Document XD0502P, Revision A, 7 Jan 2020

xsens

Xsens DOT User Manual

Revision	Date	By	Changes
A	7 Jan 2020	XUF	Initial release

Table of Contents

List of references

1. Xsens DOT Quick Setup Guide [XD0501P]
2. Xsens DOT Android Programming guide [XD0201P]
3. Magnetic Calibration Manual [MT0202P]

1 Introduction

Xsens DOT is a wearable sensor platform, incorporating 3D accelerometers, gyroscopes and magnetometers to provide an accurate 3D orientation. The embedded processor in the sensor handles sampling, calibration, strapdown integration of inertial data and Xsens Kalman Filter core (XKFCore) algorithm for sensor fusion. With wireless data transmission through Bluetooth 5.0 protocol, 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 solution to mobile device platform. With simple-to-use SDK and comprehensive documentation, system integrators can easily develop their own wearable applications.

The Bluetooth Low Energy (BLE) data transmission, lightweight form factor and IP68 rating features 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

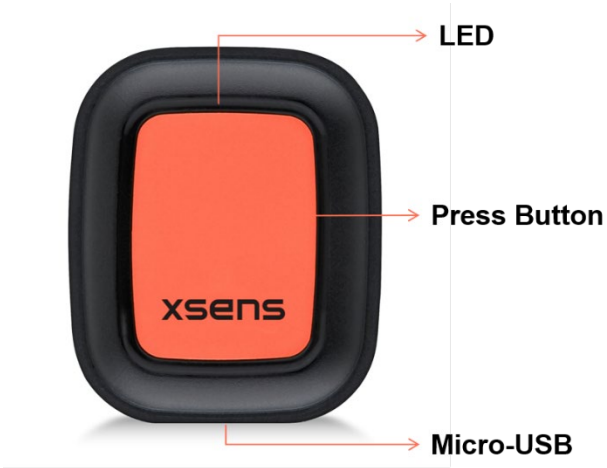

Figure 1: Xsens DOT

2 Xsens DOT Overview

A standard Xsens DOT development kit contains:

- 5 DOTs

Figure 2 Sensor coordinate system

- 1 charging station with power cable

Figure 3 charging station

The software package includes:

- Xsens DOT Software Development Kit (SDK) for Android
- Java DOC for SDK
- Xsens DOT App for Android
- Xsens DOT Android Programming guide
- Xsens DOT User Manual

You can download the software package via this link.

The Xsens DOT App is a simple demonstration for easy and quick use of Xsens DOT. It can connect the sensors, visualize and log the output data. Magnetic Field Mapper (MFM) and Over-the-Air (OTA) firmware update functions are also included in the App. Refer to the *Xsens DOT Quick Setup Guide* for more instruction on how to use this App.

The SDK is intended to make application development easily accessible for Xsens DOT. Refer to *Xsens DOT Android Programming Guide* and *Java documentation for SDK* for more detailed information.

3 Xsens DOT Software Framework

A general software framework of Xsens DOT is presented in Figure 4 below. Strap down integration (SDI) and sensor fusion algorithm (XKFCore) are integrated in firmware. You can get both the orientation and velocity increments directly from SDI and the 3D orientation from XKFCore. Xsens DOT are factory calibrated, making the sensor more accurate repeatable and robust. In SDK, data parser is provided to parse the data from the SDI and conversion functions are also included in data plotting and data logging. See more details about SDI, sensor fusion, MFM and OTA in the following sections.

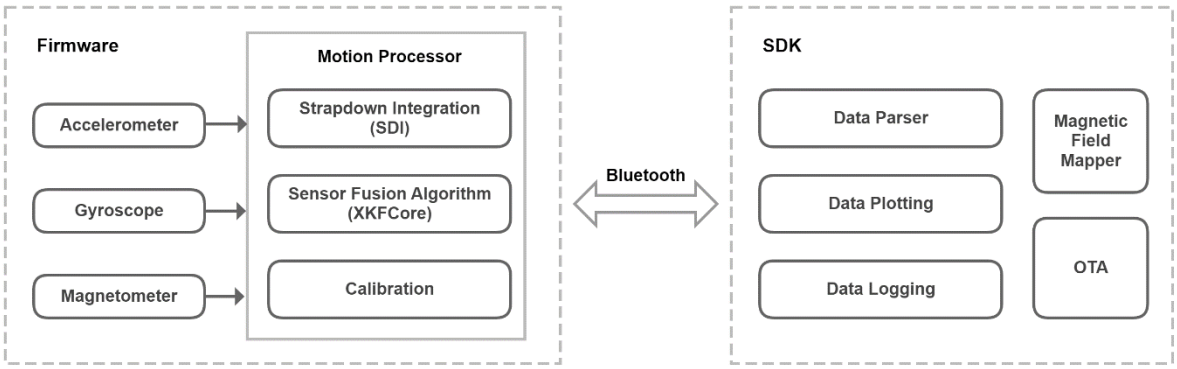

Figure 4 Xsens DOT Software Framework

Strapdown Integration

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

The angular velocity and acceleration data are sampled and calibrated at a high frequency (800 Hz) by the embedded MCU of Xsens DOT 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, information is preserved to ensure precise orientation tracking.

The SDK data parser has built-in functions that convert SDI quantities to calibrated angular velocity (rad/s) and acceleration (m/s2) data. Please refer to the *Java documentation for SDK* for more details.

Sensor fusion algorithm

The 3D orientation of the sensor is computed by Xsens' latest Kalman filter core algorithm for sensor fusion, optimized for human motions. It uses output from SDI to compute a statistical optimal 3D orientation estimate of high accuracy with no drift for both static and dynamic movements.

The sensor fusion algorithm uses the measurement of gravity and Earth magnetic north to compensate for slowly increasing errors from the integration of rate of turn data. It also gives out the free acceleration - acceleration in the local frame from which the local gravity is deducted.

Magnetic Field Mapper

The direction of the measured earth magnetic field is used as a (3D) compass to determine the direction of the Earth true north (heading or yaw), used as an absolute reference in the calculation of 3D orientation.

Objects in the environment near the sensor, like steel, motors or electronics devices will cause disturbance to the magnetic field. XKFCore algorithm running in the motion processor can compensate for errors caused by temporary 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 or lasts for a long duration, it's more difficult for the algorithm to compensate for and will influence heading accuracy.

NOTE: Never expose the 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. This will not damage the unit but will render the calibration of the magnetometers useless, typically observed as a (large) deviation in heading.

If one of the following situations is observed **in a homogeneous magnetic field**:

- persistent drift in yaw
- over ±10% deviation from magnetic norm=1, see Figure 5
- fluctuation when rotating the sensor in different directions, see Figure 6

or the sensor is attached to an object that influences the magnetic field (e.g. ferromagnetic object), it's best to carry out Magnetic Field Mapper (MFM) on this sensor to calibrate the magnetometer to the local magnetic field.

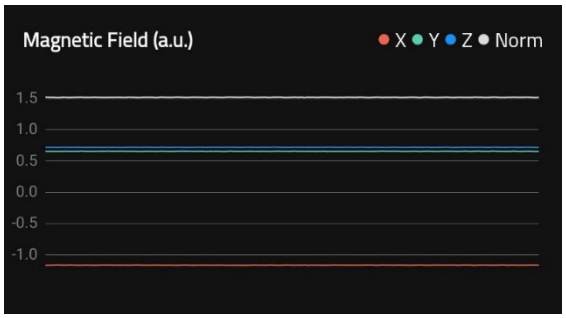

Figure 5 Norm deviation

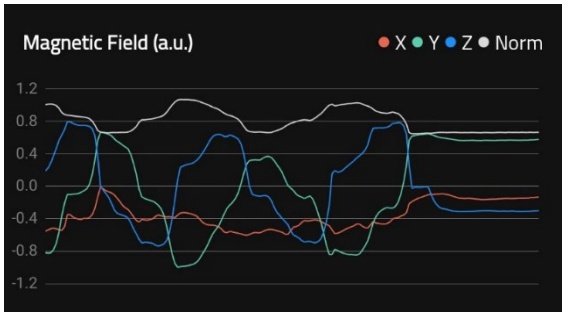

Figure 6 Norm fluctuate when rotating

Homogeneous environment means there should be no ferromagnetic objects within at least three meters. Keep in mind that the structure of the building you are in (floor and ceiling), common objects such as furniture (desks, tables etc) and appliances (e.g. treadmill motors, computers, smartphones at close proximity etc) are all likely to contain magnetic materials and cause distortions to the magnetic field. The ideal environment should be outdoor, but if it's impossible then indoor locations far away from ferromagnetic objects would be preferred, e.g. in the middle of a large room.

Before carrying out the MFM it is extremely important that the **measurement should be carried out in a homogeneous magnetic field**.

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

1. Connect target sensors
2. Choose *Magnetic Field Mapper* in *Advanced* tab
3. Select connected sensor to start MFM
4. Rotate the sensor slowly around all three axes and multiple directions to collect data for magnetic field calibration.
5. Stop the MFM when all directions are covered and check the result. If the result shows *Good* or *Acceptable*, write the measurement values to device. Otherwise (*Fail* or *Bad*) a re-do is required to achieve a successful MFM result

An .mtb file containing the calibration data will be created during the MFM. You can find it in the same directory of the logging data: *Android/data/com.xsens.dot.android/files*

Firmware Update

Continuous firmware releases are scheduled to add new features, or sometimes required to fix bugs. With OTA firmware updates available in Xsens DOT, you can easily update the sensors to latest version.

If you are using Xsens DOT App to update the firmware, make sure the demo App is updated to the latest version first.

Note: sensors can only update through OTA when **in charging status**.

There are two OTA update options:

1. **Download from server**
   It's always recommended to update the device using Xsens server. You can check firmware update with these two servers:
   - Stable server – download from this server for stable firmware releases
   - Beta server – download from this server for beta firmware releases
2. **Update from local mfw file**
   This is an advanced feature, unless explicitly instructed by Xsens support please do not use this feature.

After a successful firmware update, sensor will reboot to complete the update. Please wait for the sensor to connect again and you can see the firmware version being updated.

4 Xsens DOT State Machine

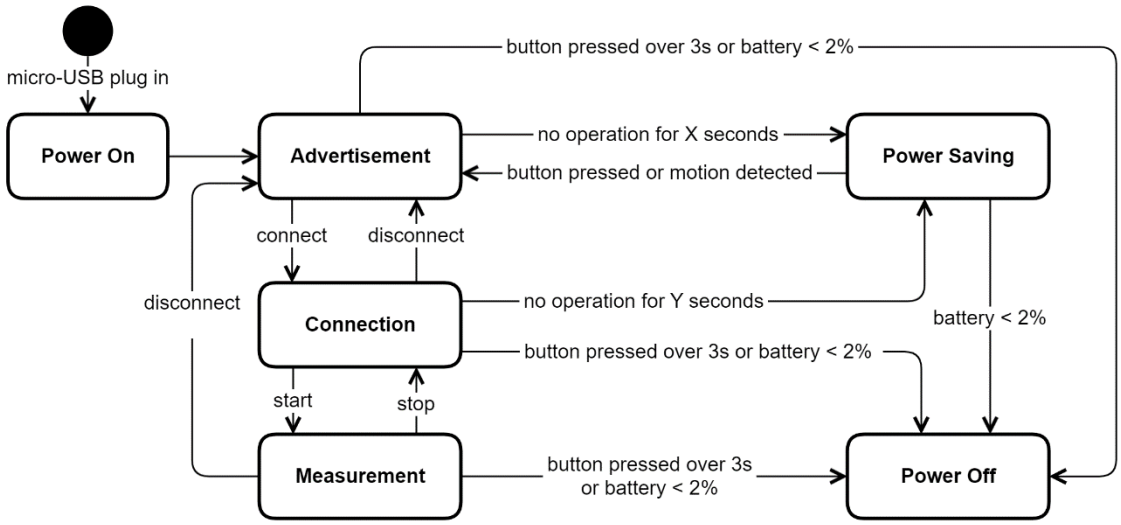

Figure 7 Xsens DOT State Machine

Power On

Power on the charger station and plug in the sensors to the micro-USB port of the station to power on the sensors. Sensor will go to advertisement mode a few seconds later.

A 45mAH LIR2032 rechargeable coin cell battery comes with the sensor and can provide power up to 6 hours with continuous measurement.

Advertisement

In advertisement mode sensor will perform operation idle detection, waiting for BLE connection from mobile devices. If no BLE connection is detected over 10 minutes in this mode, sensor will enter power saving mode.

Connection

You can connect up to 5 sensors at the same time in Xsens DOT App. Though no sensor connection limit is set in SDK, we recommend you connect within 5 sensors to guarantee a good performance in BLE data transmission.

Once the connection is established, following information can be read/write through BLE connection.

Table 1 Characteristics in connection mode

Item	Description
MAC address	unique MAC address for each sensor
Tag	name of the sensor, saved in non-volatile memory
Firmware version	firmware version
Battery	battery level

Identify	identify the connected sensor. LED will fast blink 8 times and a long pause, lasting for 8 seconds.
Power off	power off the sensor

If the reconnection feature is enabled, a reconnection will start automatically once the connection is lost. When no operations, like measurement or calibration is started for 30 minutes after the connection, the sensor will enter power saving mode.

Power Saving

In power saving mode, sensor will turn off the signal pipeline and BLE connection, put the MCU in sleep state to ensure the minimum power consumption. Sensor can be woken up when:

- Button is pressed
- Any motion is detected by accelerometer

Time thresholds to enter power saving mode in advertisement mode (10 minutes) and connection mode (30 minutes) are saved in non-volatile memory and configurable in SDK to allow customization. The sensor will return to advertisement mode once it leaves the power saving mode.

Measurement

After connection, you can start data plotting and logging. Xsens DOT is able to 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 DOT is aligned with East, the y-axis with North and the z-axis upward.

Table 2 Plotting Data

Data			Unit
Orientation	x	Orientation in Euler angels, roll	degree
	y	Orientation in Euler angels, pitch	degree
	z	Orientation in Euler angels, yaw	degree
Free acceleration	x	Free acceleration in local frame, East	m/s^2
	y	Free acceleration in local frame, North	m/s^2
	z	Free acceleration in local frame, Up	m/s^2
Acceleration	x	Acceleration in sensor frame, x axis	m/s^2
	y	Acceleration in sensor frame, y axis	m/s^2
	z	Acceleration in sensor frame, z axis	m/s^2
Angular velocity	x	Angular velocity in sensor frame, x axis	degree/s
	y	Angular velocity in sensor frame, y axis	degree/s
	z	Angular velocity in sensor frame, z axis	degree/s
Magnetic field	x	Magnetic field data in sensor frame, x axis	a.u.
	y	Magnetic field data in sensor frame, y axis	a.u.
	z	Magnetic field data in sensor frame, z axis	a.u.
	n	Normalization of magnetic field data	a.u.

Table 3 Logging Data – Default Mode

Abbreviation	Data	Unit
PacketCounter	Sample counter	(-), wraps at 4,294,967,295
SampleTimeFine	Timestamp	µs, wraps at 4,294,967,295
dQ_W	Angle increment, real part	(-) quaternion values
dQ_X	Angle increment, imaginary X	(-) quaternion values
dQ_Y	Angle increment, imaginary Y	(-) quaternion values
dQ_Z	Angle increment, imaginary Z	(-) quaternion values
dV[1]	Velocity increment, x axis	m/s
dV[2]	Velocity increment, y axis	m/s
dV[3]	Velocity increment, z axis	m/s
Mag_X	Calibrated local magnetic field, x-axis	a.u. (arbitrary units) normalized to earth field strength
Mag_Y	Calibrated local magnetic field, y-axis	a.u. (arbitrary units) normalized to earth field strength
Mag_Z	Calibrated local magnetic field, z-axis	a.u. (arbitrary units) normalized to earth field strength
Quat_W	Orientation as quaternion, real part	(-) quaternion values
Quat_X	Orientation as quaternion, imaginary X	(-) quaternion values
Quat_Y	Orientation as quaternion, imaginary Y	(-) quaternion values
Quat_Z	Orientation as quaternion, imaginary Z	(-) quaternion values
FreeAcc_X	Free acceleration in east direction	m/s^2
FreeAcc_Y	Free acceleration in north direction	m/s^2
FreeAcc_Z	Free acceleration in local up direction	m/s^2
Status	Sensor clipping status	(-)

In Xsens DOT App, logging data are stored as csv files under *Android/data/com.xsens.dot.android/files* directory in the SD card for Android devices.

Users can access conversion functions that are in SDK, to convert orientation in quaternion to Euler angels. Similarly, there are function available as part of SDK to convert delta_angles (dQ) and delta_velocity (dV) to quantities of acceleration (m/s2) and angular velocity (deg/s).

Table 4 Status Definition

Data (Bit mask)	Abbreviation	Status
0x00000100	FL_ClipAccX	accelerometer is out of range in x axis
0x00000200	FL_ClipAccY	accelerometer is out of range in y axis
0x00000400	FL_ClipAccZ	accelerometer is out of range in z axis
0x00000800	FL_ClipGyrX	gyroscope is out of range in x axis
0x00001000	FL_ClipGyrY	gyroscope is out of range in y axis
0x00002000	FL_ClipGyrZ	gyroscope is out of range in z axis
0x00004000	FL_ClipMagX	magnetometer is out of range in x axis
0x00008000	FL_ClipMagY	magnetometer is out of range in y axis
0x00010000	FL_ClipMagZ	magnetometer is out of range in z axis

To give more flexibilities to BLE data transmission payload, Xsens DOT supports 3 data output modes:

- Default mode
- Inertial data mode
- Orientation data mode

The mode information is also saved in non-volatile memory.

Table 5 Data Output Modes

Mode	BLE payload/byte	Plotting data	Logging data
Default mode	63	• Orientation • Free acceleration • Acceleration • Angular velocity • Magnetic field	see Table 2
Inertial data mode	35	• Acceleration • Angular velocity • Magnetic field	• PacketCounter • SampleTimeFine • dQ • dV • Mag • Status
Orientation data mode	36	• Orientation • Free acceleration	• PacketCounter • SampleTimeFine • Quat • Free acc • Status

Power off

The sensor will power off if one of the following conditions is met:

- Press the button over 3 seconds
- Power off from App & SDK

Also, the sensor will automatically shut off when the battery level is lower than 2% to prevent battery drain.

LED Patterns

Xsens DOT has different LED patterns to indicate different sensor states. Table 6 shows the behavior of the LED.

Table 7 LED Patterns

LED Pattern	Sensor State
OFF	Powered off
ON	USB Powered, not charging (battery full)
Fade In/Out, 1 second cycle	USB Powered, charging (battery < 25%)
Fade In/Out, 2 second cycle	USB Powered, charging (25% <= battery < 50%)
Fade In/Out, 3 second cycle	USB Powered, charging (50% <= battery < 75%)
Fade In/Out, 4 second cycle	USB Powered, charging (75% <= battery < 100%)
Blink 1x per second	Advertising, waiting for connection
Blink 1x every 10 seconds	Connected, not measuring
Blink 2x every 10 seconds	Connected, measuring
Fast blink 8 times and then a short pause	Identifing
Fast blink 2 times and then a long pause	In bootloader mode
Blink 8x per second	MCU/battery is overheated during battery charging, charging is stopped to pretect MCU and battery
On for 1 second and fade out in 3 seconds	Device is being powered off

5 Specifications

Table 8 Xsens DOT specifications

Physical Properties	
Attachment	Straps
Latency	30 ms
Battery life (continuous use)	Up to 6 hours
Weight	10.8 g
Dimensions	36.30 x 30.35 x 10.80 mm (l x w x h)
Operating temperature range	0°C - 50°C
IP Rating	IP68
Internal sampling rate	800 Hz
Wireless update rate with 5 Xsens DOT	60 Hz
Communication	Best performance with Bluetooth 5.0 devices
Communication platform	Android Mobile devices with Android OS version 8 or above
Operating frequency range	2401 - 2480 MHz
Max radiated output power with internal antenna (EIRP)	+5 dBm
Orientation Performance	
Static (Inclination | Heading)	0.5° | 1.0° 1σ RMS
Dynamic (Inclination | Heading)	1.0° | 2.0° 1σ RMS
Sensor components	
Full scale	± 2000°/s | ± 16g | ± 8 Gauss
Dimensions	3 axes

Table 9 Battery Specifications

Item		**Characteristics**
Capacity	Nominal	45 mAh
	Minimum	40 mAh
Nominal Voltage		3.7V
Dimension	Diameter	20.0 (Max) mm
	Height	$32_{+0.2}$ mm
Weight		2.6 g
Working Temperature		-20 ~+60 °C
Storage Temperature		20±1 °C

6 Important Notices

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 fire.
- Strictly prohibits use leave the DOT sensor close to fire or inside of a car where temperature may be above 60℃. Also do not charge / discharge in such conditions.
- Thoroughly read the user's manual before use, inaccurate handling of 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.

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 Center, where engineers and other Xsens users meet. Please visit this Help Center:

⇒ Help center: https://base.xsens.com
⇒ Support page: https://www.xsens.com/support

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 wide band low power data communication system".

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