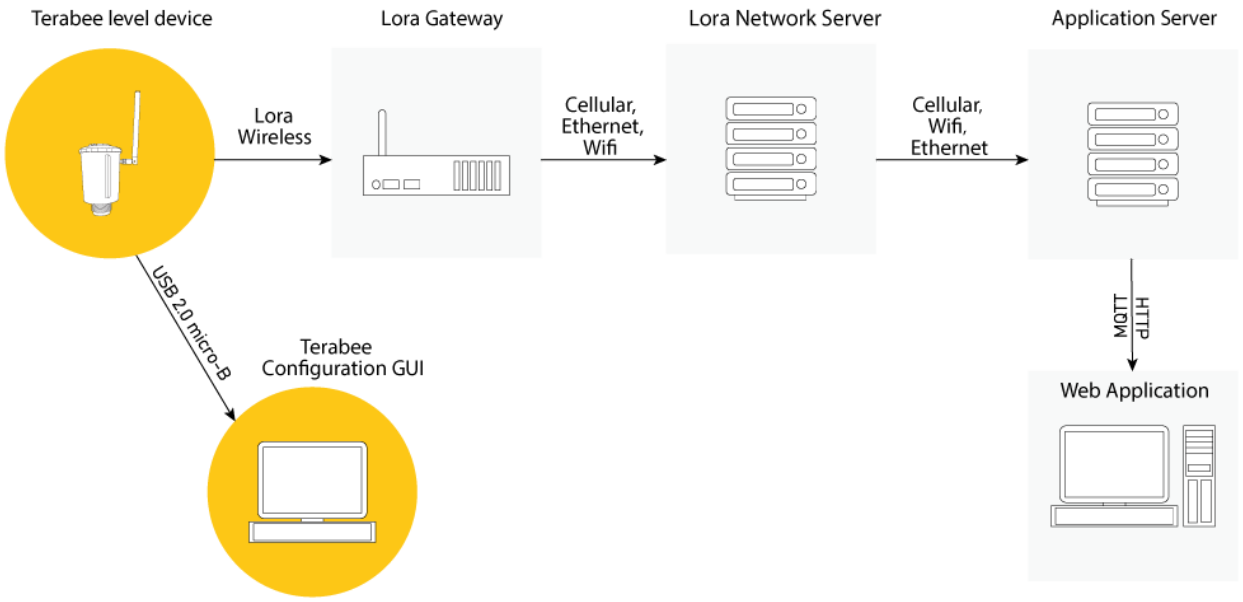
LoRaWAN overview

Terabee provides an IoT end-device which uses the standardized wireless LoRa protocol to transmit data over the LoRaWAN network. Please note that for successful data transmission, the user is responsible for Terabee device integration with a LoRaWAN network. This includes a LoRa gateway; registration of the Terabee device on a LoRa network server; and an application server of users choice.

Figure 2 illustrates the Terabee device fit in the LoRaWAN typology, and required integration components as well as process.



During the production step, Terabee devices are assigned several unique identifiers, which are used to securely activate the device and allow safe (encrypted) data transmission over a private or public LoRa network. LoRaWAN gateways receive encrypted data packets from the end-devices within reception range, and transmits the data messages to the LoRaWAN network server via Ethernet or wireless connection.

The LoRa Network Server establishes secure connections from the Terabee end-device to the user Application, and ensures the authenticity of each device on the network as well as integrity of each message transmitted (without accessing the application data).

The Application server is responsible for securely receiving, managing and decrypting data packet information transmitted from the Terabee end-device. Decrypted messages can then be sent for display on the user dashboards or data portals (web-application).

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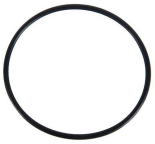
Inside the Package

The following items & components are included in the standard LoRa Level Monitoring XL product offering:

Components	Visuals	Comment
LoRa Level Monitoring XL device		
LoRa Antenna		Available in two versions : 1. 868 MHz 2. 915 MHz *Note : Terabee does not provide the antenna as a separate accessory*
Standard Type D battery, 3.6V, 19 AH (replaceable)		Shipped inside the level device *Note: The Terabee device does not support rechargeable batteries. For more information, see the "Device Maintenance" section.*
USB 2.0 Micro-B cable (50cm)		Allows device connection to PC and access to Terabee Configuration Software
O-Ring		Ensures IP65 sealing between the level device and installation point (e.g Terabee flange accessory)

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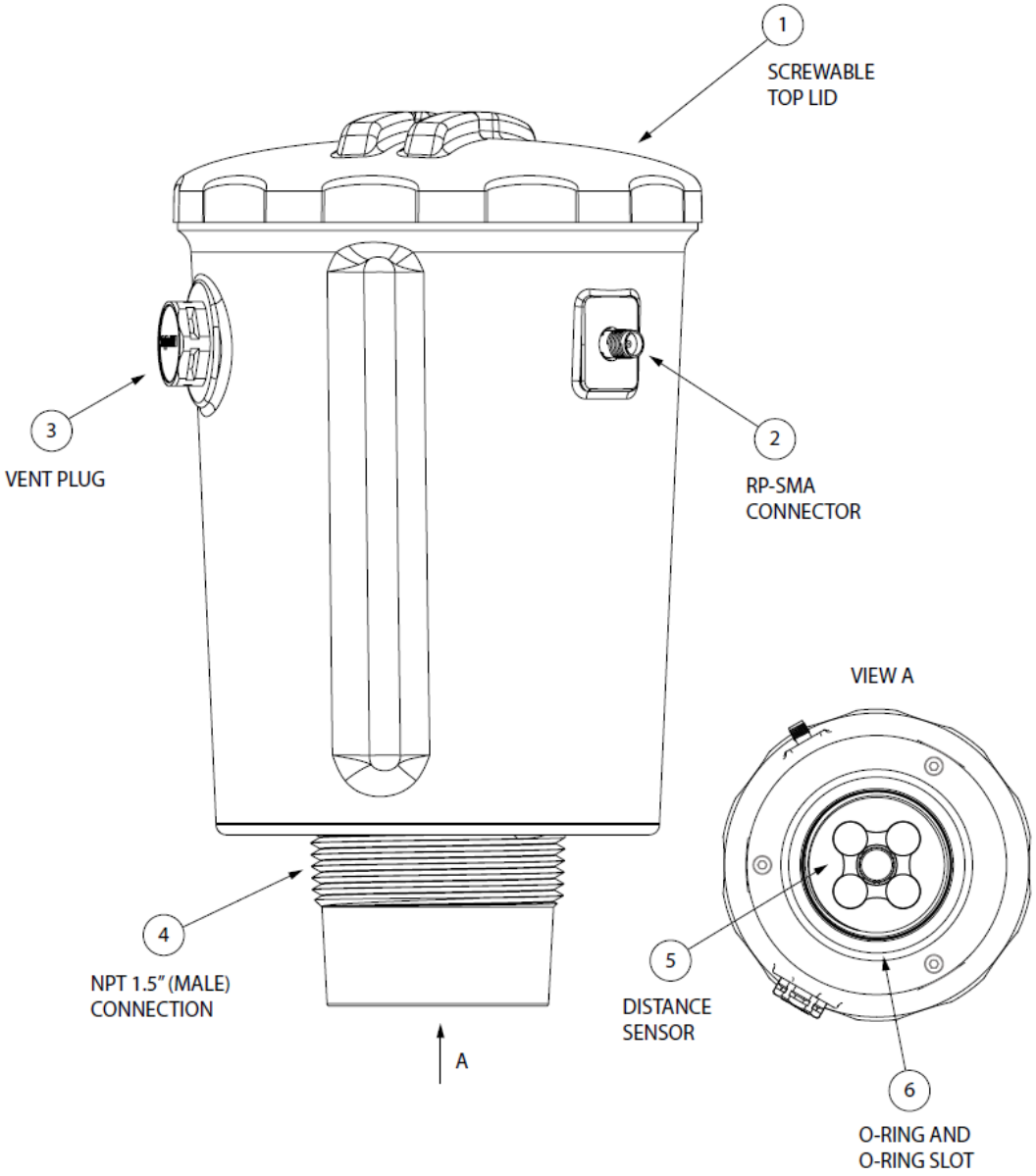
Onboard features and controls

External features



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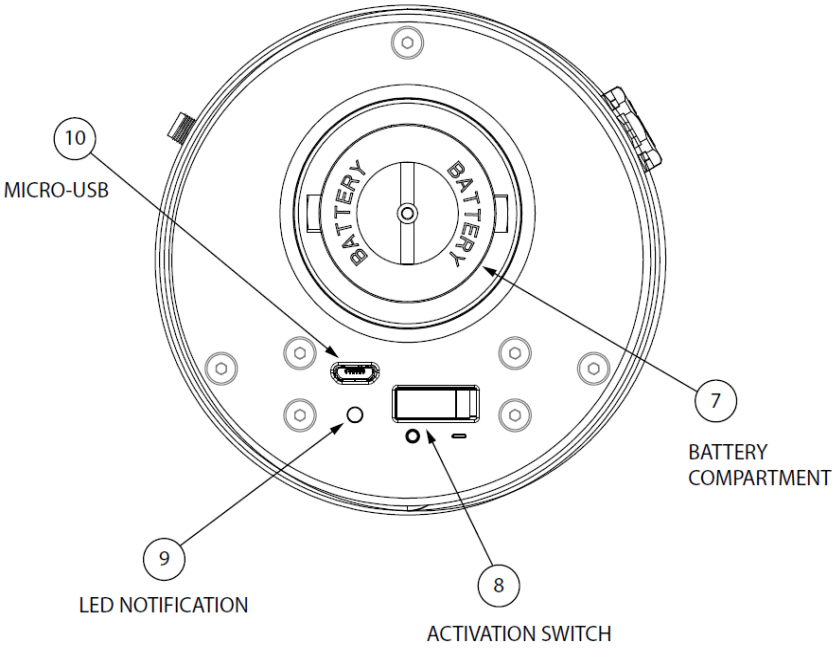
No.	Feature	Description
1	Screwable top lid	Provides sealed (IP65) protection to the control panel under the lid.
2	RP-SMA Connector	External connection point to support connectivity with a LoRa antenna.
3	Vent plug	Integrated plug to avoid condensation and water accumulation inside the device, during exposure to outdoor weather
4	NPT 1.5" (male) connection	Compatible with female NPT 1.5" threaded connection for screw-in installation of the level device
5	Distance Sensor	Terabee proprietary distance sensor with long-range measurement characteristics, based on LED Time-of-Flight technology
6	O-ring and O-ring slot	Ensures water tight sealing between the level device and selected mounting equipment

Important! *Do not unscrew (untight) the vent plug on the level device, unless instructed by the Terabee team. Unscrewing the vent plug will compromise the IP65 seal.*

Internal features and controls



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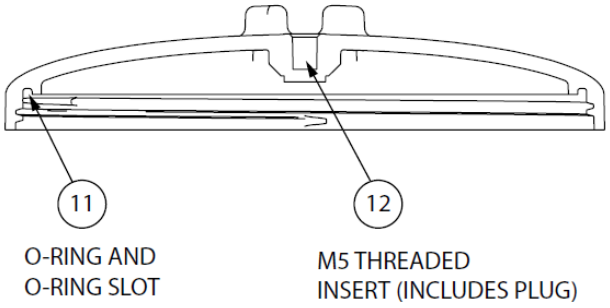

No.	Feature	Description
7	Battery Compartment	Access for the onboard battery unit.
8	Activation Switch	Device power ON / OFF. During connection to the USB interface, the switch is not responsive.
9	LED Notification	Multi-color LED for visual feedback on device operations
10	Micro-USB	Access for connection to PC, power via USB
11	O-ring and O-ring slot	Ensures water tight sealing between device and top lid. Do not remove the O-ring.
12	M5 threaded insert (includes plug)	Available slot for hook insert (middle of lid). In cases when not used, please keep the provided insert plugged to avoid accumulation of water and dirt

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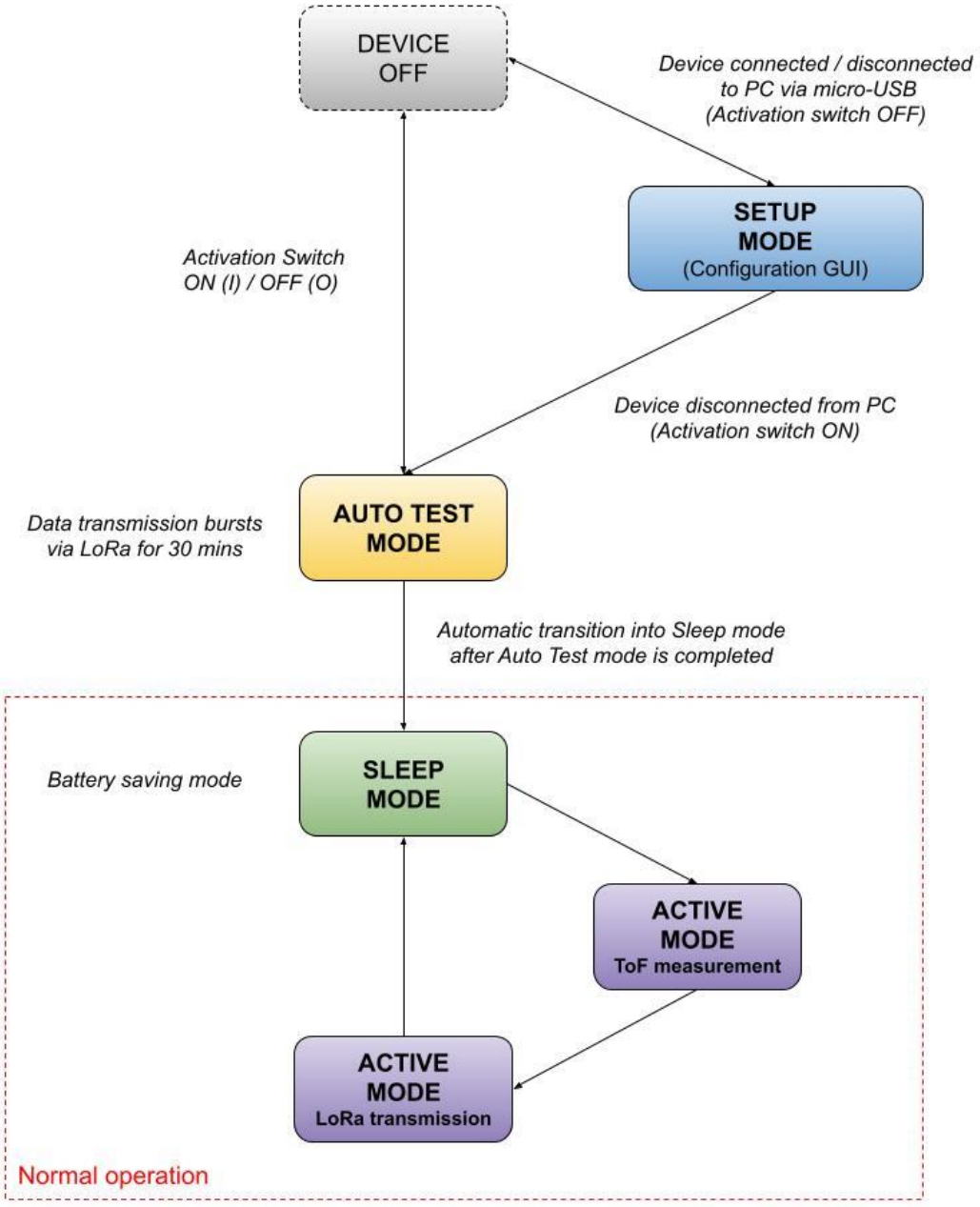
Onboard modes overview

The Terabee device includes 4 modes, explained in more detail below:

1. Setup mode
2. Autotest mode
3. Sleep mode
4. Active mode



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Setup mode (1)

Mode entered as soon as the device is connected to a PC via the USB 2.0 Micro-B interface. The mode is used mainly for device connection to the Terabee Configuration GUI, which allows users to perform distance measurement tests, network connection tests, and device parameter configuration/saving on device.

During Setup mode, power to the device is provided via USB interface from the connected PC, without affecting (draining) the onboard battery.

Please ensure that the onboard switch is set to (0) position before connecting the Terabee device to a PC using the USB interface. Connecting the Terabee device with a USB interface while the device is activated will have no effect.

When switching to setup mode - after the device has been operated whilst being powered by the battery - please wait 5-10 seconds before physically connecting the USB 2.0 micro-B connector. Faster connection may result in failure to enter the Setup mode.

Autotest mode (2)

Autotest mode provides users with short bursts of data via LoRaWAN - to help verify successful network connection and data transmission.

The mode is automatically entered after turning the onboard activation switch ON, (I) position. An alternative way to start the auto test mode is to unplug the micro-USB cable from the device, while the activation Switch is ON.

Right after activation, device will do the following:

1. Attempt to join the LoRa network (OTAA mode) - this process can take up to 90 seconds. This step is skipped if ABP is selected as an activation method.
2. Send 15 uplink transmissions to the LoRa network server, with 2-3 minute intervals between each transmission. Total auto test time may take between 30-40 minutes.

Please note that the first measurement in auto test mode may take up to 6-7 minutes. Further transmission intervals are set between 2-3 minutes, however this may increase in cases when larger distances are measured.

Throughout the autotest mode, the Terabee device will cycle through active and sleep states. The following table describes operations for each state.

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State	Operation	LED	LED meaning
Active	1. system charging for operations 2. perform distance measurement 3 uplink payload transmission (Rx1) 4. downlink payload receival slot (Rx2)	GREEN (3 blinks) BLUE (3 blinks)	Currently in active state Uplink transmission
Sleep	Device is in battery-saving mode for 2min (equivalent to being turned OFF)	Not available	

After 15 uplink transmissions, the device will automatically enter sleep mode (exiting the autotest mode). When in autotest mode, the power is supplied by the onboard battery.

Sleep mode (3), Active mode (4)

Sleep mode is the battery saving mode, allowing the device to achieve years of autonomy. The Terabee device will be in sleep mode for most of its time while deployed on the field.

Based on pre-configured parameters, the Terabee device will wake up (exit) from the sleep mode and enter the active mode for a short period of time. During active mode, the Terabee device will:

1. Perform system charging for operations
2. Perform a distance measurement
3. Execute an uplink message transmission via LoRa to the configured network (Rx1)
4. Open slot for downlink messages (Rx2).

After the sequence is completed, the device will go back to sleep mode, until the next wake-up is scheduled. The LED indication is not used during sleep nor active mode, in order to preserve battery lifetime.

Please note that during active mode, distance measurements and data transmission always happen in the same "wake up window".

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LED notifications

LED Pattern	Reason / Cause	Meaning
GREEN x continuous blinking (0.5 sec intervals)	Device is connected to the PC via micro-USB interface	Device is in SETUP MODE. Power is provided via micro-USB connection (PC)
RED x 1 blink	1. Activation switch is turned ON (I position) 2. Device has been connected to PC via USB interface	Device boot up. After the red LED switches off, the device is successfully initiated
BLUE x continuous blinking (0.25 sec intervals)	Automatic initiation after device boot up is completed	Device enters AUTO TEST mode, and is attempting to join LoRa network (OTAA configuration)
BLUE x 3 blinks (0.5 sec interval)	Available only AUTO TEST mode	Uplink message sent from device to the network server
GREEN x 3 blinks (10 sec intervals)	Available only in AUTO TEST mode	Regular blinking (every 10 sec) indicates that the device is operating in AUTO TEST mode.
WHITE LED activated for 1 sec (before system reset start)	In the Terabee Configuration GUI the FACTORY RESET is selected.	Reset factory operation selected and to be be started immediately
ERROR NOTIFICATIONS		
RED x constantly ON	Activation switch is turned ON (I position)	Error during device boot up.
RED x 1 blink (5 sec intervals)	After activation switch is turned ON (I position)	Device configuration error. One or more of the network and/or application parameters are not configured or configured incorrectly
RED x 2 blinks (5 sec intervals)	After failed connection to network	Device failed to connect to the network
RED x continuous blinking (0.1 sec intervals)	Internal system error detected	Device firmware has experienced a crash

Please see Appendix for recommended recovery steps on LED error notifications.

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Setup and device initiation

1. Connect antenna

Join the provided LoRa antenna with the Terabee device. To do this, locate the RP-SMA connector on the device external part, and gently screw in the antenna clockwise until it is locked.

Please use the cap to screw the antenna to the device. Once the antenna is locked, hold the cap fixed (use one hand) and rotate the main antenna body to adjust for a preferred antenna position (other hand).

Use the 3-point hinge system to manipulate the antenna in the preferred position.

2. Register device with a network server

Before operation, the user must register the Terabee device with a selected LoRa network server provider. This step includes assigning several unique identifiers between the Terabee device and the network server, which enables device recognition on the network and secures further data exchange.

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An integration example with The Things Network (TTN) server is provided in a separate document (Official product webpage → Downloads section → Documentation → LoRa Level Monitoring XL integration with The Things Network).

Please note that without registering the Terabee device with a LoRa network, it is not possible to transmit data via LoRa protocol!

3. Activate device

Next, unscrew the TOP lid of the device (clockwise), and power it by turning the onboard switch to (I) position. Power will be immediately supplied to the device by the battery. The onboard LED will indicate successful bootup accordingly

4. Connect to network

After initiation, the device will enter AUTO TEST MODE, during which it will :

1 - attempt to join (request) the LoRa network. This step can take up to 90 sec, and is only present in the OTAA activation method. Onboard LED will constantly blink BLUE to indicate network connection, and

2 - transmit 15 uplink messages to the LoRa network server of users' choice, with 2-3 minutes intervals. The onboard LED will blink BLUE (3 times) - to indicate each uplink payload transmission. Total time for auto test mode may vary between 30-40 minutes.

If the device is set to operate in the ABP activation method, it will skip the network join part (step 1) and directly start transmission of 15 uplink messages (step 2).

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5. Ready for operations

Once the autotest mode has ended, the device will enter the battery saving mode (SLEEP MODE), until it will be automatically powered again for measurements and LoRa data transmissions based on pre-configured intervals.

Before further device installation, please screw back & lock the upper device lid to ensure IP65 protection to inner electronic components. Make sure that the antenna connection is tight (no free movements).

Default device parameters

Terabee device comes pre-configured with default network and applications parameters. The following list provides an overview of these parameters, configured during the production process.

Activation method :	OTAA
Device EUI :	*provided, unique to each device*
Application EUI :	-
Application Key :	*provided, random to each device*
Radio Frequency (LoRa) :	EU868 MHz; US915 MHz
Adaptive Data Rate (ADR) :	Enabled
Spreading Factor :	-
Uplink Confirmation :	Disabled
Measurement and Transmission Interval :	1 reading / 1 hour
Level Estimation :	Disabled

When using the Terabee Configuration GUI with the Terabee device, the software auto-fills the codes in the DevEUI and AppKey parameter fields.

Device EUI (DevEUI) and Application Key (AppKey) codes for each device can be also found embedded in a QR code that is printed on a label - located on the inner side of the TOP lid. Example is presented below.

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Using Terabee Configuration GUI

Terabee LoRa Level Monitoring XL comes with a Configuration GUI (Graphical User Interface) to provide users with an easy way to perform distance measurement tests, and configure device parameters. Terabee software supports operation on Windows, Linux and Mac operating systems.

Connection

Connect the Terabee device to a PC using micro-USB cable (included in the package). The USB 2.0, Micro-B connector is located under the TOP device lid. Upon successful physical connection, the LED will constantly blink GREEN, and it will continue to do so - as long as the Terabee device is linked to the PC. Power supply to the device is now provided via USB interface (battery is not affected).

Download and install the Terabee Configuration GUI, located under the Downloads section of the official product page. Open the Terabee Configuration GUI application.

The top navigation bar allows the user to easily navigate and switch between different sections of the software (HOME, NETWORK, APPLICATION, ABOUT), at any time.

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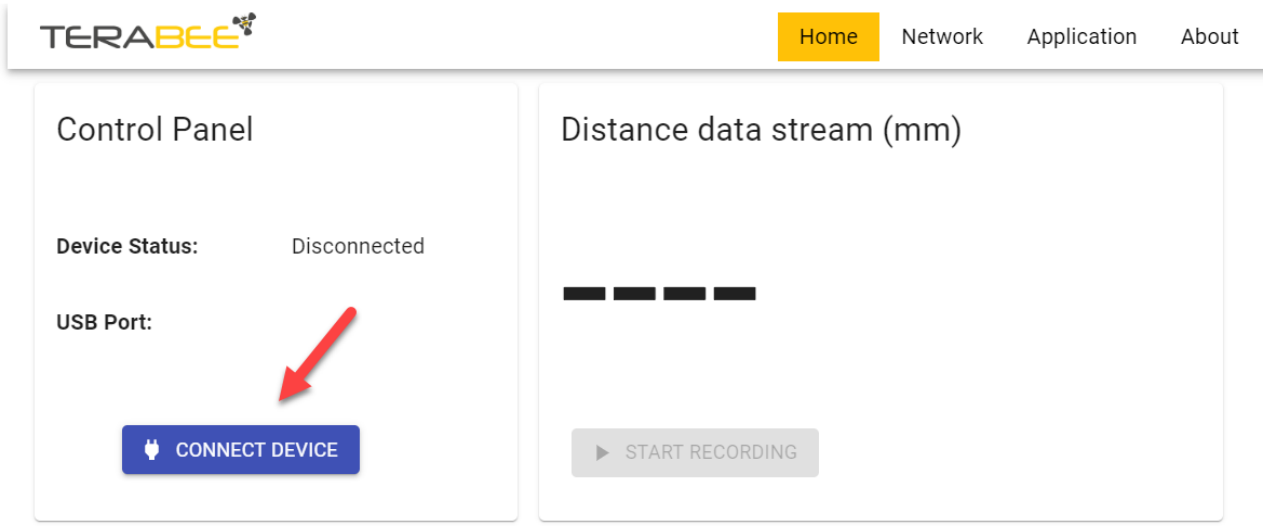
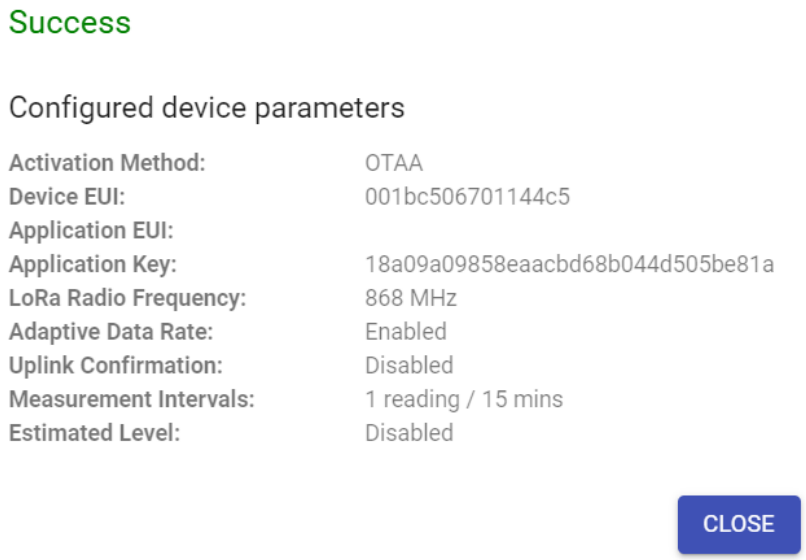
Home tab

Under the Control Panel, click on CONNECT DEVICE. The software will automatically recognize & display the USB port to which the Terabee device has been joined, and connect to the GUI.



After successful connection - a dialog window will appear, showing currently configured device parameters. Click on CLOSE to continue.



Under the Control Panel, the Device Status field will now change to CONNECTED. Device status can also be found in the footer (bottom left), at any time while using the software. Current software version can also be found in the footer (bottom right).

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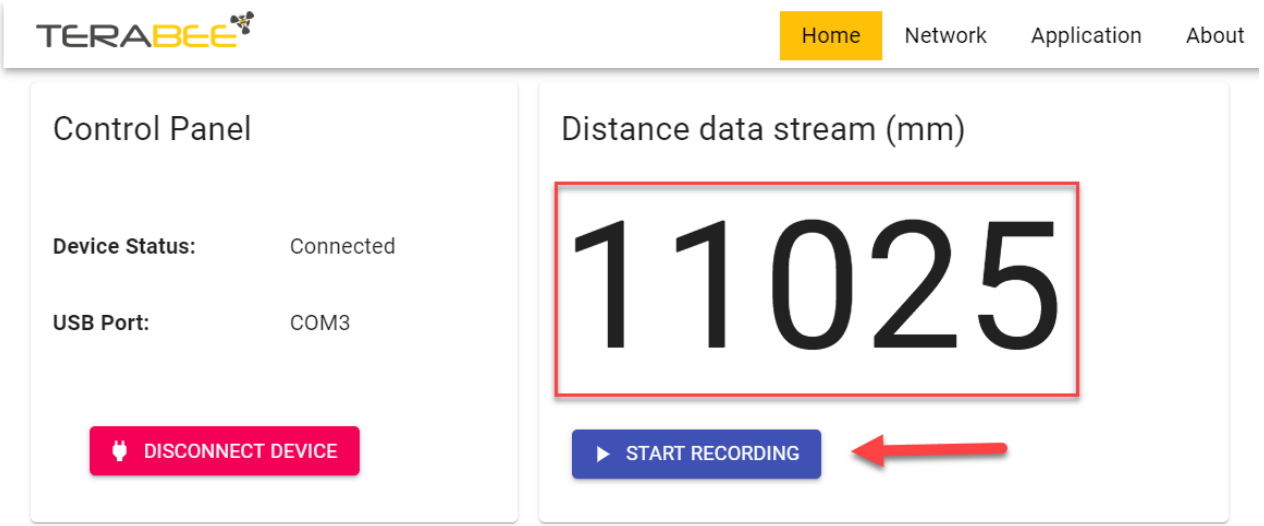
Immediately after connecting, a distance data stream will be available on the left side of the Home tab, showing real-time measurements from sensor to target (in millimeters).

Please note that fast streaming of distance data from the device is only possible via the USB interface, and not available for communication via LoRa protocol.



Users can extract measured distance data in a txt file format, by clicking on START RECORDING. Select a preferred location for the file and click SAVE. When enough data is gathered, click on STOP RECORDING. Below is an example of distance measurements extracted on a Txt file from the Terabee Configuration GUI.

At any point, the user can disconnect the device by clicking DISCONNECT DEVICE.

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Network tab

This tab features parameters related to the LoRa network, determining how the device operates with the selected network. The following section describes each of the parameter fields and available selection options.

Activation method and unique keys

Activation method	Input parameter	Definition
OTAA (Over the air activation)	**Device EUI (DevEUI)**	unique 64 bit end-device identifier in the network. DevEUI parameter field is automatically pre-filled with device specific code (provided by Terabee device)
	Application EUI (App EUI)	unique 64 bit code, enabling an extra identification layer. If an application EUI code is provided by the selected network server provider please input this.
	Application Key (AppKey)	128 bit application encryption key to secure communication between device and network. AppKey parameter field is automatically pre-filled with device specific code (provided by Terabee device)
ABP (Activation by Personalization)	**Device Address (DevAddr)**	32 bit code, identifies the end device within the network
	Network Session Key (NwkSKey)	shared between the LoRa network and end-device, Unique per network
	Application Session Key (AppSKey)	shared between the application and end-device, used for message payload encryption, unique per application

Below is an example of fully configured unique device keys, using the OTAA activation method. The Terabee GUI allows automatic revert back to device default Device EUI, at any point - this can be done by clicking the circular arrow inside the Device EUI field.

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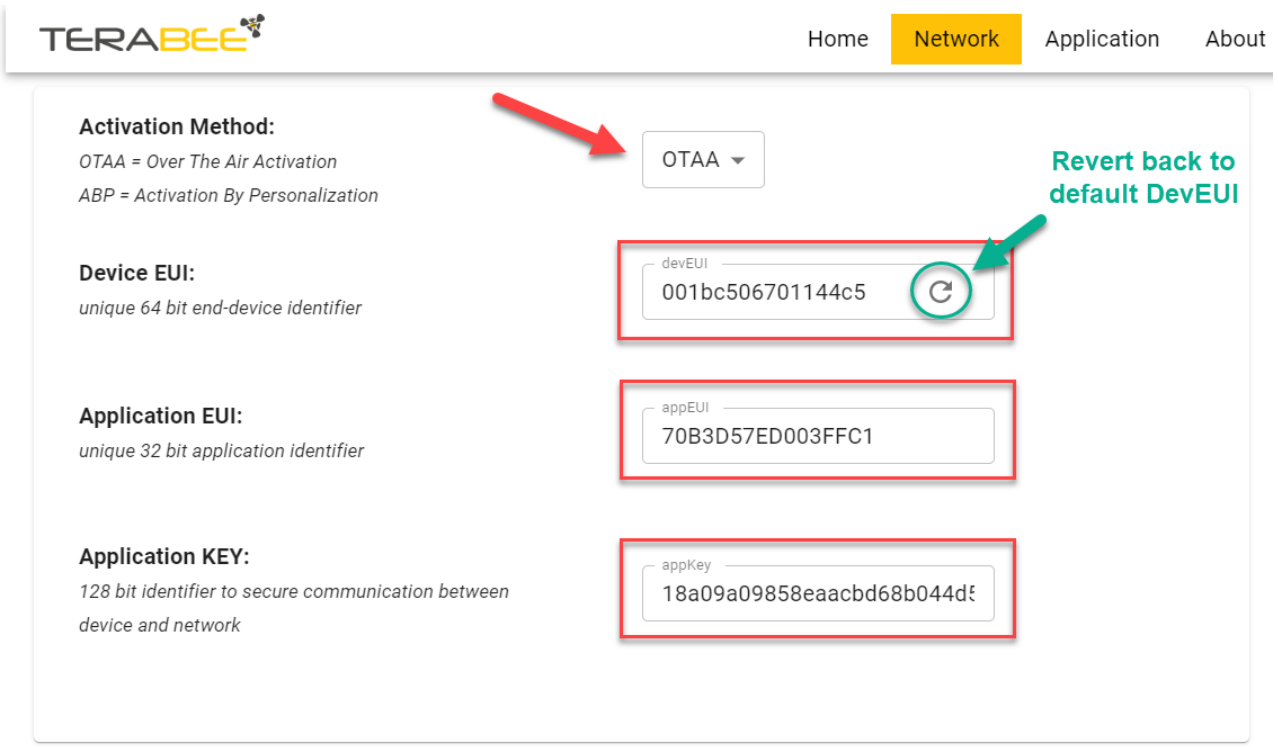

Radio Frequency (LoRa)
Depending on the Terabee device version this field will indicate LoRa Radio Frequency : EU868 MHz or US915MHz. Please note that this parameter can not be modified using the Terabee Configuration GUI.

Adaptive Data Rate (ADR)
Enables the system to automatically set data rate and spreading factor for optimal performance. By default, ADR functionality is ENABLED. Selecting DISABLED option will require manual setting of the Spreading Factor (SF) parameter.

Spreading Factor (SF)
Determines the amount of chirps used to represent a symbol. The higher the SF value is, the more chirps used to represent a symbol and the longer data air time. Options available:

SF7, SF8, SF9, SF10, SF11, SF12.

By default ADR is enabled, meaning that optimal spreading factor will be regularly evaluated and selected automatically by the device. In order to choose a manual spreading factor, please set ADR to DISABLED.

Uplink Confirmation
After every uplink data packet transmission (Rx1 window), the end-device will inquire and wait for an acknowledgement message from the gateway (Rx2 window). By default this setting is disabled to save battery.

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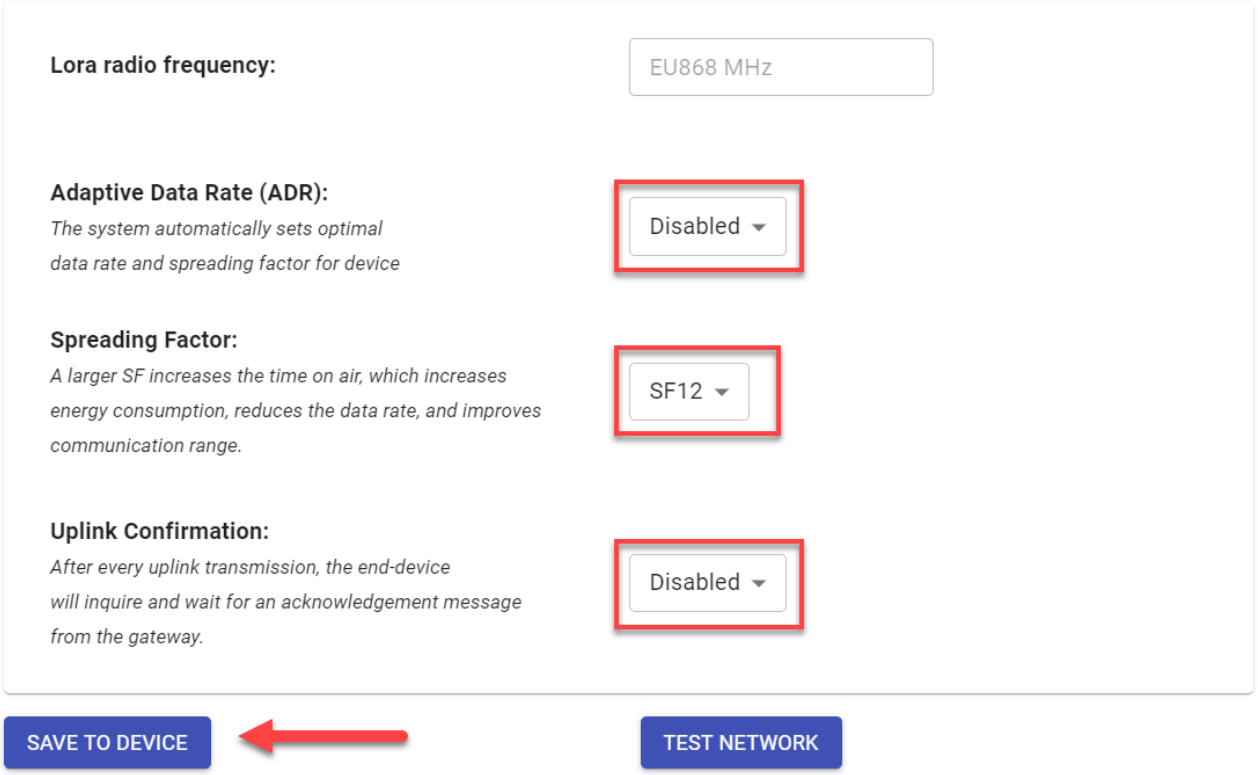
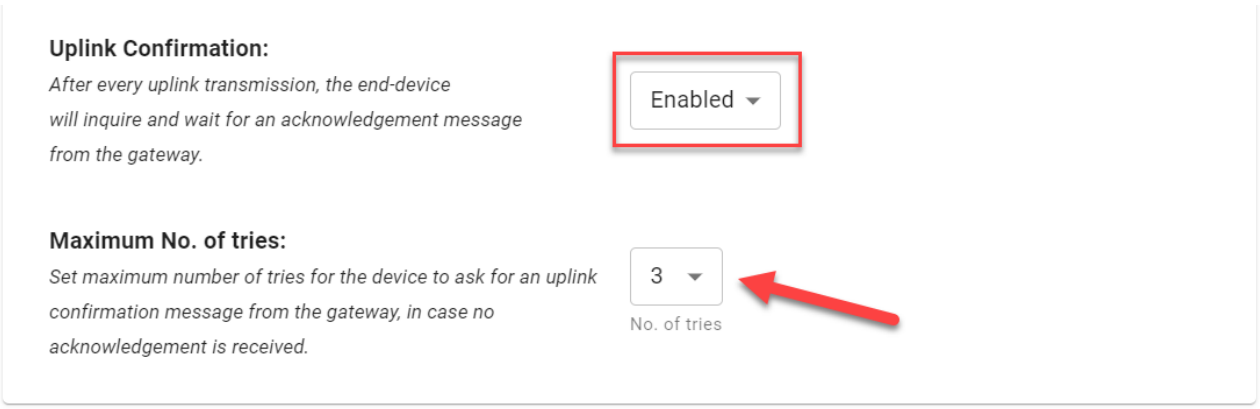


Maximum no. of tries (Uplink Confirmation)
Parameter only available if "Uplink Confirmation" is Enabled. Defines the maximum number of trials for the end-device to reach the gateway (if no response/downlink confirmation has been received), before stopping the uplink confirmation request. Options between 1, 2, 3, 4, 5 tries are available.



SAVE TO DEVICE
Once parameters have been configured, click on SAVE TO DEVICE (bottom left) to register and store configured network parameters to your Terabee device. A dialog window will appear to indicate successful parameter registration and also list these for confirmation.

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TEST NETWORK

For OTAA operations, Terabee Configuration GUI offers users the possibility to test Terabee device connection to the network server and confirm whether the gateway is in range for successful data transmission via LoRaWAN.

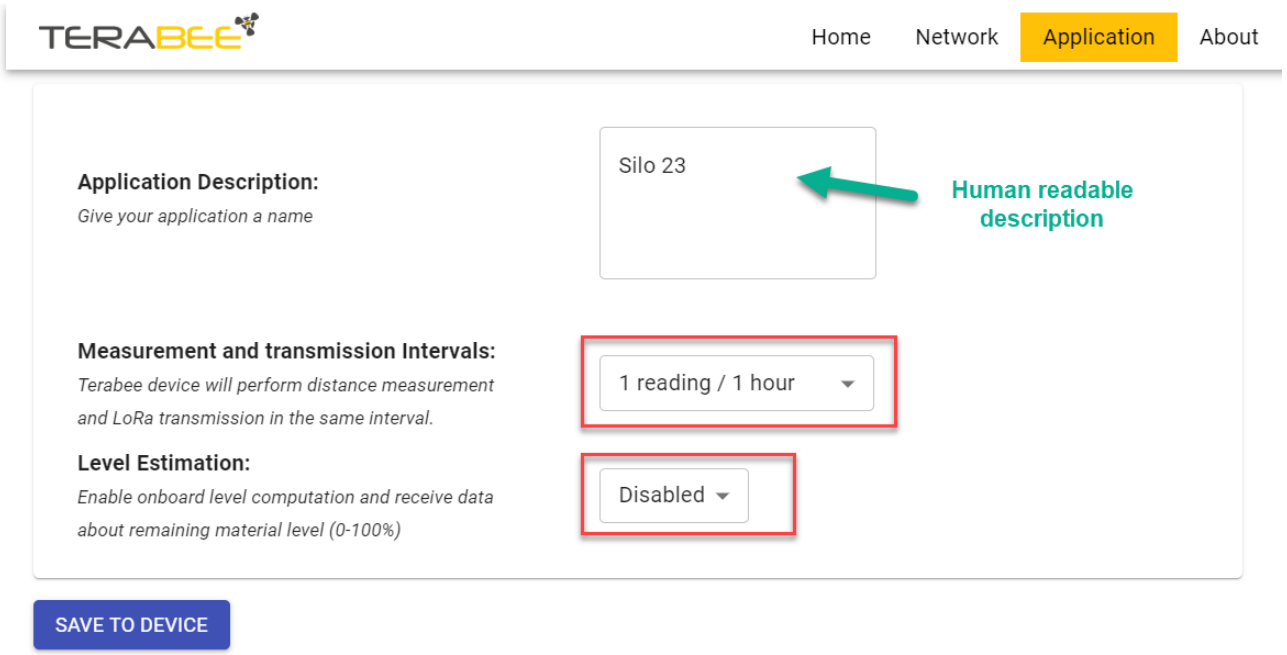
By clicking on TEST NETWORK (bottom right), the Terabee device will:

1. Save currently specified network & application parameters to device
2. Initiate a join request procedure
3. After a successful network connection (join request accepted), it will send an uplink message with a test payload “BBBB”
4. Wait for an acknowledgement message via downlink.

After successful network connection & test payload exchange, a dialog window will appear indicating this.

Application tab

Allows users to set device parameters specific to particular application requirements, including measurement and transmission intervals.



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Application Description
Optional field. Allows users to give their device or application a human-readable description. Maximum 20 characters are allowed.

Measurement and transmission intervals
Allows users to specify the Time-of-Flight sensor measurement frequency together with the data transmission via LoRaWAN. Available frequencies include:

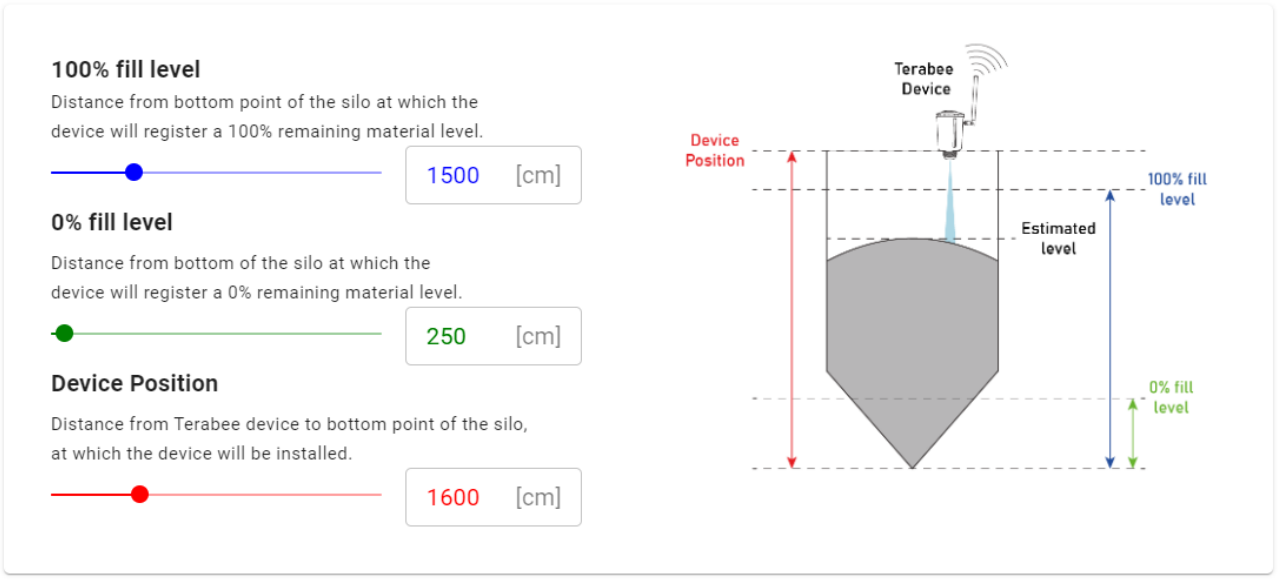
1 reading per 24 hours
1 reading per 6 hours
1 reading per 1 hour (default)
1 reading per 15 mins

Level estimation
Enables or Disables (default) system onboard computation of remaining material level in silos. If enabled, the following 3 extra parameters will appear in the section below that are necessary to be configured in order to provide an accurate material level estimation.

100 % fill level: distance (in cm) from bottom of the silo at which the device will register a 100% filled material level.

0 % fill level: distance (in cm) from bottom of the silo at which the device will register an empty silo (0% fill level)

Device position: distance (in cm) from Terabee device to bottom point of the silo, at which the device will be installed. Position on Z axis.



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To modify these parameters and change distances, the user can either use the slider or input exact values in the corresponding number field. The silo illustration (right side) provides a visual example of the 3 parameter setup.

***Important**. Please note that the Terabee Configuration GUI is only used as a means to configure the device for operation. The software is not intended to provide any recommendations on most suitable mounting possibilities, or other information related to the device physical installation in the silo or tank.*

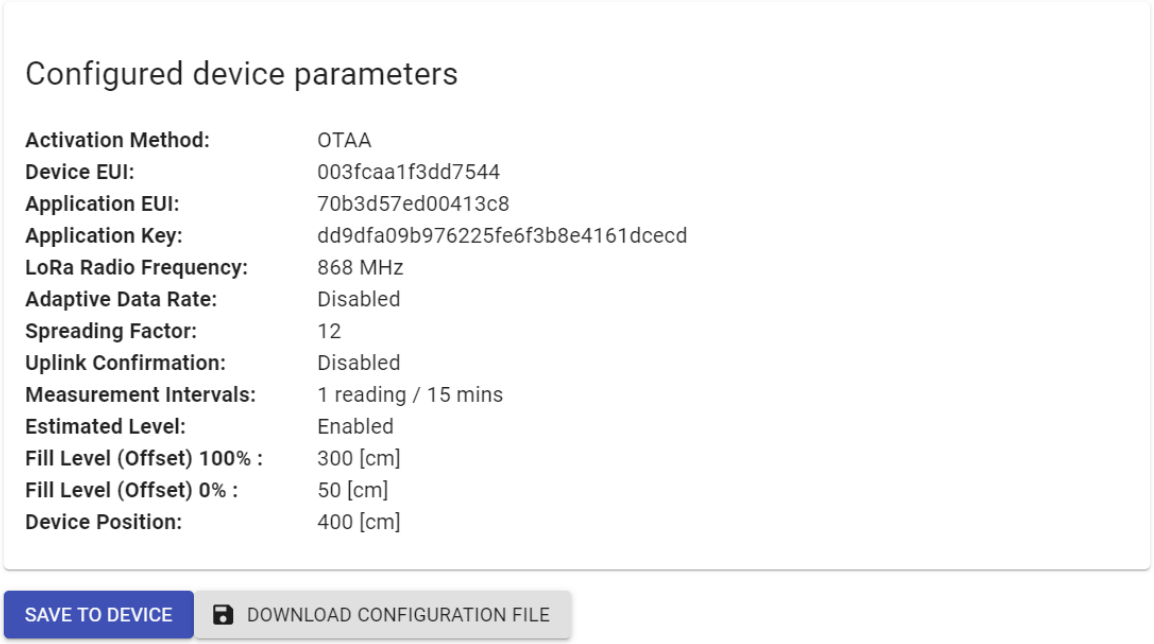
SAVE TO DEVICE

Once parameters have been configured, click on SAVE TO DEVICE (bottom left) to register and store configured network parameters to your Terabee device. A dialog window will appear to indicate successful parameter registration and also list these for confirmation.

About tab

This section provides generic information about the Terabee device and the current device firmware, software (GUI) version.

A summary of all CONFIGURED DEVICE PARAMETERS is also available. Parameters will be updated in real-time as soon as these are changed in the corresponding NETWORK and APPLICATION tabs and fields.



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Please note that actual parameters under CONFIGURED DEVICE PARAMETERS section are ones selected in the Terabee Configuration GUI - and is not a list of settings currently saved on the device.

Users also have the possibility to save modified parameters to the device (SAVE TO DEVICE) or download .json format file with configured parameters for further use outside the Terabee GUI (DOWNLOAD FILE).

At the bottom of the ABOUT tab the following functionality is also available:

UPGRADE FIRMWARE
Allows users to upload a newer (or older) version of the Terabee device firmware - usually to unlock new features and improve operations by fixing known bugs. Ensure you have a firmware file from Terabee before continuing with the firmware upgrade process.

Click on UPGRADE FIRMWARE, select the corresponding *.tera.bin file from your PC and click on OPEN. Onscreen instructions will guide you through the upgrade process.

Important! Do not disconnect the Terabee device from the PC during the firmware upgrade process. Failure to properly follow the instructions can result in a bricked device.

Once firmware has been successfully upgraded, navigate to the HOME tab and click CONNECT DEVICE. You can now verify the new firmware version in *ABOUT tab → Device Information - Device firmware version*.

FACTORY (DEFAULT) RESET
Automatic reset of Terabee device to its default settings. Please note that all previously configured parameters will be lost and set to factory settings.

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Device maintenance

LoRa Antenna

Terabee device uses an external LoRa antenna to support data communication over LoRaWAN. The following characteristics describe the Terabee provided antenna : IP67, +2 dBi antenna gain, hinged design with possible 3 positions (0°, 45°, 90°).

Two antenna versions are available from Terabee (*Please note that Terabee does not sell these separately, as accessories*) :

- EU 868 MHz
- US 915 MHz

In cases when the user prefers to integrate a non Terabee LoRa antenna, this is also possible. Please make sure that : (1) the selected antenna matches with available LoRa radio frequencies on the Terabee device, (2) antenna gain and power are supported by local regulations.

Important! *Make sure the ERP (Effective Radiated Power) and EIRP (Effective Isotropic Radiated Power) are within the regulatory limits. For instance, in Europe maximum allowed antenna gain is: +2.15 dBi.*

Battery compatibility

Each Terabee device comes with a single replaceable battery, Standard Type D.

- Type of Battery: Lithium Thionyl Chloride
- Rated Voltage: 3.6V
- Cell Size: D,R20
- Capacity: 19000mAh
- Non-rechargeable: Yes
- Compatible models:

  EVE (Energy Very Endure) Battery ER34615

Please note that using batteries from other suppliers or with different consumption characteristics may result in decreased overall battery lifetime or complete incompatibility (device won't start or operate)

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Battery replacement

Battery compartment is located under the sealed top lid of the Terabee device. Before opening the device, ensure that water or moisture cannot enter the onboard electronics. Please follow these steps for battery replacement :

1. Make sure the device is deactivated - onboard switch position is set to (0)
2. Unscrew the top lid and open the battery compartment by rotating clockwise (use a coin or a tool)

3. Remove the discharged battery and replace it with the new unit (ensure correct positioning)
4. Close the battery compartment with the lid and turn anti-clockwise to lock.

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5. Close and screw back the top device lid to ensure IP65 sealing.
6. The battery replacement has been successfully executed.

Please use batteries that are in full capacity (100%), as replacements using semi-discharged batteries will result in reduced battery lifetime and shorter cycles between device maintenance.

Individual replacement batteries are not provided/sold by Terabee. It is recommended to acquire these via external electronic component providers. Terabee also advises to use genuine replacement batteries, and cannot guarantee function and safety of the device in case unapproved batteries are used. Unapproved batteries may result in faster discharge (shorter lifetime), potential damage to devices or danger to users.

Battery information & handling recommendations

- *Batteries provided by Terabee are not rechargeable. Do not charge or open the battery.*
- *Do not expose the battery to ambient temperatures higher than 100 °C. Under no circumstances allow exposure to fire.*
- *For battery replacement, please use only lithium-thionyl chloride units, standard type D.*
- *Follow regional regulations for battery disposal after end-of-life*
- *Do not handle used batteries in front of children. Keep used batteries out of reach from children.*

Battery lifetime

The Terabee device provides a long service life. Battery lifetime will strongly depend on the configured device parameters (e.g measurement/transmission intervals, spreading factor, etc), application climatic conditions (e.g temperature and humidity levels), measured distance by the ToF sensor, data transmission air time (*often dictated by distance between the Terabee device and the gateway*) and more.

The following battery lifetime estimates are based on the following conditions :

Ambient temperature:	-20°C; +25°C; +65°C
Distance from target:	10 meters
Target material:	white, 80% reflective
Spreading factor:	SF7
Measurement intervals:	1 reading / 1 hour

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Battery lifetime estimation @ -20°C: 4.5 years

Battery lifetime estimation @ +25°C: 6 years

Battery lifetime estimation @ +65°C: 4.5 years

Above battery lifetime estimates assume device operation 24/7 in the specified temperature. Please note that battery lifetime will strongly be impacted by the onboard TOF sensor measured distance. Larger distances will reduce battery lifetime faster.

Device cleaning

Regular maintenance, including ToF sensor cleaning is not necessary nor provisioned for the Terabee device.

In cases when the device is used in silos with exposure to large amounts of dust / powder materials / dirt on a regular basis, sensor lens cleaning may be required. If large amounts of dust or dirt build-up has accumulated on the sensor lens over a longer period of time, it may block light emission from the sensor - resulting in invalid reading output (error message, value 1). In such cases, please clean the sensor lenses by using a soft cloth and mild soap. Remove residues of soap using a wet, lint-free cloth. After that, the ToF sensor will be able to register an accurate distance measurement once again.

For an integrated self-cleaning system that will help avoid dust/dirt accumulation on sensor lenses, please contact the Terabee team to explore development opportunities.

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LoRaWAN communication

General uplink payload structure

Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
Distance data MSB	Distance data LSB	Material level percentage	Battery Voltage MSB	Battery Voltage LSB	Error Code

MSB = most significant byte, LSB = least significant byte

Error codes bit structure

Certain error codes will be detected and reported by the firmware using the last byte of the LoRa payload (byte 5). Each bit in the byte represents an error as described below.

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
RFU	RFU	RFU	RFU	TOF-TIMEOUT	BATTERY	LORA_LOW_POWER_FAIL	WDT_RESET

RFU = reserved for future use

Data output definition

1 - Distance data : raw distance measurements performed by the onboard ToF sensor. Output is provided in millimeters. Possible outputs under distance data include:

Output type	Output (decimal)	Output (hexadecimal)	Meaning
Valid reading	500 to 60000	0x1F4 - 0xEA60	ToF sensor successfully registered a distance measurement
Target too close	0	0x0000	Detected target is closer than the minimum range of the ToF sensor (50cm)
Target too far	65535	0xFFFF	Detected target is farther than the maximum range of the ToF sensor (60m)

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Invalid reading	1	0x0001	ToF sensor failed to register a measurement. Possible causes : - Ambient light is too high - Target surface is too reflective - Received signal is too weak

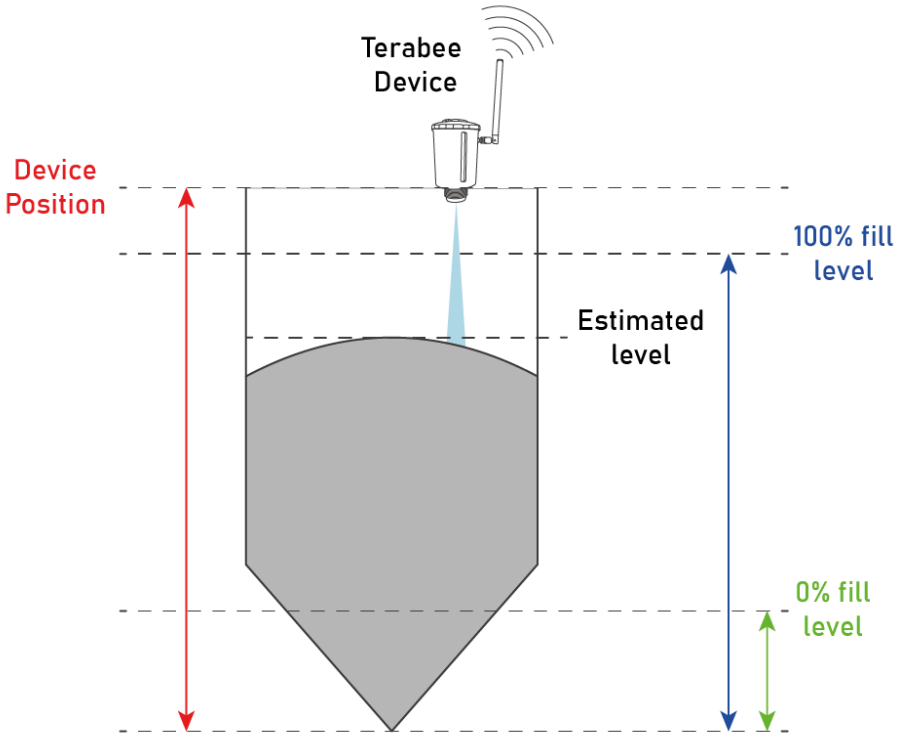
2 - Material level percentage : output shown in percentage (0-100%) and represents current material fill level inside the silo / tank from the total material level (set by the user). In order to obtain accurate level estimation, the user is responsible for setting 3 parameters via the Terabee Configuration GUI:

100% fill level - distance from bottom of silo to the point where the device will output a 100% fill level (full)

0% fill level - distance from bottom of silo to point where the device will output a 0% fill level (empty)

Device position (Z axis) - distance from bottom of silo to the exact point where the Terabee device will be installed (reference point is the sensor lenses).

By default, material fill level estimation is disabled. If enabled, this value is then computed onboard the device after every ToF measurement - by converting the raw distance data collected (sensor-to-material surface) into remaining material fill level (%).



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In cases when the level output is equal to ERROR, please see the distance output provided in the same frame, for better interpretation of the data. Examples are provided below :

Distance (0) → Level (ERROR) → Detected target is closer than the minimum range of the ToF sensor (50cm)

Distance (1) → Level (ERROR) → ToF sensor failed to register a measurement

Distance (65535) → Level (ERROR) → Detected target is farther than the maximum range of the ToF sensor (60m)

3 - Battery voltage : current state of battery, output is provided in millivolts (mV).

Please note that battery voltage may fluctuate even within a shorter period of time, often due to sudden changes in ambient temperature. Voltage usage profile may also differ depending on selected device measurement/transmission intervals.

4 - Error codes : informs/alerts the user about potential error modes that have been detected by the device firmware. Possible error cases and corresponding messages are presented in the table below:

Error output	Meaning
WDT_RESET	System reset has been triggered due to an unexpected error.
LORA_LOW_POWER_FAIL	Embedded LoRa module failed to enter sleep mode. If possible, please restart the device.
BATTERY	System failed to read voltage from the battery. If possible, please restart the device.
TOF_TIMEOUT	System failed to get a response from the onboard ToF distance sensor. If possible, please restart the device.

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Uplink payload decoding function (example)

```
function isKthBitSet(byte, k){
  return byte & (1 << k);
}

function decodeErrors(errorByte){
  var errors = {};

  if (isKthBitSet(errorByte, 0))
    errors["WDT_RESET"] = "System reset has been triggered due to an"
      + " unexpected error. ";


  if (isKthBitSet(errorByte, 1))
    errors["LORA_LOW_POWER_FAIL"] = "Embedded LoRa module failed to"
      + " enter sleep mode. If possible, please restart the device.";

  if (isKthBitSet(errorByte, 2))
    errors["BATTERY"] = "System failed to read voltage from the battery."
      + " If possible, please restart the device.";

  if (isKthBitSet(errorByte, 3))
    errors["TOF_TIMEOUT"] = "System failed to get a response from the"
      + " onboard ToF distance sensor. If possible, please restart the device.";
  return errors;
}

function decodeLevelPercentage(level){
  if (level === 255)
    return "LEVEL_ERROR";
  return level;
}

function decodeDistance(distance){
  if (distance === 0)
    return "TARGET_TOO_CLOSE";

  if (distance === 65535)
    return "TARGET_TOO_FAR";

  if (distance === 1)
    return "INVALID_READING";
  return distance;
}
```

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```
function Decoder(bytes, port) {
    var distance = decodeDistance(bytes[0]<<8 | bytes[1]);
    var levelPercentage = decodeLevelPercentage(bytes[2]);
    var batteryVoltage = bytes[3]<<8 | bytes[4];
    var errorCode = decodeErrors(bytes[5]);

    return {
        distance: distance,
        levelPercentage: levelPercentage,
        batteryVoltage: batteryVoltage,
        errorCode: errorCode
    };
}
```

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Appendix

Recovery steps for error LED notifications

Error	Automatic recovery	Recommended steps
Device boot up error	No	Contact Terabee support for a more detailed troubleshooting of the issue
Device configuration error	No	Please make sure that necessary network and application parameters are properly configured. This may include unique keys (DevEUI, AppEUI, AppKEY, devAddr, appSKey, nwkSKey), selecting appropriate spreading factor or data transmission intervals. This can be done using the Terabee Configuration GUI. If the error persists, please contact Terabee support
Network connection error	Device is programmed to restart within 30 sec after error has been detected. This is done for cases when gateway/network has experienced issues, allowing a Terabee device to automatically rejoin the network - after it has been installed in the field.	1. Make sure the provided LoRa antenna is properly connected to the Terabee device. If a non-Terabee antenna is employed, please ensure it supports the corresponding LoRa frequency. 2. Make sure the gateway is powered, operational, and is properly configured with the selected network server 3. Make sure that (a) the exchanged unique keys, and (b) activation method are identical on the Terabee device side and the network server 4. Make sure the Terabee device is in communication range with the LoRa gateway. Please note that physical abstractions (buildings, mountains, hills etc) in the line of sight between the device and the gateway may reduce the LoRa communication range.
Device firmware crash	Device is programmed to restart within 30 sec after error has been detected. Rarely, this may be a necessary step in cases when an internal error needs to be handled and resolved.	If the issue error persists, after re-initiation, please contact Terabee support for a more detailed troubleshooting of the issue.

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