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xsens

Xsens DOT User Manual

Revision	Date	By	Changes
A	7 Jan 2020	XUF	Initial release.
B	25 April 2020	XUF	Add charger spec and attachment method. Add magnetic distortion description. Add cleaning and storage method. Update firmware update operations. Add sensor components specifications. Add coordinate systems. Add heading reset function. Update data outputs information.
C	27 August 2020	XUF	Add sync and recording LED. Update software package. Add multiple sensor connection tips. Update state transition diagram. Add synchronization feature. Add recording function. Add firmware compatibility. Update Xsens DOT specifications.
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F	25 Mar 2022	XUF, MRA	Add notes for charging LED patterns Add when to perform MFM section Add best practice for orientation drift Add troubleshooting section
G	9 June 2022	XUF	Add Activate sensor section

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List of references

1. Xsens DOT Quick Setup Guide [XD0501P]
2. Xsens DOT SDK Programming guide for Android [XD0201P]
3. Xsens DOT SDK Programming guide for iOS [XD0202P]
4. Xsens DOT BLE Services Specifications [XD0506P]
5. Magnetic Calibration Manual [MT0202P]

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1 Introduction

Xsens has released the 2nd generation of Xsens DOT hardware (hereinafter as v2). The hardware upgrade includes specification improvements as well as user experience optimizations. The Xsens DOT sensor and charger have been upgraded as a drop and replaceable hardware to the existing first generation. Refer to the [Product Change Notification](#) for the details about this upgrade. This document is applicable to v2 with the latest firmware (v2.0.0) and software (v2021.0) versions. Refer to this [link](#) for the archived user manual for v1 hardware.

Xsens DOT is a wearable sensor development platform which features sensor incorporating 3D accelerometer, gyroscope and magnetometer to provide an accurate 3D orientation. The embedded processor in the sensor handles sampling, calibration, strap-down integration of inertial data and the Xsens Kalman Filter core (XKFCore) algorithm for sensor fusion. With wireless data transmission through Bluetooth 5.0, Xsens DOT can provide real-time 3D orientation as well as calibrated 3D linear acceleration, angular velocity and (earth) magnetic field data to a receiving device.

Xsens DOT is the start of a new Xsens product line bringing Xsens sensor solutions to mobile device platforms. With simple-to-use Software-Development-Kit (SDK) and comprehensive documentation, system integrators can easily develop their wearable applications.

The Bluetooth Low Energy (BLE) data transmission, lightweight form factor and IP68 waterproof rating widen the application areas of Xsens DOT, making it easy and durable to use in various scenarios. Using different combinations of 5 sensors, it's flexible to apply Xsens DOT to customized measurement cases.

Fields of use:

1. Health and rehabilitation
2. Sports and exercise science
3. Ergonomics



Figure 1: Xsens DOT sensors with a charger

2 Getting Started

2.1 Xsens DOT set

A standard Xsens DOT v2 set contains:

- 5 Xsens DOT sensors
- 1 charger with power cable
- Xsens DOT software package



Figure 2: Xsens DOT set

The easiest way to get started with Xsens DOT is to use the Xsens DOT app (Android/iOS) to connect the sensors. You can get to know the capabilities of Xsens DOT and to configure the sensor according to your needs. Refer to this [unboxing tutorial](#) to get started quickly.

2.2 Xsens DOT sensor

Xsens DOT sensor provides 3D angular velocity using a gyroscope, 3D acceleration using an accelerometer and 3D earth magnetic field using a magnetometer. Combined with Xsens sensor fusion algorithms, 3D orientation and free acceleration are provided. With the wireless nature of Bluetooth 5.0, Xsens DOT sensor is an excellent measurement unit for tracking human body motions.

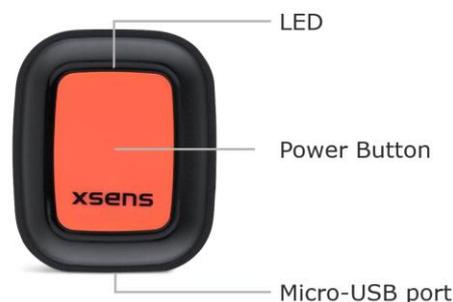


Figure 3: Xsens DOT sensor

On top of the sensor is the LED giving the indications of sensor states. There is a power button in the middle of the sensor. A micro-USB port at the bottom can be used to charge the sensor.

2.2.1 Activate sensor

When using the DOT sensors for the first time, you need to activate the sensors by connecting them to a powered USB cable. You can directly connect to the micro-USB port at the bottom of the sensor, or place multiple sensors in the charger and then connect the charger.

The sensors are shipped in transport mode so that they are in a minimal discharge state to maximize the battery power and extend shelf life. Once the sensor is activated from the transport mode, it is ready for use and doesn't need to be activated again.

2.2.2 Power ON/OFF

The sensor can be powered on by pressing the power button for 2 seconds, and it can be turned off by pressing the power button for over 3 seconds. During that, the LED will give a clear indication by its LED patterns. Refer to section 3.3.1 and 3.3.2 for more details about power ON/OFF.

2.2.3 LED patterns

Xsens DOT v2 sensor has LED patterns to indicate different sensor states.

Table 1: LED patterns

Type	LED colour	LED patterns	Sensor state
General states		ON for 2 seconds	Sensor is being powered on
		ON for 1 second and then fade out	Sensor is being powered off
	-	OFF	Power saving or off
		Blink 1 time per second	Bluetooth broadcasting
		Blink 1 time every 10 seconds	Ready to use (Bluetooth connected)
		ON during sync period, all sensors blink (very quick) synchronously for 3 second if sync succeeds.	Syncing
		Blink 2 times (very quick) every 2 seconds	After a successful sync and during measurement (both streaming and recording)
		Blink 8 times (ultra-quick) and a short pause, last for 10 seconds.	Sensor is being identified
		Blink 2 times (very quick) and a long pause	Bootloader - normal state. This LED status will briefly appear after a successful firmware upgrade
Charging states ¹		Fade in and out, 2-seconds cycle	Charging (battery ≤ 20%)
		Fade in and out, 2-seconds cycle	Charging (20% < battery ≤ 90%)
		ON	Fully charged (battery >90%)

¹ The charging state LED patterns will only be displayed if users don't enable the "Power on via USB plug in" option and the sensor is turned off during charging. Otherwise, sensor will show general state LED patterns as they have higher priority. It is worth noting that this is only about LED display, as long as a powered USB cable is connected, the sensor will be charging.

Error states		ON	Bootloader - error state. Refer to the trouble shooting section for further information.
		Blink 8 times per second	Microcontroller unit (MCU) or battery overheated during charging. Refer to the trouble shooting section for further information.

2.2.4 Reset sensor

In case of firmware failure and the sensor cannot respond to any operations defined in the firmware, a hardware reset function is provided. Follow the steps below to reset the v2 sensor:

1. Press and hold the power button for a minimum of 11 seconds and then release
2. Power on the sensor again by pressing the power button for 2 seconds

2.3 Charger

The charger is a docking station for 5 sensors and includes a plastic cover shell, along with a USB power cable. You can open the charger by holding the cover shell and pull out the docking from the right side.

Each docking slot features an embedded micro-USB port. Sensors can be charged by plugging them into the respective slots. Another micro-USB port placed on the right side of the Xsens DOT charger is used to power on and charge all the sensors docked in the charger. To power this micro-USB port, an adapter of 5V/300mA is enough but we would recommend using a 5V/500mA adapter (5 sensor loads) based on standard USB 2.0 power supply.



Figure 4: Charger with power cable

The USB communication hub is integrated in the v2 charger. Using the Xsens DOT Data Exporter software installed on a PC, you can export the recording files from 5 sensors to the PC at the same time via the charger.

2.4 Body straps and accessories²

You can check all the available straps and accessories from the [webshop](#). Refer to this [BASE article](#) for more information on sensor attachment.

2.5 Software

As Xsens DOT serves as a wearable sensor development platform, we provide all the software needed for different demands. The software package can be download [here](#) and includes:

- Xsens DOT Software Development Kit (Android/iOS)
- Xsens DOT app (Android/iOS)
- Xsens DOT Server
- Xsens DOT Data Exporter
- SDK Documentations (Android/iOS)
- SDK Programming guide for Android
- User Manual
- BLE Service Specifications

2.5.1 Supported platforms

Table 2: Software supported platforms

Software	Supported platforms
SDK and APK for Android	<ul style="list-style-type: none">• Android OS 8.0 and above• ARMv8 CPU architecture, arm64-v8a ABI (64-bit)
SDK and app for iOS	<ul style="list-style-type: none">• iOS 11.0 and above
Xsens DOT Server	<ul style="list-style-type: none">• Windows 7, 10• MacOS• Raspberry Pi
Xsens DOT Data Exporter	<ul style="list-style-type: none">• Windows 10
Bluetooth requirements	<ul style="list-style-type: none">• Best performance with BLE 5.0, DLE³ supported• Compatible with Bluetooth 4.2

2.5.2 Choose your software

You can choose to use different software according to your demands. Please refer to the following instructions on how to choose your software:

- If you focus on the motion data and want to quickly understand the data outputs and capabilities of Xsens DOT, download and install **Xsens DOT app**. It will allow you to:
 - Scan and connect the sensors
 - Data real-time streaming

² Xsens DOT attachment solutions will be more diverse and flexible as we continue to improve

³ Data Length Extension

- Record data in sensor and export to other devices
- Magnetic field mapping
- Firmware update and other functions

Refer to this [BASE article](#) for detailed guidance on Android app and iOS app operations. Xsens DOT app [tutorial video](#) is also available.

- If you are a developer or system integrator wanting to build your own applications, download **Xsens DOT Software Development Kit** (SDK) for Android or iOS applications. Refer to the SDK programming guide and the following example code to get started:
 - Android example: https://github.com/xsens/xsens_dot_example_android
 - Android example: https://github.com/xsens/xsens_dot_example_ios
- If you are familiar with Bluetooth protocol and development, and you want to build applications on any other platforms with Bluetooth 5.0, a lower level **Xsens DOT BLE Service Specifications** is provided to enable direct communication with Xsens DOT. For Windows or MacOS, an open-source project - Xsens DOT Server is provided. You can download it from: https://github.com/xsens/xsens_dot_server.

2.6 Tips for best practice

2.6.1 Multiple sensors connection

Although there is no connection limit in the Xsens DOT app, SDK or BLE services, hardware and OS constraints of the central devices have a ceiling to the maximum number of sensors that can be connected simultaneously. For Android, MacOS and Windows, it is possible to connect up to 7 sensors. In iOS, Linux PC or Raspberry Pi, it is possible to connect up to 11 sensors. The actual connection capability is highly dependent on the device you choose.

However, the BLE performance cannot be guaranteed if the connection limit is reached. If big data loss or connection failure cases are observed, reduce the sensor connection number or the transmission payload.

2.6.2 Magnetic distortion

Ferromagnetic material (iron or steel), magnets or strong electrical currents (several amperes) in the environment near the sensor will cause disturbances to the local magnetic field. The magnetometer in Xsens DOT sensors is used as a 3D compass to determine the direction of the Earth true north (heading or yaw) and is used as an absolute reference in the calculation of 3D orientation. For detailed information about the influence of magnetic field on orientation, see the PhD thesis "[Inertial and magnetic sensing of human movement near ferromagnetic materials](#)" D. Roetenberg 2006. For best results when measuring with Xsens DOT, it is advised to avoid highly magnetized areas when carrying out measurements, particularly in the beginning of the measurement.

To check the magnetic distortion, you can use the Xsens DOT app to check the Magnetic Norm⁴ in magnetic field data after connecting at least one DOT. Look at the Magnetic Norm curve while moving in the measurement area.

- Areas for which the magnetic norm = 1 and the variation remains within ± 0.2 are **magnetic homogeneous** and is optimal for carrying out the measurements (see Figure 5). However, if the measurement begins with a magnetic norm of around 2 or 3, and remains within ± 0.2 of this value, the orientation should remain accurate.
- If the Mag Norm will vary depending on the location and orientation of the device (see Figure 6), there are magnetic distortions in the environment.

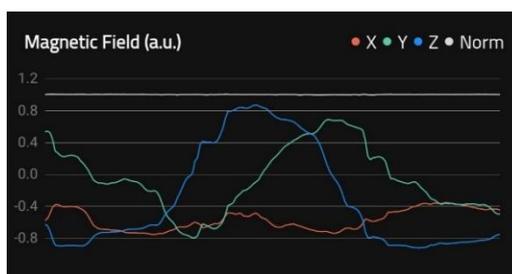


Figure 5: Mag Norm is constant while moving

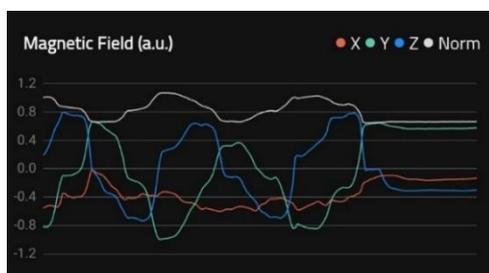


Figure 6: Mag Norm fluctuates when moving

XKFCore algorithm running in the motion processor can compensate for the magnetic disturbance caused by short or fast fluctuating disturbances by optimally using the available sensor information and valid assumptions about the application. However, if the disturbance is slow and large ($> \pm 0.2$) or lasts for over 30s, it's difficult for the algorithm to compensate for and will influence heading accuracy.

If the magnetic field norm has large fluctuations, or the Xsens DOT sensor is attached to an instrument or prosthesis that influences the magnetic field (e.g. ferromagnetic object), it is best to carry out Magnetic Field Mapping (MFM) for this DOT (see section 3.4) to recalibrate the magnetometer.

NOTES:

- **Never expose sensor to strong magnetic fields.** The sensor contains the absolute possible minimum of ferromagnetic materials. Nonetheless, some minor components can be magnetized permanently by exposure to strong magnetic fields.

⁴ Magnetic Norm (Mag Norm) is the norm of all magnetic axis vectors (X, Y and Z) combined. It can be used as an indication of magnetic distortions.

This will not damage the unit but will render the calibration of the magnetometers useless, typically observed as a (large) deviation in the heading.

2.6.3 Drift in orientation data

To guarantee heading accuracy and, therefore, to avoid drift in orientation data, the sensors must be kept still at the beginning of the measurement for 2-3 seconds.

Magnetic interferences can also affect orientation accuracy, please refer to section 2.6.2 to check the presence of magnetic distortion and perform the MFM if needed.

2.6.4 Cleaning method

To clean the Xsens DOT sensors and charger, use a moist cloth to wipe the surface.

2.6.5 Long-term storage guidelines

Follow the recommended guidelines to preserve the battery life of the sensors:

- Operating temperature: 0°C - 50°C.
- Storage temperature: 25°C±10°C.

If the sensors will be stored for a prolonged period of 3 months or longer:

1. Charge all sensors to >90%. You can know the battery level is >90% when the LED shows solid green.
2. Disconnect sensors from charger.
3. Power off the sensors if they are powered on with the USB plugin.

Recharge your Xsens DOT sensors **every 3 months** according to the recommended guidelines to slow the rate of battery ageing thereby improving the battery shelf life.

2.7 Troubleshooting

Table 3: Trouble shooting

Problem	Solution
Sensor LED is solid red, indicating it's in bootloader error state	Reset the sensor by pressing the power button over 11 seconds.
Sensor LED is blinking fast in red and lasts for more than 10 seconds, indicating overheat during charging	Stop charging the sensor and leave it for a while to see if the LED is back to normal. If not, please try to reset the sensor.

If the solution does not work for you, please contact our customer support. Customer support contact information can be found in section 6.2.

3 Xsens DOT Overview

The signal processing architecture of Xsens DOT sensor is presented in Figure 7. The strap down integration (SDI) and sensor fusion algorithms (XKFCore) are integrated into the firmware. You can obtain the orientation increments and velocity increments from SDI, as well as the 3D orientation and free acceleration from XKFCore. Xsens DOT sensor is factory calibrated, making it more accurate repeatable and robust.

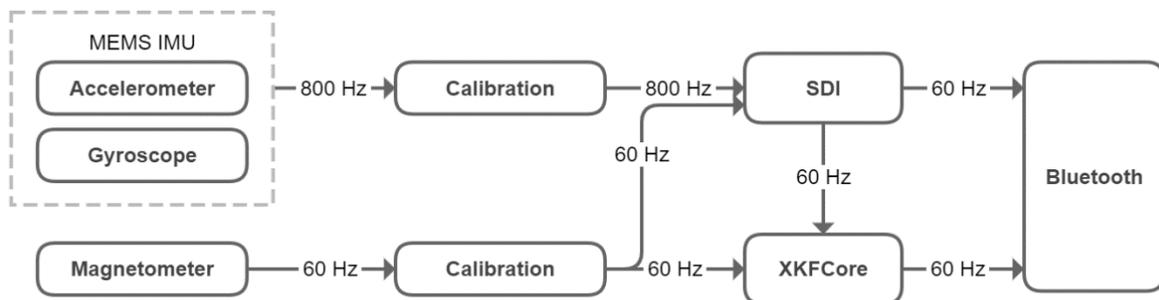


Figure 7: Xsens DOT signal processing architecture

3.1 Strapdown integration

Strap down integration is a method used to compute orientation and velocity increments by integrating angular velocity from gyroscope and acceleration from the accelerometer.

The angular velocity and acceleration data are sampled and calibrated at a high frequency (800 Hz) by the embedded MCU of Xsens DOT sensor to maintain accuracy under dynamic movements such as running and jumping. Due to the high sampling frequency, the data cannot be transmitted via Bluetooth directly and would typically present an excessive computational load on the receiving host device (e.g., mobile phone). The SDI algorithm receives the high-rate sensor input and processes it into a lower-rate signal at 60 Hz. The main advantage of using the SDI algorithm is that the accuracy is maintained, and information is preserved to ensure precise orientation tracking.

The SDK data parser has built-in functions to convert SDI quantities to calibrated angular velocity (rad/s) and acceleration (m/s²) data. Refer to data conversion sections in SDK programming guides.

3.2 Sensor fusion algorithm and filter profiles

The 3D orientation of the sensor is computed by Xsens' latest Kalman filter core algorithm (XKFCore) for sensor fusion, which is optimized for human motions. It uses the output from SDI to compute a statistical optimal 3D orientation estimate of high accuracy, with no drift for both static and dynamic movements. The XKFCore uses the measurement of gravitational acceleration and Earth magnetic north to compensate for slowly increasing errors from the integration of the rate of turn data, and also gives out free acceleration.

As described above, the XKFCore makes assumptions on the range of acceleration and magnetic field sensed to obtain orientation. Since those quantities can widely differ among different user applications, multiple filter profiles are introduced to improve the orientation estimation accuracy. As a result, the XKFCore is optimised to suit different types of movements and applications. Find below additional information on the filter profiles available to choose which is best suited for your application.

Table 4: Filter profiles

Name	Description
General	This filter profile is the default setting. It assumes moderate dynamics and a homogeneous magnetic field. External magnetic distortion is considered relatively short.
Dynamic	This filter profile assumes fast and jerky motions that last for a short time . The dynamic filter uses the magnetometer for stabilization of the heading and assumes very short magnetic distortions. Typical applications are when sensors are applied on persons for sports such as sprinting.

3.3 Xsens DOT sensor state transition

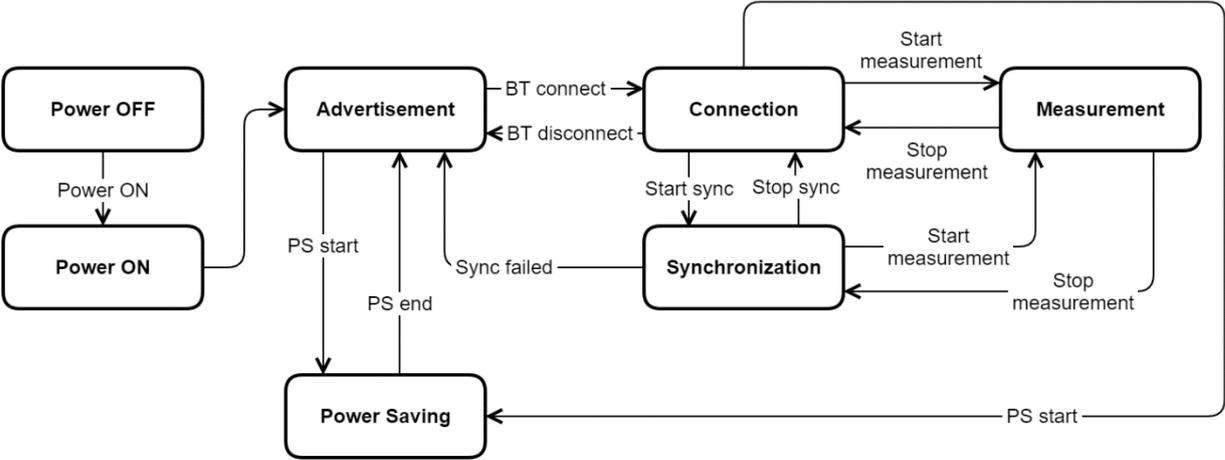


Figure 8: Xsens DOT state transition diagram

3.3.1 Power ON

You can power on the sensor by pressing the power button for 2 seconds. Sensor will go to advertisement mode after powered on.

With the firmware 2.0.0, there is more power on options to allow you to choose whether to power on the sensor via USB plugin. By default, power on by USB is disabled. So, the sensor will be in charging status if connected with USB cable. In the charging status, the sensor keeps charging until battery full and it will not do Bluetooth advertising.



Figure 9: USB power on disabled

You can change this setting via Xsens DOT app (v2021.0) or the SDK (v2021.0). By enabling USB power on, the sensor will power on immediately after the USB plugin. With this feature, you can power on multiple sensors with the USB plugin at once.



Figure 10: USB power on enabled

3.3.2 Power OFF

Sensor will power off under 3 conditions:

1. Power button is pressed over 3 seconds
2. Receive power off command
3. Battery level is lower than 2%.

3.3.3 Advertisement

In advertisement mode, sensors will perform operation idle detection, waiting for BLE connection from host devices. With the default power saving settings, if there is no BLE connection detected over 10 minutes⁵ during advertisement, the sensor will enter power saving mode.

3.3.4 Connection

Once the Bluetooth connection is established, information such as MAC address, device tag name, battery level and charging status... etc. can be retrieved from the sensor. In Xsens DOT app, a reconnection will start automatically once the connection is lost.

If no measurement is started over 30 minutes⁶ during connection, sensor will enter power saving mode.

There is no sensor connection limit set in any software provided by Xsens. Refer to section 2.6.1 for best practices on connecting multiple sensors.

⁵ Default time threshold which can be changed in Xsens DOT app, SDK or by BLE services.

⁶ Default time threshold which can be changed in Xsens DOT app, SDK or by BLE services.

3.3.5 Synchronization

Each sensor has its own clock domain. So, it is important to have the measurement data time-synchronized between different sensors, especially in scenarios where multiple sensors are required simultaneously, e.g., calculation of joint angles.

All the sensors will be time-synced to a common sensor time base after synchronization. As the sensor clock drifts, the synchronization accuracy will decrease over time (Table 4).

Table 5: Synchronization accuracy

Time	Accuracy
After 30 min	1 ppm
After 1 hour	4 ppm

A successful synchronization will take about 14 seconds. During the synchronization, one sensor will be the root node, whereas the remaining sensors are scanners. The root node will periodically send out advertisement messages while the scanners will receive the messages and correct their own time domain by calculating the skew and offset of the root clock.

To achieve a better synchronization result, it is advised to put the root node in a central position of all the scanners. In Xsens DOT app, the first connected sensor will be the root node. SDK users and other developers can set their own rules to choose the root node.

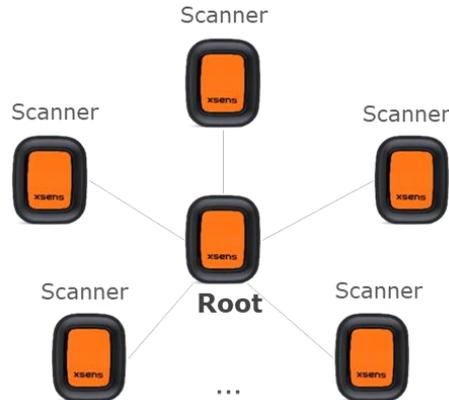


Figure 11: Root and scanners in synchronization

Synchronization should take place before the measurement so that all the sensor data are time-synced. After a synchronization, multiple measurements can be started and stopped without additional synchronization. Refer to this [BASE article](#) for details about synchronization in Xsens DOT app.

NOTES:

- Stop the synchronization after all the measurements to prolong the battery life.

3.3.6 Measurement

Two types of measurement are available with Xsens DOT. Table 6 shows the available output rates for different types of measurement.

Table 6: Output rates

Measurement	Available output rates
Real-time streaming	1Hz, 4Hz, 10Hz, 12Hz, 15Hz, 20Hz, 30Hz and 60Hz
Recording	1Hz, 4Hz, 10Hz, 12Hz, 15Hz, 20Hz, 30Hz, 60Hz and 120Hz

By choosing lower output rates, less data per unit time will be transmitted when compared to the standard 60Hz output rate. As a result, this can mitigate the occurrence of data loss in Real-Time Streaming mode and less data will be stored, thereby recording time can be extended. Conversely, the higher output rate (120Hz) is better suited for high-dynamic applications, where a larger amount of data is needed. However, the higher output rate is only available for Recording mode.

Real-time streaming

In real-time streaming, motion data is streamed and logged to central device (such as the mobile phone) via constant Bluetooth connection.

Sensor fusion data, inertial data and other custom data combinations are provided in real-time streaming, together with packet counter and timestamp. Refer to Chapter 4 for data output specifications.

NOTES:

- In the Xsens DOT app, to make plotting data readable, orientation data will always be displayed in Euler angles, whereas data in the log file will be stored in the chosen format (Euler or quaternion).
- In the Xsens DOT app, to make plotting data readable, inertial data will always be displayed as acceleration (m/s²) and angular velocity (degrees/s) whereas data in the log file will be stored in the chosen format (high fidelity, delta quantities or rate quantities).
- Sensor will still be in streaming status even if the Bluetooth connection is lost. So stop the streaming after every measurement to prevent battery drain.

High fidelity mode

High fidelity mode is available in real-time streaming. In this mode, Xsens proprietary data format will be transmitted via Bluetooth and parsed in Xsens DOT app or SDK. The advantage of this mode is that even in the case of transient data loss, higher frequency (800 Hz) information is still preserved with lower output data rate (60 Hz).

High fidelity data will be parsed to `delta_q`, `delta_v` in Xsens DOT app. Functions to parse high fidelity data to `delta_q`, `delta_v` or calibrated angular velocity and acceleration are available in SDK. Refer to SDK programming guide for detailed information.

Recording

In recording mode, motion data is stored within the sensor internal storage and can be exported for post-processing. The internal storage of the v2 DOT is 64MB. The available recording time depends on the selected output frequency. For example, the available recording time is around 6 hours at 60Hz. With higher output frequency comes less available recording time.

Recording can be started and stopped using Xsens DOT app and these functionalities are available in Xsens DOT SDK or BLE Service Specification manual. Bluetooth connection is not required during recording.

Recording will also stop in the following situations:

- power button is pressed for 1 second during recording.
- time is up for timed recording sessions.
- flash memory is over 90%.

Data can be exported via Bluetooth or via USB connection. Wireless data transfer using Bluetooth is suitable for exporting small files (a few minutes). However, when exporting large amounts of data, it is recommended to use Xsens DOT Data Exporter to export via USB on PC. Refer to this [BASE article](#) on how to use Data Exporter.

As a rule of thumb, when exporting from 5 sensors through the charger, the export speed is around 0.16Mbps. It takes around 10 min to export 60 min's recording at 60Hz.

When exporting data via Bluetooth, it is advised to select few sensors at a time to prevent data transmission loss or connection failure. You can choose different types of data configurations and select recording files when exporting.

Note that free acceleration is not included. For further information on how to calculate it from other quantities, refer to this [BASE article](#).

3.3.7 Power saving

In power-saving mode, sensors will turn off the signal pipeline and BLE connection, put the MCU in a sleep state to ensure minimum power consumption. In this state, sensors cannot be discovered by host devices.

The default time thresholds to enter power saving mode is set to 10 min in advertisement mode and 30 min in connection mode. Power saving mode can be disabled and the time thresholds can be adjusted in Xsens DOT app, SDK or by BLE services.

Sensors will exit power saving mode when:

- Power button is pressed
- Acceleration is detected by accelerometer

Once the sensor enters power saving mode, you can wake it up by pressing the power button or simply shaking it. Xsens DOT will return to advertisement mode when exiting power saving mode.

3.3.8 Button callback function

If there is a single click on the power button during connection, a BLE notification will be sent with a timestamp when this single click is applied. This function is called "Button callback". It is further explained in the Xsens DOT SDK programming guide and the BLE Service Specification. Refer to those for more information.

3.4 Magnetic Field Mapper

When Xsens DOT sensor is mounted to an object that contains ferromagnetic materials, the measured magnetic field can become distorted, causing errors in measured orientation. To correct for known magnetic disturbances, Magnetic Field Mapper function has been developed to allow users to remap the magnetic field of the sensor.

The MFM can be executed in a few minutes and yields a new set of calibration values that can be written to the Xsens DOT's non-volatile memory, which means it will not be erased by powering off or firmware updates.

For SDK users, MFM function is published in v2022.0.0 SDK for both Android and iOS. Refer to the MFM section in the SDK programming guide for details.

3.4.1 When to perform MFM

To obtain the accurate measurement data, when using DOT for the first time, please do an MFM in the environment where the measurement is to be performed.

If you observe objects such as metals or motors in the environment, refer to section 2.6.2 to confirm the existence of magnetic interference and perform MFM if necessary.

3.4.2 How to perform MFM

You can perform MFM with 5 sensors at the same time. Here is a detailed [BASE article](#) about how to do MFM in the app.

A .mtb file containing the calibration data will be created during the MFM. You can find it in your mobile phone:

- Android: under this directory *Android/data/com.xsens.dot.android/files/mfm*
- iOS: Go to Files app → On My iPhone → Xsens DOT → mfm

3.5 Firmware Update

Continuous firmware releases from Xsens are scheduled for new features, improvements, and bug fixes. With Over-the-Air (OTA) firmware update function in Xsens DOT, you can easily update the sensors to latest firmware version with Xsens DOT app.

For SDK users, device firmware update via OTA is published in v2021.0 SDK for both Android and iOS. Refer to device firmware update sections in the SDK programming guide.

NOTES:

- Make sure app is updated to the latest version first before carrying out the OTA.
- Sensors can only upgrade or downgrade when **in charging status**.
- Do not exit the update page or close the app during OTA.
- Network connection is required for OTA.

3.5.1 Firmware update

Once the sensor is connected, you can receive firmware update notifications if a new version of firmware is available in Xsens DOT app. If no notification is received, the current firmware version is up to date.

Follow these steps to perform a firmware update:

1. Put sensors in charging status
2. Open Xsens DOT app and connect the sensors you want to upgrade
3. Follow the notification badge, go to **Advanced** → **Device Firmware Update**, choose **Upgrade**
4. Check available new firmware version, select sensors to upgrade
5. Check release notes and start upgrade
6. Check upgrade status after all upgrade is done. The sensor will automatically reboot after firmware upgrade
7. Wait 10 seconds for sensor rebooting and then you can connect the sensors again to experience the new firmware.

3.5.2 Firmware downgrade

Firmware downgrade function is provided to downgrade the **beta** firmware versions to the last stable version. Stable firmware versions cannot downgrade to any previous versions.

Moreover, if a new stable version is available, beta versions cannot rollback to previous stable versions. You can only update the beta versions to the new stable version under this circumstance. If downgrading to a previous firmware version is needed, contact technical support.

3.5.3 Firmware compatibility

Refer to the [firmware changelogs](#) for its compatibility with hardware, SDK and Xsens DOT app.

NOTES:

- Sensors with incompatible firmware versions can always be connected and upgraded to the latest firmware version in the Xsens DOT app.

4 Output Specifications

Data output from Xsens DOT is represented in different coordinate systems. Each data output is explained below.

4.1 Coordinate systems

4.1.1 Sensor coordinate system

The **sensor coordinate system (S)** is a right-handed coordinate Cartesian system that is body-fixed to the sensor. Depicted below is the sensor coordinate system on DOT, using small x , y and z .



Figure 12: Xsens DOT sensor coordinate system

4.1.2 Orientation coordinate system

By default, the **local earth-fixed reference coordinate system (L)** used is defined as a right-handed Cartesian coordinate system with:

- X positive to the East (E).
- Y positive to the North (N).
- Z positive when pointing up (U).

This coordinate system is known as East-North-Up (ENU) and is the standard in inertial navigation for aviation and geodetic applications. With the default ENU (**L**) coordinate system, Xsens yaw output is defined as the angle between East (X) and the horizontal projection of the sensor x-axis, positive about the local vertical axis (Z) following the right-hand rule. The origin of the reference frame is located in correspondence of the location of the accelerometer. For additional information on the position of the accelerometer, check out the Xsens DOT technical drawing at chapter 5.4.

The orientation calculated by Xsens DOT is the orientation of the sensor coordinate system (**S**) with respect to the local earth coordinate system (**L**). Xsens DOT can output a North referenced Yaw, also referred to as Heading. By default, the orientation output is in the

East-North-Up (ENU) frame, meaning that Roll, Pitch and Yaw will equal 0 degrees when the x-axis of the sensor is aligned with East, the y-axis with North and the z-axis upward:

- X positive when pointing to the local magnetic East
- Y positive when pointing to the local magnetic North
- Z positive when pointing up

True North vs. Magnetic North

As defined above the output coordinate system of Xsens DOT is with respect to local Magnetic North. The deviation between Magnetic North and True North (known as the magnetic declination) varies depending on your location on earth and can be roughly obtained from various models of the earth's magnetic field as a function of latitude and longitude.

4.1.3 Heading reset

Heading reset function allows the user to align heading outputs among all sensors and with the object they are connected to. Performing a heading reset will determine the orientation and free acceleration data with respect to a different earth-fixed local frame (L'), which defines the L' frame by setting the X-axis of L' frame while maintaining the Z-axis along the vertical. It computes L' such that Yaw becomes 0 deg.

The heading reset function must be executed **during real-time streaming and with measurement mode including orientation output**. The reset orientation is maintained between measurement start/stop and connection/disconnection but will be lost after a device reboot.

The heading reset can be performed in Xsens DOT app and is available in SDK. Follow these steps to do the heading reset in app:

1. Put sensors in charger to give an aligned heading for all sensors; you can also choose to place the charger flat on a surface so the Z-axis of sensors all pointing upwards.
2. Connect the sensors
3. Start sensor fusion data measurement
4. Press the ⋮ button and select [Reset Heading]. It will apply to all the sensors under measurement
5. Choose [Revert Heading] if you want to undo the heading reset.

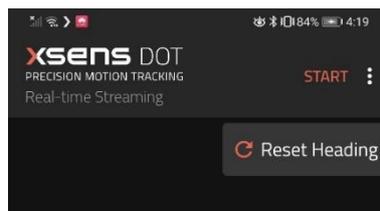


Figure 13: Heading reset/revert in Xsens DOT app

Refer to *Xsens DOT SDK programming guide* for the implementation of heading reset function with SDK.

4.2 Sensor data outputs

Calibrated data has been going through Strapdown Integration and Inverse Strapdown Integration.

4.2.1 Calibrated delta_q and delta_v

This output is coning- and sculling compensated strap down integrated data in the sensor coordinate system (**S**). Delta_q and Delta_v values represent the orientation change and velocity change during a certain interval. For Xsens DOT, this interval is 16.67 ms (60 Hz) by default.

Table 7: Delta_q and Delta_v outputs

Data	Unit
dq	(-) quaternion values
dv	m/s

dq can also be noted as delta_q, delta_angle, del_q or OriInc. dv can also be noted as Delta_v, delta_velocity, del_v or VelInc.

It is possible to multiply consecutive dq values to find the total orientation change over a specific period. Note that this data is not drift free, as it has not been processed by the sensor fusion filters. Use the orientation output for drift free orientation.

Calibrated acceleration can be obtained from the following formula, where dt=1/output rate (in the standard scenario in which the output rate is 60Hz, then dt = 1/60 = 16.667ms)

$$\text{Calibrated acceleration} = \frac{dv}{dt}$$

Functions are available as part of SDK to convert dq and dv to quantities of angular velocity (deg/s) and acceleration (m/s²). Refer to SDK programming guide and documentations for more information.

4.2.2 Calibrated inertial data and magnetic field data

Output of calibrated 3D linear acceleration, 3D rate of turn (gyro) and 3D magnetic field data is in sensor coordinate system (**S**).

The units of these data output are as follows:

Table 8: Inertial and magnetometer data outputs

Data	Unit
Acceleration	m/s ²
Angular velocity	degree/s

Magnetic field	a.u. (arbitrary units) ⁷ normalized to earth field strength
----------------	--

4.2.3 Orientation

The output orientation can be presented in different parameterizations:

Table 9: Orientation outputs

Parameterization	Unit
Quaternions	(-) quaternion values
Euler angles	degree. Yaw, pitch, roll (ZYX Euler Sequence. Earth fixed type, also known as Cardan or aerospace sequence)

A positive rotation is always “right-handed”, i.e., defined according to the right-hand rule (corkscrew rule). Refer to this [BASE article](#) for detailed definition of orientation outputs, and how quaternions, Euler angles relate to each other.

Users can access conversion functions in SDK to convert orientation in quaternions to Euler angles. Refer to SDK programming guide for more information.

4.2.4 Free acceleration

Free acceleration is the acceleration in the local earth coordinate system (**L**) from which the local gravity is deducted.

Table 10: Free acceleration outputs

Data	Unit
Free acceleration	m/s ²

4.2.5 Timestamp and packet counter

Each data message from Xsens DOT is accompanied by a packet counter and a timestamp.

Packet Counter

Packet counter starts with every new measurement and increase with every generated data message. This value wraps at 0xFFFFFFFF.

SampleTimeFine

Contains the timestamp of an output expressed in 1MHz clock ticks of the device’s local clock. The unit of the SampleTimeFine is microsecond. If the data output rate is 60 Hz, the time interval between two SampleTimeFine is 16667 μs.

⁷ one a.u. is the magnetic field strength during calibration at Xsens’ calibration lab, approximately 40 uT.

SampleTimeFine starts when the sensor is powered on and wraps at 0xFFFFFFFF ($2^{32}-1$), which is about 1.2 hours after the sensor is on. SampleTimeFine will restart from 0 if the sensor reboots.

4.2.6 Status

The status in the logging file is expressed in decimal. Refer to the table below for status definitions.

Table 11: Status Definition

Data (Bit mask)	Data in decimal	Abbreviation	Description
0x00000100	16	FL_ClipAccX	Accelerometer is out of range in x-axis
0x00000200	32	FL_ClipAccY	Accelerometer is out of range in y-axis
0x00000400	64	FL_ClipAccZ	Accelerometer is out of range in z-axis
0x00000800	128	FL_ClipGyrX	Gyroscope is out of range in x-axis
0x00001000	256	FL_ClipGyrY	Gyroscope is out of range in y-axis
0x00002000	512	FL_ClipGyrZ	Gyroscope is out of range in z-axis
0x00004000	1024	FL_ClipMagX	Magnetometer is out of range in x-axis
0x00008000	2048	FL_ClipMagY	Magnetometer is out of range in y-axis
0x00010000	4096	FL_ClipMagZ	Magnetometer is out of range in z-axis

5 Physical Specifications

5.1 Sensor specifications

The specifications apply to Xsens DOT 2nd generation sensor.

Table 12: Xsens DOT sensor specifications

Physical Properties	
Attachment	Application dependant, straps available by Xsens (sold separately)
Latency	30 ms
Battery life	Around 8 in continuous measurement
Weight	11.2 g
Dimensions	36.3 x 30.4 x 10.8 mm (l x w x h)
Operating temperature range	0 – 50 °C
Storage temperature range	25 ±10 °C
IP Rating	IP68
Internal storage	64 MB
Recording time	Depends on output rate, 6 hours @60Hz
Synchronization accuracy	1 ppm for 30 min, <4 ppm for 1 hour
Internal sampling rate	800 Hz
Output rate	1Hz, 4Hz, 10Hz, 12Hz, 15Hz, 20Hz, 30Hz, 60Hz and 120Hz (120Hz is only for recording)
Communication	Best performance with Bluetooth 5.0 devices
Communication platforms	<ul style="list-style-type: none"> • Android OS 8.0 or above • iOS 11.0 or above • Windows, MacOS, Raspberry Pi
Operating frequency range	2401 - 2480 MHz
Max radiated output power with internal antenna (EIRP)	+5 dBm

Table 13: Orientation Performance

Orientation	Accuracy
Static (Inclination Heading)	0.5° 1.0° 1σ RMS
Dynamic (Inclination Heading)	1.0° 2.0° 1σ RMS

5.2 Charger specifications

The specifications apply to Xsens DOT 2nd generation charger.

Table 14: Charger specifications

Physical Properties	
Weight	115 g (without DOTs)
Dimensions	183.6 x 53.6 x 21.1 mm (l x w x h)
USB communication hub	Yes
Operating voltage	5V
Power consumption	120 mA (460 mA with DOTs)
Operating temperature range	0-70 °C
Storage temperature range	40-100 °C
Environmental humidity range	20-80%RH NC

5.3 Sensor components specifications

Table 15: Gyroscope specifications

Gyroscope	Unit	Value
Standard full range	[°/s]	±2000
Sensitivity	[LSB/g]	16.4
In-run bias stability	[°/h]	10
Bandwidth (-3dB)	[Hz]	255
Output noise density	[°/s/√Hz]	0.007
g-sensitivity	[°/s/g]	0.1
Nonlinearity	[%FS]	0.1
Scale factor variation	[%]	0.5 (typical) 1.5 (over life)
Sample Frequency	[Hz]	800
Resolution	[bit]	16

Table 16: Accelerometer specifications

Accelerometer	Unit	Value
Standard full range	[g]	±16
Sensitivity	[LSB/g]	2048
In-run bias stability	[mg]	0.03
Bandwidth (-3dB)	[Hz]	324 (Z axis: 262)
Output noise density	[μg/√Hz]	120
Nonlinearity	[%FS]	±0.5
Sample Frequency	[Hz]	800
Resolution	[bit]	16

Table 17: Magnetometer specifications

Magnetometer	Unit	Value
Full scale	[Gauss]	±8
Total RMS noise	[mGauss]	0.5
Resolution	[mGauss]	0.25
Nonlinearity	[%FS]	0.2
Sample Frequency	[Hz]	60
Resolution	[bit]	16

Table 18: Alignment specifications

Parameter	Unit	Value
Non-orthogonality (accelerometer)	[°]	0.05
Non-orthogonality (gyroscope)	[°]	0.05
Non-orthogonality (magnetometer)	[°]	0.05
Alignment (gyr to acc)	[°]	0.05
Alignment (mag to acc)	[°]	0.1
Alignment of acc to the module board	[°]	0.2
Non-orthogonality (accelerometer)	[°]	0.05

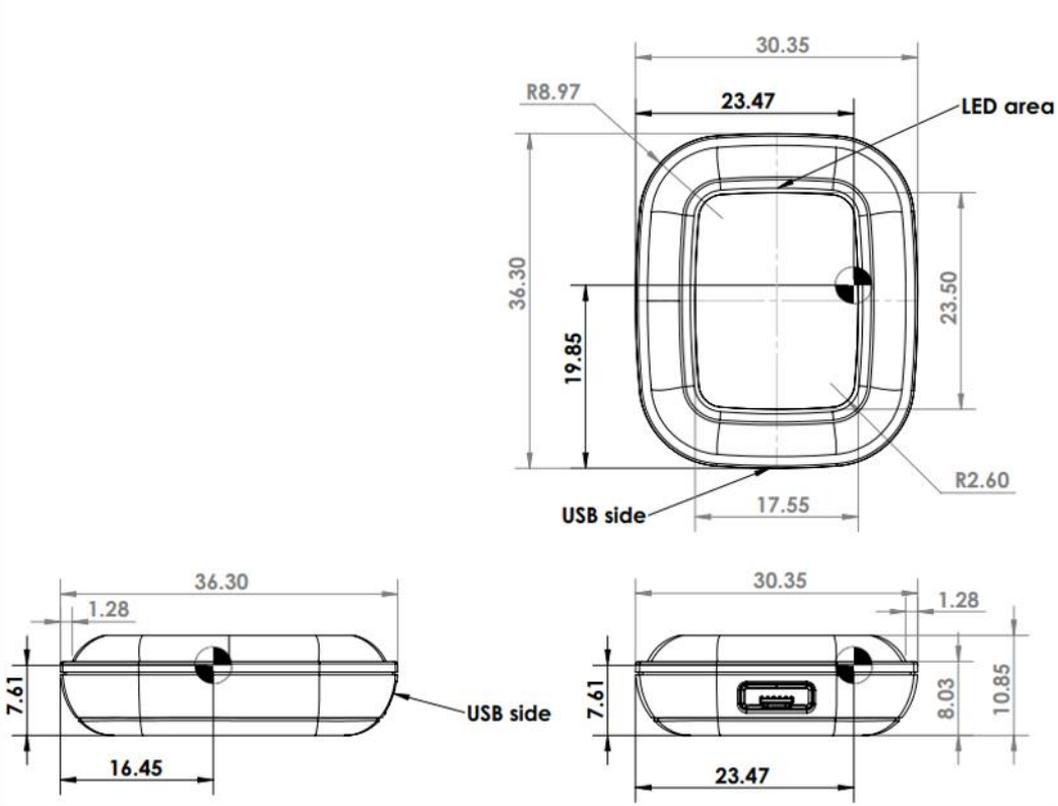
5.4 Battery specifications

LIR2032H rechargeable coin battery is used in the 2nd generation of the sensor.

Table 19: Battery Specifications

Parameter		Value
Capacity	Nominal	70 mAh
	Minimum	65 mAh
Nominal Voltage		3.7V
Dimension	Diameter	20.0 (Max) mm
	Height	32 _{+0.2} mm
Weight		3.15 g
Working Temperature		-20 ~ +60 °C
Storage Temperature		20±1 °C

5.5 Sensor technical drawing



All dimensions are in millimeters
 Tolerances: ISO 2768
 Roughness: NEN 3634

 Accelerometer reference

Figure 14: Sensor technical drawing

5.6 Charger technical drawing

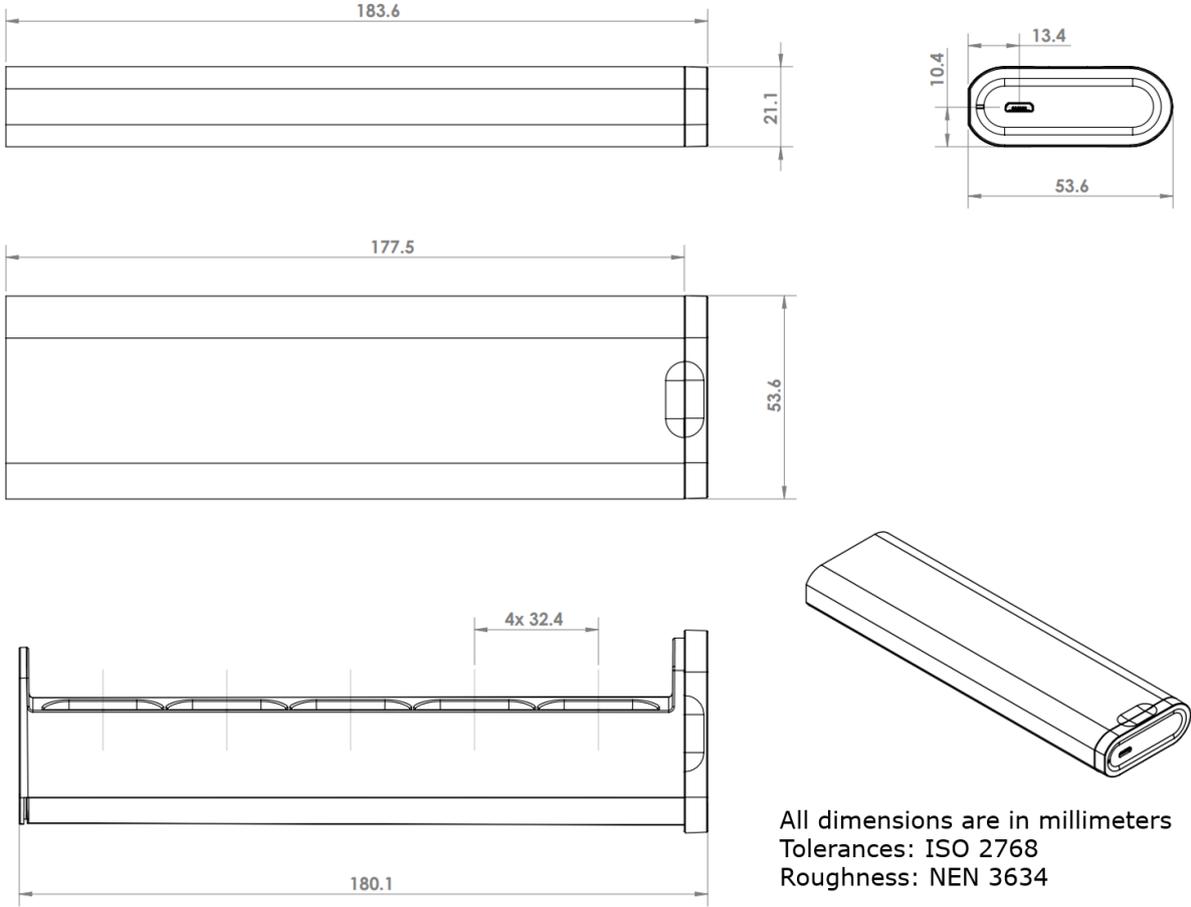


Figure 15: Charger technical drawing

6 Important Notices

6.1 Warranty and Liability

Xsens warrants the products manufactured by it to be free from defects in material and workmanship for a period of two years from the date of delivery. Products not subjected to misuse will be repaired, replaced or credit issued at the sole option of Xsens Contact Xsens via <http://www.xsens.com/support> for return material authorization (RMA) prior to returning any items for calibration, repair or exchange. The product **must be returned in its original packaging** to prevent damage during shipping.

The warranty shall not apply to products repaired or altered or removed from the original casing by others than Xsens so as, in Xsens opinion, to have adversely affected the product, products subjected to negligence, accidents or damaged by circumstances beyond Xsens control.

NOTE: Xsens reserves the right to make changes in its products in order to improve design, performance, or reliability.

Subject to the conditions and limitations on liability stated herein, Xsens warrants that the Product as so delivered shall materially conform to Xsens' then-current specifications for the Product, for a period of one year from the date of delivery. ANY LIABILITY OF XSENS WITH RESPECT TO THE SYSTEM OR THE PERFORMANCE THEREOF UNDER ANY WARRANTY, NEGLIGENCE, STRICT LIABILITY OR OTHER THEORY WILL BE LIMITED EXCLUSIVELY TO PRODUCT REPAIR, REPLACEMENT OR, IF REPLACEMENT IS INADEQUATE AS A REMEDY OR, IN XSENS' OPINION IMPRACTICAL, TO REFUND THE PRICE PAID FOR THE PRODUCT. XSENS DOES NOT WARRANT, GUARANTEE, OR MAKE ANY REPRESENTATIONS REGARDING THE USE, OR THE RESULTS OF THE USE, OF THE PRODUCT OR WRITTEN MATERIALS IN TERMS OF CORRECTNESS, ACCURACY, RELIABILITY, OR OTHERWISE. Xsens shall have no liability for delays or failures beyond its reasonable control.

The Xsens DOT sensor contains a Lithium-Ion Coin cell battery. For safety reasons:

- Strictly prohibits opening the DOT sensor.
- Strictly prohibits heat or throw the DOT sensor into the fire.
- Strictly prohibits use leave the DOT sensor close to fire or inside of a car where the temperature may be above 60°C. Also do not charge / discharge in such conditions.
- Thoroughly read the user's manual before use, inaccurate handling of the lithium-ion rechargeable cell may cause leakage, heat, smoke, an explosion, or fire, capacity decreasing.
- Strictly prohibits put cell into a microwave oven, dryer, or high-pressure container.
- When the Xsens DOT is not used for an extended period, store it in a place with low humidity and low temperature. Refer to section 2.6.5 for long-term storage guidelines.

Strictly keep the DOT sensor away from children. DOT sensor can be attractive to children due to its color and shape, and they could put it in their mouth and swallow it with the danger of suffocation.

6.2 Customer Support

Xsens is glad to help you with any questions you may have about the Xsens DOT, or about the use of the technology for your application. The fastest way is Xsens' Help Centre, where engineers and other Xsens users meet. Please visit this Help Centre:

- ⇒ Help centre: <https://base.xsens.com>
- ⇒ Support page: <https://www.xsens.com/support>

6.3 Product Compliance

European Union regulatory compliance

Based on the tested mode of operation(s), the applicable performance criteria, and specified acceptance criteria, this device complies with the essential requirements and other relevant provisions of:

Short name	Directive
Radio Equipment Directive (RED)	2014/53/EU
Electromagnetic compatibility (EMC)	2014/30/EU
Low Voltage (Product Safety)	2014/35/EU
Restriction of the use of certain hazardous substances (RoHS)	2011/65/EU

FCC compliance

Based on the tested mode of operation(s), the applicable performance criteria, and specified acceptance criteria, this device complies with Part 15 of the FCC Rules.

Object classification	Directive
Computers and other digital devices, unintentional radiator	47 CFR 15

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.

This device contains FCC ID: XPYANNAB1 IC: 8595A-ANNAB1

Japan radio equipment compliance

The ANNA-B112 module complies with the Japanese Technical Regulation Conformity Certification of Specified Radio Equipment (ordinance of MPT N°. 37, 1981), Article 2, Paragraph 1:

- Item 19 "2.4 GHz band wideband low power data communication system".



Find more detailed information on Xsens DOT certification [here](#).