IOT WIRELESS VIBRATION SENSOR
USER MANUAL

Revision 0.1

REVISIONS

DATE	Revision	Change Description	Prepared by	Approver
04/06/2023	Rev 0.1	Initial draft NEW Version		

Contents

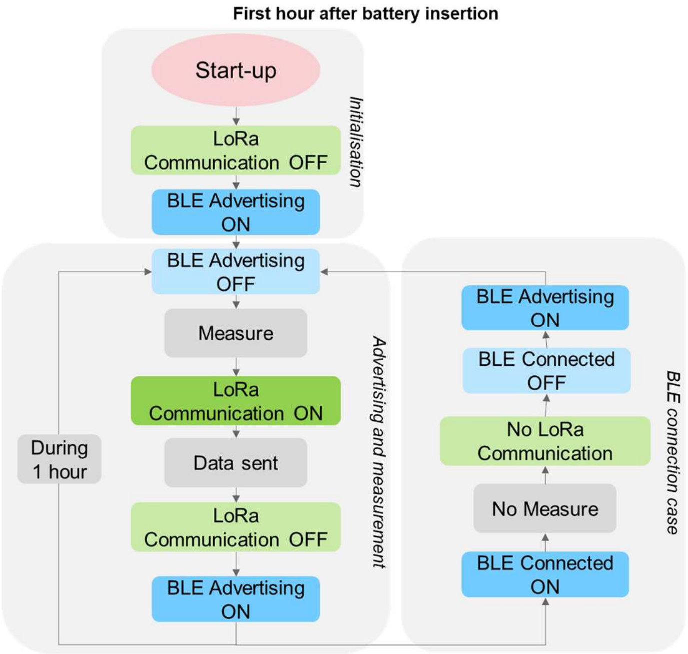
1. General Description

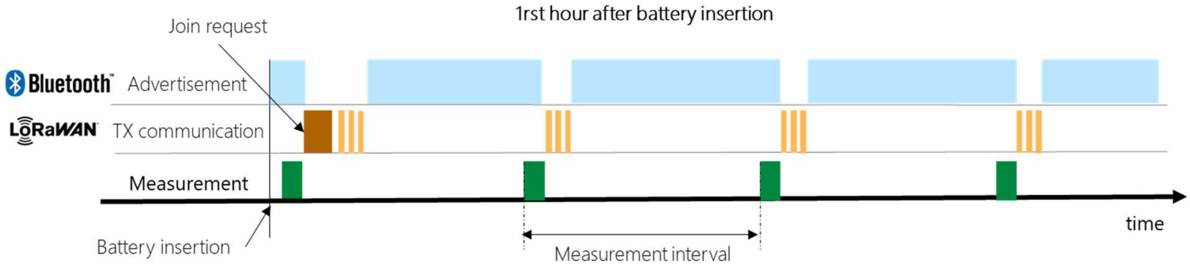
The SL-VLH/SL-V3LH vibration sensor has two BLE modes and one LoRaWAN™ mode:

- BLE advertising mode - Starts automatically when the battery is inserted. Advertising occurs at a rate of once per second.
- BLE connected mode – After each advertisement, the user can initiate a change to connected mode. When connected, the user can configure the device and use other special features.
- LoRaWAN™ mode – Used to communicate with an external network. The device can also be configured via LoRaWAN™ during the first hour after connection.

1.1. DEVICE START-UP

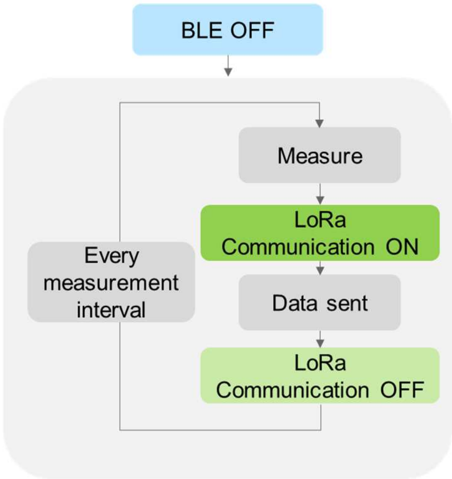
1) Insert battery. On-board LED will flash once upon proper installation.
2) The sensor will begin BLE advertising at the rate of once per second. This rate is not correlated with the measurement interval.
3) After the first BLE advertisement, the sensor will transmit a "Join Request" on the LoRaWAN™ frequency. If successful, sensor data will be transmitted via uplink messages at intervals determined by the sensor default settings. BLE features are disabled during the LoRa communications.
4) Once LoRaWAN™ communications are complete, the sensor will revert back to BLE advertising.
5) During advertising, the user can respond and establish the BLE "Connected" mode. While in Connected mode, the user can configure LoRaWAN™ transmit interval and FFT features.
6) At sixty minutes after start-up, all BLE features are disabled, and data communications will only proceed via the LoRaWAN™ connection protocol. The measurement interval will follow the settings established during the BLE Connected mode time. The sensor configuration can be adjusted via LoRaWAN™ communications just as it was during the initial sixty-minute BLE time.
7) At any time after the initial sixty-minute BLE mode operation, a new sixty-minute period can be initiated by placing a magnet close to the magnet symbol on the sensor housing. Depending on the how long the magnet is applied, either the new BLE mode can be initiated, or the sensor can be reset. See section 4 regarding the Magnetic Switch.





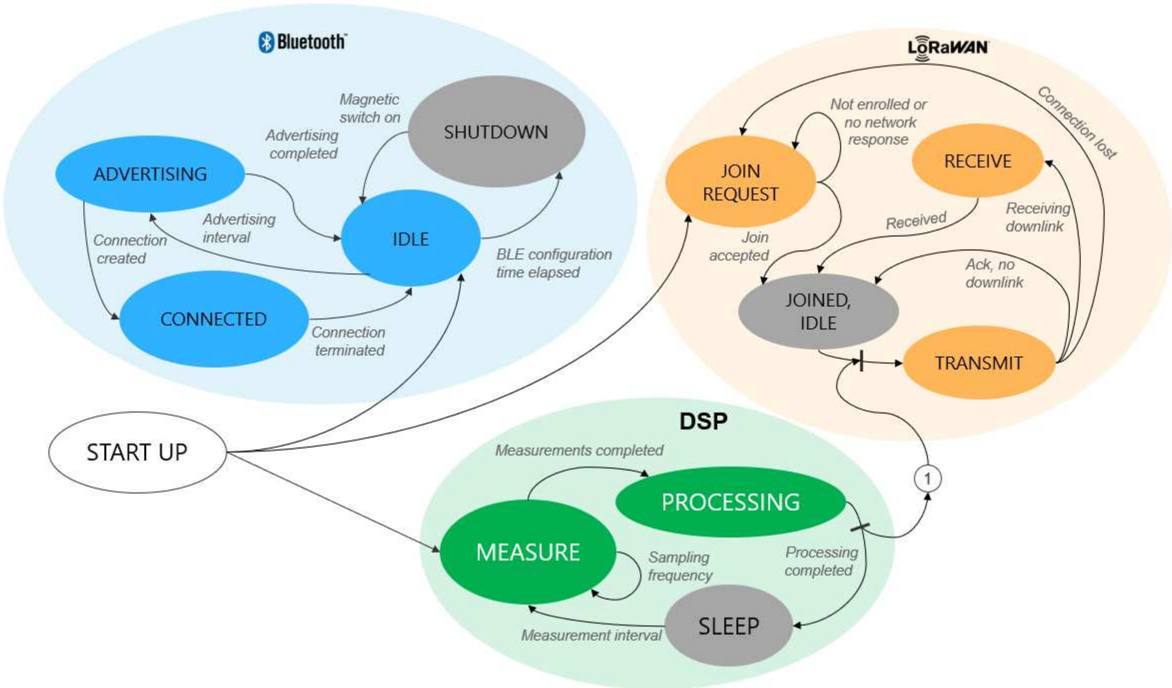
8) One hour after start-up:
   - BLE is disabled
   - Data communication will proceed only via the LoRaWAN™ connection. The device will be in the idle state between transmissions.
   - If the LoRaWAN process was completed successfully at start-up, the processed data is transmitted via three uplink messages in sequence. The measurement will follow the settings established during the BLE Connected mode time. The sensor configuration can be adjusted via LoRaWAN™ communications just as it was during the initial sixty-minute BLE time.

After 1 hour



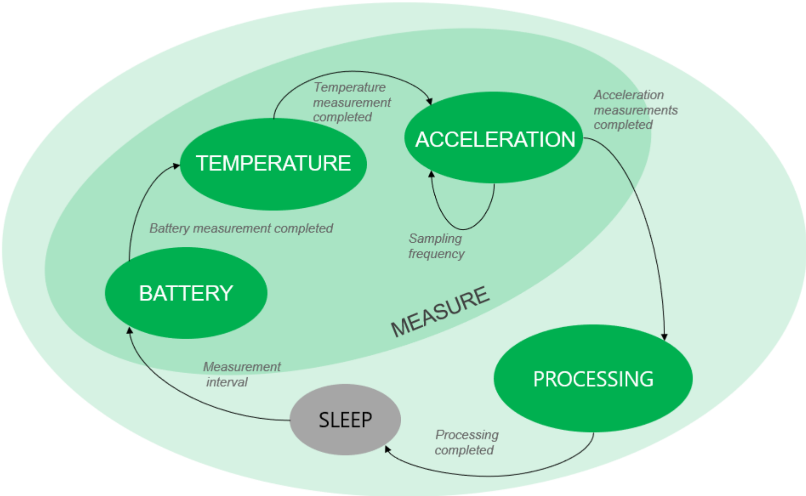
1.2. MODES OF OPERATION

The device operation can be summarized by the following state machine diagram.



1.3. DATA COLLECTION

Sensor measurements are performed and transmitted at a configurable interval from 1 min up to 24 hours. This is driven by the *Measurement interval* parameter.



Upon wake-up, the device powers the sensing element and waits for about 3 seconds to let the accelerometer boot and stabilize its output.

A measurement consists of reading the battery level, temperature, and a set of 4096 acceleration values at a configurable rate.

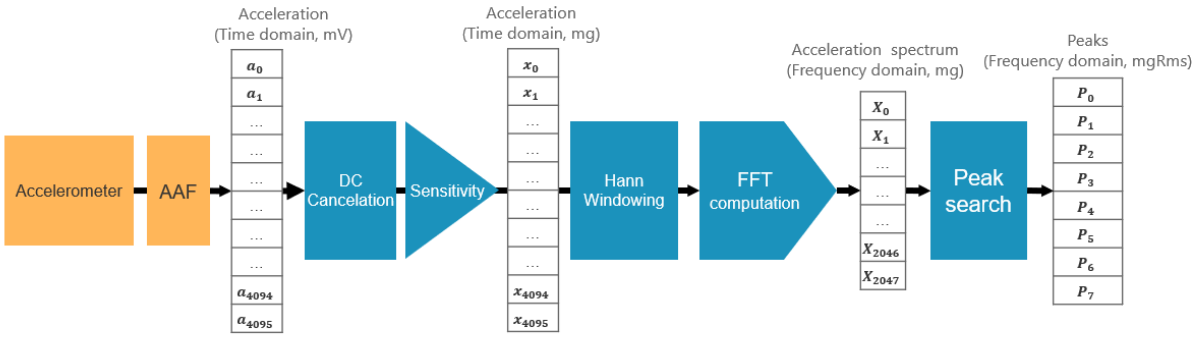
Data	Unit	Accessibility
Battery level	%	LoRaWAN™, BLE
Temperature	°C	LoRaWAN™, BLE
Acceleration	mg	LoRaWAN™, BLE (FFT peaks only)

1.4. DATA PROCESSING

The data processing signal chain transforms the acceleration raw data into frequency peaks. The sensor computes a new value based on the acceleration waveform: peak to peak

$$x_t: time\ domain\ single\ accleration$$

$$P2P = max\ (f(x_t) - min\ (f(x_t)$$



The data processing signal chain transforms the acceleration raw data into frequency peaks. Acceleration data is collected at a selected sampling frequency. Raw data passes through an anti-aliasing filter. Once a set of acceleration readings is measured (4096 points), the embedded algorithm removes the DC signal (to remove the bias voltage of the sensing element) and multiplies the results by the sensor element calibration sensitivity (mV/g). The algorithm then applies a Hann window to the signal and converts it into a normalized FFT spectrum. Finally, a peak search algorithm extracts the most significant peaks from the spectrum.

Certain data is saved for each of the peaks:

Parameters	Description
Peak frequency	Frequency of the peak (Hz)
Peak magnitude RMS	Single frequency peak magnitude RMS (gRMS)
Window RMS	Root means square of the peak's window. Each peak contains the RMS of a unique window. In case of multiple peaks in the same window the value will be duplicated.

The formula is given by:

Considering:

$$X_i: frequency\ domain\ single\ bin\ (two - sided\ power\ spectrum)$$

$$\beta_{hann}: scaling\ factor\ compensation\ due\ to\ hanning$$

$$X_i = \text{abs}(FFT(x_t))$$

$$\beta_{hann} = \sqrt{\frac{8}{3}}$$

$$WIN_{RMS} = \beta_{hann} * \sqrt{\frac{2}{4096^2} \sum_{i=win_{start}}^{win_{end}} X_i{}^2}$$

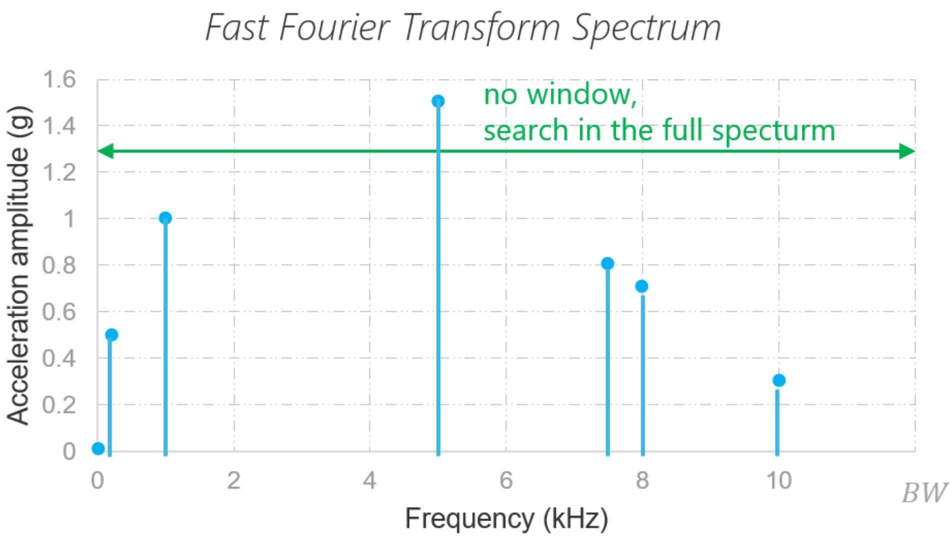
Note that only “Peak values” are accessible by the user. Raw data and raw FFT spectrum are stored for internal computation and are not available outside the sensor.

From this point, several customer defined options are available to further process the data into useful output information.

The customer can establish and configure up to eight windows across the FFT spectrum. For each window, the user can configure the following parameters:

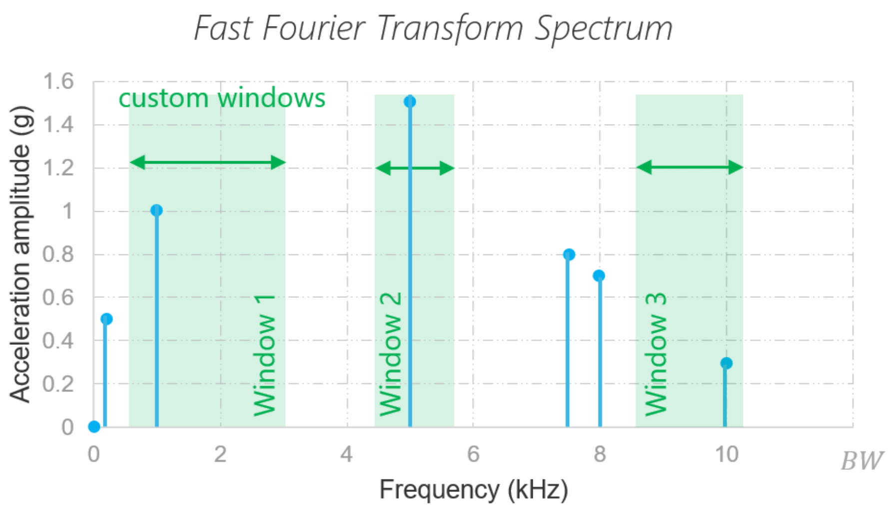
Parameter	Description	
Peak number	Up to 24 peaks can be identified for any custom window The total number of peaks in all windows cannot exceed 24	
Number of bins	Number of bins around the main beam to be integrated into the window RMS. This parameter can be used to filter side lobes and avoid multiple peaks found around the same frequency	
Minimum frequency	Minimum frequency of the search window	These define the bandwidth of each window
Maximum frequency	Maximum frequency of the search window	

By default, no windows have been established or configured. The peak search covers the full spectrum.



Typical FFT spectrum showing the highest eight peaks.

It is possible to program up to 8 custom windows to define several regions of interest. Any peak ouside the windows will be ignored.



Typical FFT spectrum showing eight peaks and 3 windows

1.5. COMMUNICATION – LoRaWAN™

The device includes a LoRaWAN™ MAC 1.0.3 rev A compliant interface (see LoRaWAN® 1.0.3 Specification). It operates as a Class A end-device. The LoRaWAN™ communication protocol operates in an unlicensed radio spectrum. The part number must be selected to match with the region of operation and be in line with the local regulation.

Region	Frequency	Channel Plan	Common name
United State (US)	915 MHz	US902-928	US915

The LoRaWAN™ upload interval can be configured by the customer for any time between one minute and 24 hours (in one-minute steps).

Data upload consists of this information:

- Battery status
- Sensor internal temperature
- Most significant FFT peaks as configured by the user
- Raw sensor data (time domain accelerometer signal) is not available for upload

All customer configurable parameters can be adjusted via LoRaWAN™ using a data download:

- Data capture/upload interval
- Number of peaks
- Number of bins around the peaks
- Number of windows
- Window minimum frequency
- Window maximum frequency

Many of the LoRaWAN™ communication features are adaptive and depend on the network quality. The parameters are negotiated and optimized with the connected gateway.

LoRaWAN™ communications are subject to various regulatory bodies around the world and features in the device firmware help maintain compliance.

1.5.1 Uplink messages format

The uplink contains sensor values such as temperature and peak information. This message is sent at every measurement interval, which means that it is sent regularly to update the server or receiving end with the latest data from the sensor.

The sensor values are expressed in the little-endian (LE) system, which is a way of storing data in which the least-significant byte (LSB) is stored at the smallest address. This is in contrast to the big-endian (BE) system, where the most-significant byte (MSB) is stored at the smallest address.

The length of the uplink frame depends on the number of peaks to be transmitted. If there are more peaks, the frame will be longer, and if there are fewer peaks, the frame will be shorter.

FFT Peak format (fPort=1)																	
Byte	0	1	2	3	4	5	6	7	8	9	10	11	12	…	8+5*n-3	8+5*n-2	8+5*n-1	8+5*n
Description	BATT	PRESET_ID	TEMP		SIG_RMS		SIG_P2P		PEAK_INFO_1						PEAK_INFO_n			

The format of the frame is composed as above:

BATT: battery level, in percentage (1 LSB = 1%). 8-bit unsigned value.
PRESET_ID: identifier of the active preset.
TEMP: current temperature. Little-endian 16-bit unsigned value. A specific value of 0x7FFF is used as an error code.

$$Temperature_{(\,°C\,)} = \frac{TEMP_{(LSB)}}{10} - 100$$

SIG_RMS: Root Mean Square value of the full signal (4096 samples) expressed in mgRMS. Little-endian 16-bit unsigned value. Range is from 0 up to 65.535g.

$$Signal\ RMS_{(g\ rms)} = \frac{SIG\ RMS_{(LSB)}}{1000}$$

SIG_P2P: Peak to peak value of the time domain signal expressed in mg. Range is from 0 up to 65.535g.

$$Signal\ P2P_{(g\,)} = \frac{SIG\ P2P_{(LSB)}}{1000}$$

PEAK_INFO_x: information related to a peak found in the FFT spectrum.

PEAK_INFO_x					
Byte	0	1	2	3	4
Description	FREQ		MAG_RMS		WIN_RMS

- *FREQ*: little-endian 16-bit unsigned value representing the central frequency of the detected peak in Hz.
- *MAG_RMS*: a little-endian 16-bit unsigned value representing the RMS magnitude of the single frequency detected peak plus 1 bin around each side of the peak.

$$Magnitude\ RMS_{(g\ rms)} = \frac{MAG\ RMS_{(LSB)}}{1000}$$

- *WIN_RMS*: an 8-bit unsigned value representing the Root Mean Square value of the window expressed in "log scale".

$$WIN_{RMS_{gRMS}} = 10^\wedge \frac{WIN_{RMS_{LSB}}*0.3149606-49.0268}{20}$$

1.5.2 Downlink messages additional format

The BEQ custom version add the implementation of an optional PRESET_ID argument. It exists four different variations of the downlink. Note that if an optional parameter (preset_id) is not used the frame length varies as following:

For the measurement interval update only, the payload size is 2 bytes instead of 3.
For the measurement interval update plus bandwidth, the payload size is 4 bytes instead of 5.

Type	Description	Fport	Payload length
Standard DSP configuration 1	Configures the DSP (BW and Meas interval)	12	4
Custom DSP configuration 2	Configures the DSP (Meas interval only)	12	2
Custom DSP configuration 3	Configures the DSP (BW and Meas interval) of a preset	12	5
Custom DSP configuration 4	Configures the DSP (Meas interval only) of a preset	12	3

DSP configuration 2,4 fport = 12			
Byte	(0)	2 (3)	3 (4)
Description	(PRESET_ID)	MEAS_INTERVAL	

DSP configuration 1,3 fport = 12					
Byte	(0)	0 (1)	1 (2)	2 (3)	3 (4)
Description	(PRESET_ID)	BANDWIDTH		MEAS_INTERVAL	

PRESET_ID: Optional parameter. Preset id to be updated with the following bandwidth and measurement interval Admissible range is [0-15]. If parameter not used it modifies the active preset.
BANDWIDTH: FFT bandwidth refers to the observable FFT bandwidth coded on a Big-endian unsigned 16-bit value. 1 LSB = 1 Hz. Range is 500Hz to 19.2 kHz
MEAS_INTERVAL: change the interval of measurement and uplink value in minutes. Big-endian unsigned 16-bit value. 1 LSB = 1 min. Range is 1min to 1440 min

1.5.3 BLE connected mode FFT Peak format

FFT peak output										
Byte	0	1	2	3	4	5	6	7	8	9	..
Description	PEAK_CNT	SIG_RMS		RESERVED		PEAK_INFO_n					…
						FREQ		MAG_RMS		WIN_RMS	…

PEAK_CNT: number of peaks detected (8 by default). 8-bit unsigned value.
SIG_RMS: RMS value of the full signal (4096 samples) expressed in mg (RMS). Little-endian 16-bit unsigned value.

$$Signal\ RMS_{(g\ rms)} = \frac{SIG\ RMS_{(LSB)}}{1000}$$

PEAK_INFO_n: information related to a peak found in the FFT spectrum.

PEAK_INFO_x					
Byte	0	1	2	3	4
Description	FREQ		MAG_RMS		WIN_RMS

- *FREQ*: Central frequency of the detected peak in Hz. Little endian 16-bit unsigned value.
- *MAG_RMS*: RMS magnitude of the single frequency detected peak. Little endian 16-bit unsigned value.

$$Magnitude\ RMS_{(g\ rms)} = \frac{MAG\ RMS_{(LSB)}}{1000}$$

- *WIN_RMS*: an 8-bit unsigned value representing the Root Mean Square value of the window expressed in “log scale”.

$$WIN_{RMS_{gRMS}} = 10\text{^}\frac{WIN_{RMS_{LSB}} * 0.3149606 - 49.0268}{20}$$

1.6. BLUETOOTH© LOW ENERGY

The device includes a Bluetooth 5.0 Low Energy compliant interface. This is a low power communication technology which should be used at short distances. It makes the SL-VLH/SL-V3LH a connectable beacon which acts as a peripheral by default and switches to a server role (pairing mode) once a remote device (central) is connected. The BLE interface should be used for device configuration only. BLE is activated automatically upon battery insertion. After one hour, the BLE is de-activated to conserve battery energy. BLE can be re-activated by using the magnet switch. After one hour, BLE is de-activated again.

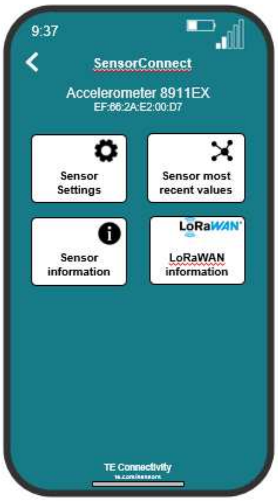
1.6.1. Bluetooth™ App for Mobile Device Communication

Apps can be downloaded from the App Store (iPhone) and Google Play (Android). Search for [App Name], download and install on your mobile device. The sensor will start the advertising mode when a battery is inserted. The sensor will continue in the advertising mode for one hour after which the BLE radio is turned off to conserve battery energy. The advertising mode can be restarted for a period of one hour by using the magnetic switch.

During the advertising period, basic sensor and status information is transmitted and can be received and read by any other BLE device in close proximity. While advertising, the sensor can enter the connected (or paired) mode and communicate with any mobile device using the BLE App. In the connected mode, various sensor parameters can be configured by the user. Sensor output data can also be viewed.

1.6.2. BLE screen examples

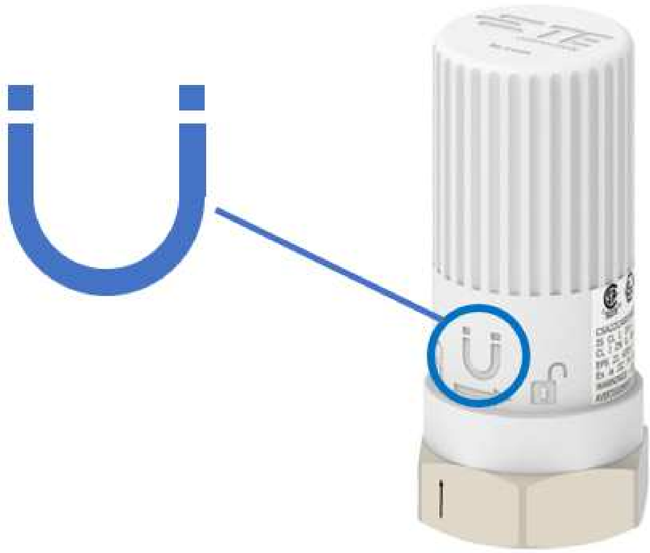
Advertising Mode



Connected Mode

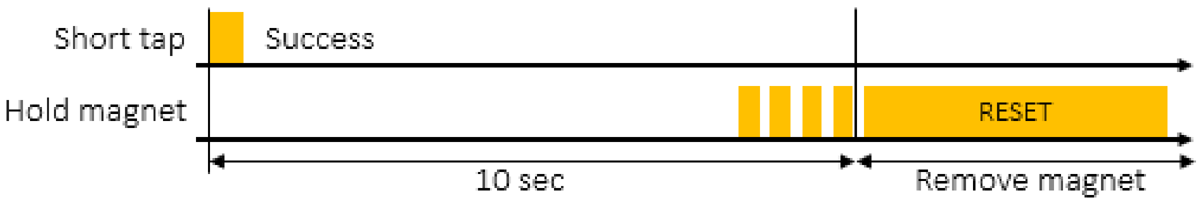
2. Magnetic Switch

The SL-VLH/SL-V3LH has an internal reed switch. This switch is activated when a strong magnet is close to the magnetic sensor location. The magnetic switch location is indicated by the magnet icon on the plastic housing. The magnet must be of sufficient strength and proximity to create a magnetic field of 25 mT at the switch location.



Two different functions are available depending on the user action:

User action	Function	LED
Short tap	Activates BLE for another one hour plus trigs a new measurement and a LoRaWAN™ transmission (uplink if joined, else join request).	One short blink. If user holds the magnet close to the switch for a longer duration, the LED will blink faster. Remove the magnet to only initiate a transmission. Else it going to initiate a sensor reset.
Hold magnet for 10+ seconds	Resets the sensor.	Wait for at least 10 seconds, to see the very fast blink. Release the magnet once a very long orange led appears



LED indicator

3. LED Indicator

The orange LED indicates the state of the SL-VLH/SL-V3LH.

Category	Mode	Description	Pattern
	Power-on/Reset	Led turned on at start up to confirm the battery insertion.	A 2 sec long on
	LoRaWAN™join request	Join request message sent	3 very short blinks
	Uplink	Sending uplink message	very short blink
Status	Success	Operation successful	very short blink
	Fail	Operation failed	1sec long on

The time plots below show the different flash sequences that occur for various actions the sensor is taking.

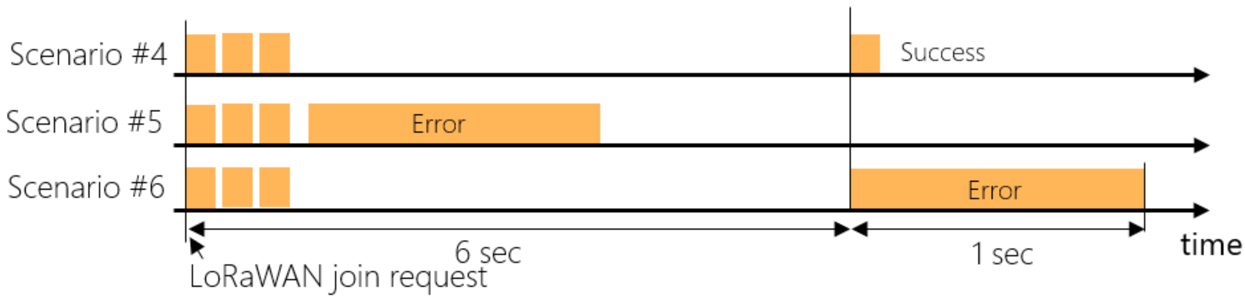
3.1. LoRaWAN™ Join request examples

A normal join request gives 3 fast blinks (few milliseconds on), a 6 second delay then another short blink. In case of error, the LED is turned on for about 1 second.

Scenario #4: A LoRaWAN™ join request is shown with 3 short blinks (few milliseconds on) and about a 6 second later, another short blink (join accept from the gateway).

Scenario #5: For EU-868 region, if an error pattern (1 sec on) is shown just after the 3 blinks, it means the device hasn't sent the message due to duty cycle restrictions.

Scenario #6: In case no response from the gateway, and after about 6 sec after the 3 short blinks, the LED is turned on for about 1 second.

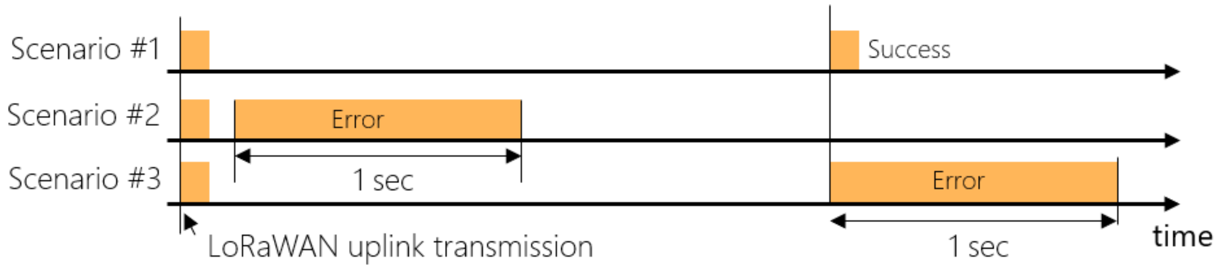


3.2. LoRaWAN™ Uplink transmission Examples

Scenario #1: A normal uplink transmission gives 1 short blink (few milliseconds on) and few seconds later, another short blink (ack from the gateway).

Scenario #2: For EU-868 region, if an error pattern (1 sec on) is shown just after a short blink, it means the device hasn't sent the message due to duty cycle restrictions.

Scenario #3: In case no response from the gateway (Confirmed message up needs a downlink with an acknowledge), delay is about 2 sec after the short blink, the LED is turned on for about 1 second (nack).



4. Presets

The SL-VLH/SL-V3LH has several adjustable functions that tailor the output data to meet user needs. To easily manage these functions, the SL-VLH/SL-V3LH has a feature called "Preset". This feature allows the user to combine functions into commonly used or unique preset configurations.

The presets are divided in two different categories:

- **User**: editable area which allows the user to create his own configurations.
- **Factory predefined**: read only preset which are callable for an easy and fast configuration

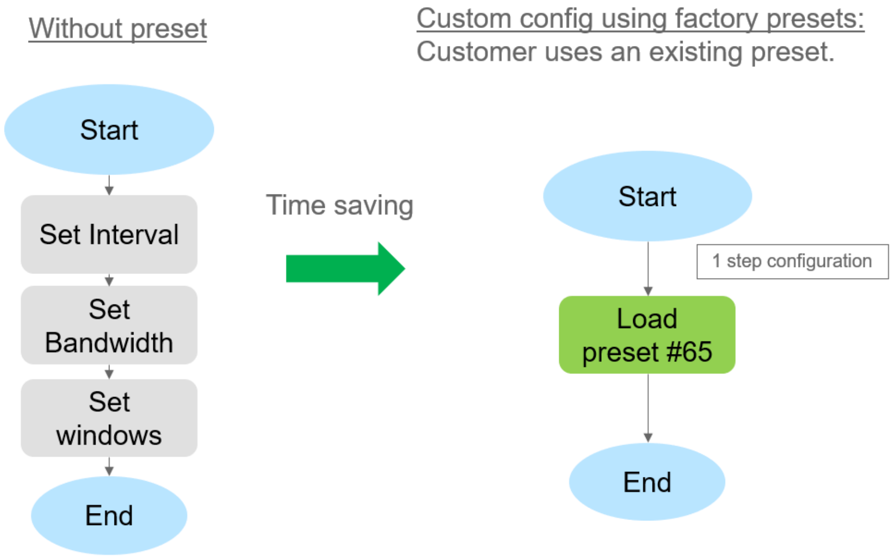
By default, the SL-VLH/SL-V3LH uses the "User preset 0". Any change to the sensor settings such as Bandwidth, Measurement interval, Windows count… will affect the "user preset 0" only. The table below shows the various preset configurations. There are 2 user adjustable configurations.

Category	Preset Name	ID	BW (Fs/2.56)	Meas interval	Windows Count	Windows			
						FreqMin	FreqMax	Integ bin	Peaks
User	User preset 0	0	16k	10 min	8	1	128	0	1
						129	256	0	1
						257	512	0	1
						513	1600	0	1
						1601	2048	0	1
						2049	4096	0	1
						4097	8192	0	1
						8193	16000	0	1
	User preset 1	1	1.6k	1 min	8	1	16	0	1
						17	32	0	1
						33	64	0	1
						65	128	0	1
						129	256	0	1
						257	512	0	1
						513	1024	0	1
						1025	1600	0	1

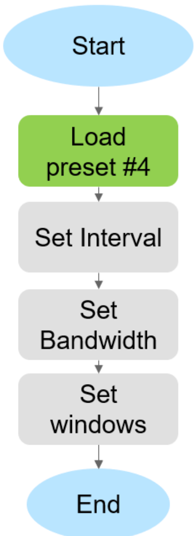
4.1. MANAGING PRESETS

By default, the sensor uses the “User Preset 0”. It is possible to switch between 2 presets by writing the preset identifier to be loaded in a specific register. It can be done anytime.

Once the preset loaded, the parameters shown in the previous table are applied and are instantaneously effective.



If the selected preset is a user preset, the parameters of the active preset can be modified (and saved) in the usual way (over BLE or LoRaWAN™) using the default commands.

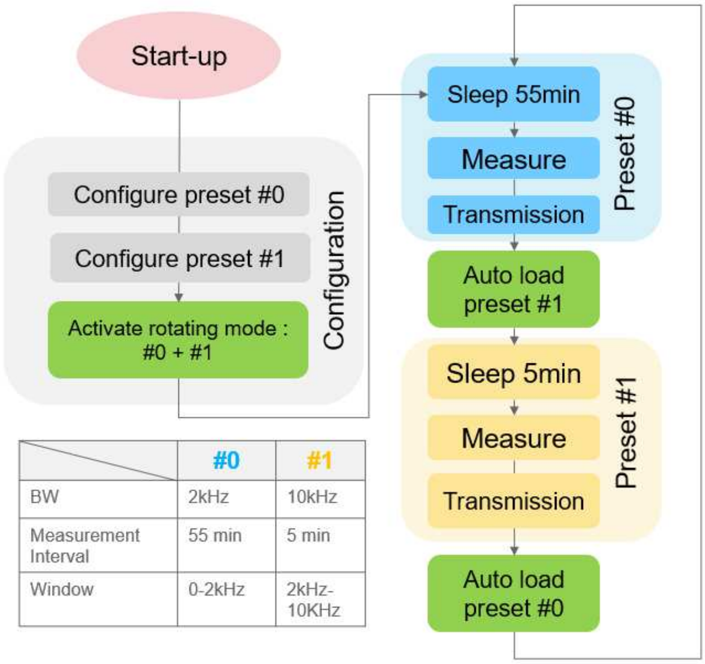


4.2. ROTATING PRESET MODE

In addition to the presets, the SL-VLH/SL-V3LH implements a feature called “Rotating mode”. This provides the user a way to alternate between two presets continuously. After the execution of a preset, the second preset queued in the mode will be loaded, then once executed it comes back to the first.

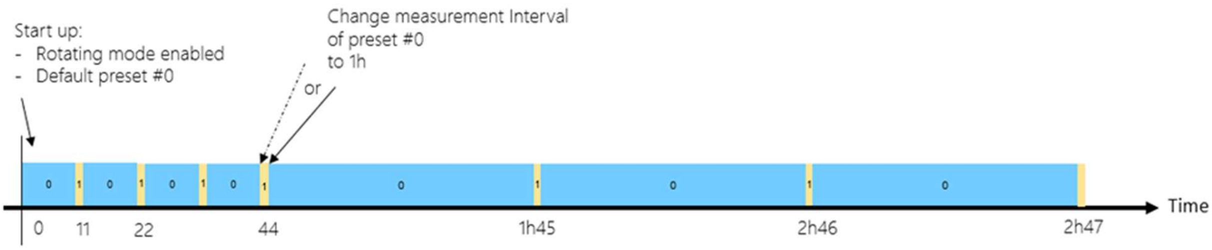
The example below shows how to take advantage of the rotating mode. Here 2 presets are configured with 2 different bandwidth and measurement interval.

The self-Rotating mode automatically switches between #0 and #1 without any external user action required



	#0	#1
BW	2kHz	10kHz
Measurement Interval	55 min	5 min
Window	0-2kHz	2kHz-10KHz

LoRaWAN simplifies device updates when rotating mode is activated. The DSP downlink messages offer an optional parameter to safely change on the fly the value of a preset. Note that these messages won’t disrupt the rotating sequency and can be sent at any time.



5. Battery

5.1. BATTERY TYPE

To meet various certification requirements, the following battery must be used:

Parameters	Typical value
Manufacturer	SAFT
Reference	LS 17330
Technology	Primary lithium-thionyl chloride (Li-SOCl2)
Nominal voltage	3.6 V
Capacity at 20°C	2100 mA
Operating temperature range	- 60°C/+ 85°C

5.2. BATTERY LIFE

The SL-VLH/SL-V3LH vibration sensor is designed to use battery power in the most efficient ways possible. However, battery quality, long term ambient temperature conditions, data collection and transmission intervals, and spreading factor will impact overall battery life.

- Battery Quality – Batteries for the sensor must be acquired from authorized distributors and sources. This ensures that batteries have been stored and transported in temperature conditions that do not exceed the manufacturer's recommended limits. End users must also store batteries within these temperature limits. If batteries are exposed to temperatures exceeding recommended limits, battery life will be affected.

- Ambient Temperature Conditions – Optimum battery life can be expected when the ambient temperature is near 25ºC. In most applications, the temperature will vary within the specified limits. These variations can shorten battery life.

- Data Collection and Transmission Intervals – The sensor consumes the most power when it is taking measurements, processing the data, and transmitting the information via radios. The user can select the intervals for these actions. Longer intervals will consume less battery power and result in longer battery life.

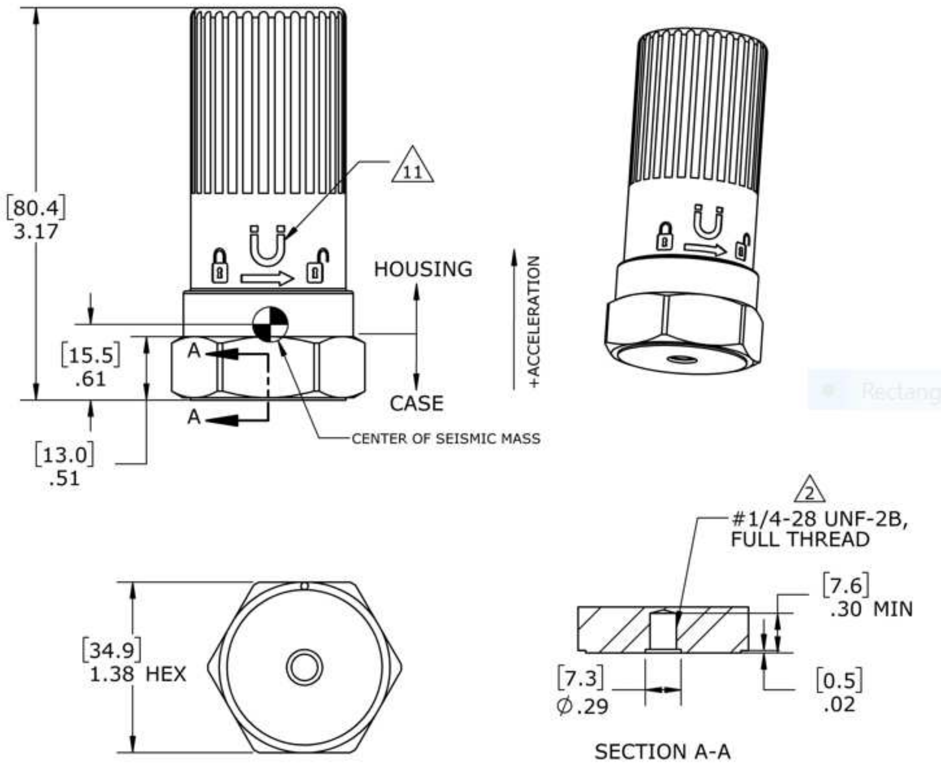
- Spreading Factor – This impacts communication performance of the LoRaWAN™ radio. A larger spreading factor increases the time on air, increases receiver sensitivity, reduces data rate, all to improve communication range. Higher spreading factors will consume more battery energy shortening battery life.

- Under the most ideal conditions, a battery life approaching 10 years may be possible. However, each application will have conditions that are something less than ideal. These typical applications should expect a battery life between 3 and 6 years.

5.3. BATTERY REPLACEMENT

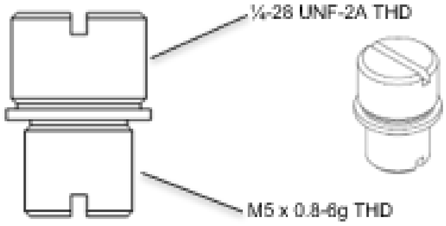
The battery must be replaced if depleted. Unscrew the plastic housing and remove it from the base. Carefully use a small tool (such as a flat screwdriver) to remove the battery. Note that it MUST be replaced by the same battery type as shown above. Substitute batteries may damage and/or bring uncontrolled behavior to the sensor. Double check the polarity and then insert the new battery inside the holder. Re-attach the plastic cover on the sensor. For specific details regarding battery installation and replacement. When complete, the battery life estimator in the firmware must be reset to a "full" battery status.

6. Dimensions



7. Mounting Considerations & Accessories

A solid mounting method is required to get optimum performance from the accelerometer. Any loose parts or unsecured mounting features will introduce noise and corrupt the signals of interest.



1/4-28:M5 Male Stud

Note – Some mounting accessories may be supplied with sample orders. For production deliveries, desired mounting accessories must be ordered as a separate item.

8. REGLUATORY STATEMENTS

FCC

This Radio Equipment is Certified for FCC (US) and ISED (Canada).

This equipment does not support simultaneous transmissions.

Changes or modifications not expressly approved or authorized by BluEyeQ LLC for compliance could void the user's authority to operate the equipment.

FCC Warning:

THIS DEVICE COMPLIES WITH PART 15 OF THE FCC RULES.OPERATION IS SUBJECT TO THE FOLLOWING TWO CONDITIONS: (1) THIS DEVICE MAY NOT CAUSE HARMFUL INTERFERENCE, AND (2) THIS DEVICE MUST ACCEPT ANY INTERFERENCE RECEIVED, INCLUDING INTERFERENCE THAT MAY CAUSE UNDESIRED OPERATION.

Note: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does not cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to correct the interference by one or more of the following measures:

▪ Re-orient or relocate the receiving antenna

▪ Increase the separation between the equipment and the receiver

▪ Connect the equipment to an outlet on a circuit that is different from that to which the receiver is connected.

▪ Consult the dealer or an experienced radio/TV technician for help.

IMPORTANT NOTE:

Radiation Exposure Statement:

This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

Déclarationd'exposition aux radiations:

Cetéquipementestconforme Canada limitesd'exposition aux radiations dans un environnement non contrôlé. Cetéquipementdoitêtreinstallé et utilisé à distance minimum de 20cm entre le radiateur et votre corps.

9. Ordering Information

Model Number:

Model Number	Description	Remark
SL-VLH	Uniaxial Accel	LoRa (915MHzUS)
SL-V3LH	Triaxial Accel	LoRa (915MHzUS)