Ellipse AHRS & INS

High Performance, Miniature Inertial Sensors

User Manual

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Revision history

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1	Oct 7, 2014	Alexis Guinamard	First public version
PRE2	Aug 25, 2014	Alexis Guinamard	Second pre-version of this document
PRE1	Mar 6, 2014	Alexis Guinamard	First pre-version of this document

Index

Terminology

ADC: Analog to Digital Converter
AHRS: Attitude and Heading Reference System
CAN (Bus): Controller Area Network
DHCP: Dynamic Host Configuration Protocol
DVL: Doppler Velocity Log
EKF: Extended Kalman Filter
EEPROM: Electrically-Erasable Programmable Read-Only Memory
FIR: Finite Impulse Response (filter)
FTP: File Transfer Protocol
FS: Full Scale
FOG: Fiber Optic Gyroscope
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
IIR: Infinite Impulse Response (filter)
IMU: Inertial Measurement Unit
INS: Inertial Navigation System
IP: Internet Protocol
LBL: Long Baseline
MAC (address): Media Access Control
MEMS: Micro Electro-Mechanical Systems
NED: North East Down (coordinate frame)
NA: Not applicable
NMEA (NMEA 0183): National Marine Electronics Association (standardized communication protocol)
PPS: Pulse Per Second (signal)
RAM: Random Access Memory
RMA: Return Merchandize Authorization
RMS: Root Mean Square
RTCM: Radio Technical Commission for Maritime Services (Protocol)
RTK: Real Time Kinematics
SI: International System of Units
TBD: To Be Defined
TCP: Transmission Control Protocol
UDP: User Datagram Protocol
UTC: Coordinated Universal Time
USBL: Ultra Short Base Line
VRE: Vibration Rectification Error
WGS84: World Geodetic System 1984
WMM: World Magnetic Model

1. Introduction

Ellipse is a miniature, high-performance MEMS based Inertial System which achieves exceptional orientation and navigation performance in a miniature and affordable package. It includes an Inertial Measurement Unit (IMU) and runs an on-board enhanced Extended Kalman Filter (EKF). The Ellipse line is divided in a comprehensive set of sensors:

The Ellipse A version is an attitude and Heading Reference System (AHRS), providing accurate orientation in dynamic conditions.

The Ellipse E and N models are Inertial Navigation Systems (INS), providing both orientation and navigation data. The use of GNSS data or other aiding equipments such as odometer or internal barometric sensor can be used to provide accurate navigation data, but also to improve orientation accuracy. The Ellipse E model accepts external GNSS data whereas the N model embeds an industrial GNSS receiver.

Figure 1.1: The Ellipse INS (N model)

To achieve the best performance in every project, specific error models have been implemented to meet applications requirements. Sensor configuration is made easy through the sbgCenter interface, provided in the SDK. The Ellipse supports a proprietary protocol for best performance, but also standard protocols such as NMEA for direct integration into existing applications.

1.1. Ellipse Overview

The following diagram shows the basic organization of an Ellipse E or N. On the Ellipse A version, this block diagram is slightly simplify as there is no GPS, barometer inside.

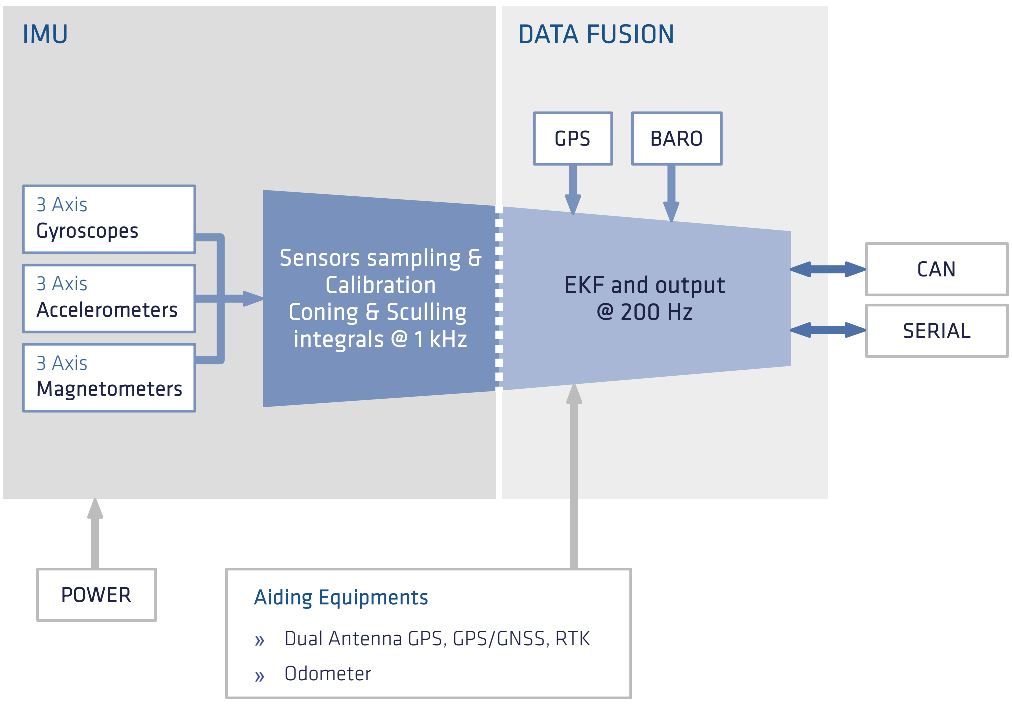


Figure 1.2: Ellipse simplified block diagram

1.2. Inertial measurement unit

As an IMU is the main component of an inertial navigation system, the Ellipse IMU has been carefully designed to take full advantage and performance of MEMS technology.

1.2.1. MEMS technology

High quality MEMS components have been selected for this IMU. This MEMS technology provides many advantages over competing technologies such as mechanical or FOG gyroscopes, servo accelerometers:

- A miniature design provides smaller, lighter products, enabling new applications to be covered.
- This technology is very robust and provides much higher shock resistance as well as maintenance free operation.
- MEMS designs provide cost effective solutions compared to other technologies such as FOG or RLG.

Note: Although the same MEMS technology is used for consumer applications such as smart-phones and tablets, there is a very large performance gap between low cost MEMS and industrial grade MEMS sensors. SBG Systems has selected for this product high end industrial grade sensors only.

1.2.2. Accelerometers

The Ellipse IMU embeds a set of 3 MEMS capacitive accelerometers. Coupled with advanced filtering techniques and sculling integrals, these accelerometers will provide consistent performance, even in vibrating environment.

	A2	A3	Remarks
Full scale (*g*)	8	16	
Scale factor stability (%)	0.1	0.1	
Linearity (% of FS)	0.2	0.2	
One year bias stability (m*g*)	5	10	
Velocity Random Walk (µ*g*/√hz)	100 (X, Y) 150 (Z)	200 (X, Y) 300 (Z)	Allan variance – @ 25°C
In run bias instability (µ*g*)	20	40	Allan variance – @ 25°C
Vibration Rectification Error (m*g*/*g*²)	7	4	
Bandwidth (Hz)	250	250	Internal low pass filters attenuation < 3 dB
Sampling rate (kHz)	3	3	
Orthogonality (°)	< 0.05	< 0.05	

1.2.3. Gyroscopes

The set of 3 high end industrial grade MEMS gyroscopes is sampled at 10 KHz. An efficient FIR filter and coning integrals computations ensures best performance in vibrating environments.

	G2	G3	G4	G5	Remarks
Full scale (°/s)	100	200	450	900	
Scale factor stability (%)	0.05	0.05	0.05	0.05	
Non-Linearity (% of FS)	0.05	0.05	0.05	0.05	
One year bias stability (°/s)	0.2	0.2	0.2	0.4	Total composite bias
In run bias instability (°/hr)	8	8	8	10	Allan variance – @ 25°C
Angular Random Walk (°/hr/√hz)	0.16	0.16	0.18	0.18	Allan variance – @ 25°C
Bandwidth (Hz)	133	133	133	133	Internal Gyro bandwidth
Sampling rate (kHz)	10	10	10	10	Advanced anti-aliasing FIR filter
Orthogonality (°)	0.05	0.05	0.05	0.05	

1.2.4. Factory Calibration and test

In order to provide best quality sensors, SBG Systems has developed unique calibration and test procedures for the Ellipse. When dealing with sensors error parameters, we consider that a good calibration is always better and more reliable than on-line sensor estimation.

We calibrate and test each product in our factory in order to provide efficient and defect free units. A calibration report is shipped with each product.

This calibration procedure allows taking the maximum precision of each sensor over the full temperature range (-40 to 85°C).

The calibration and test procedure provide:

- Functional and accuracy test of all sensors, and subsystems over full temperature range.
- Gain and bias compensation over full temperature range for accelerometers and gyroscopes,
- Non linearity compensation for gyroscopes over full measurement range,
- Gain compensation over full temperature range for magnetometers,
- Cross-axis and misalignment effects compensation for accelerometers, gyroscopes and magnetometers,
- Gyro-G effect compensation for gyroscopes.

Note: There is no bias compensation for magnetometers because bias is maintained stable over temperature by hardware design.

1.2.5. Vibration handling

The Ellipse IMU has been designed for harsh environments. Specific developments led to efficient vibration handling.

When exposed to vibrations, an accelerometer or gyroscope will have some increased bias. This vibration effect on accelerometer is called VRE. So a good starting point is to choose sensors that have low VRE in order to sustain higher levels of vibrations.

The second point is to design efficient hardware and software low pass filters that will reject out noise and unwanted signals to deliver only reliable and anti-aliased motion information.

Coning and sculling integration, described in next section is finally a good way to handle properly fast vibrating motion.

1.2.6. Coning and sculling integration

In modern "strapdown" inertial systems, angular rates from gyroscopes and accelerations from accelerometers must be integrated over time to maintain an orientation and navigation solution.

As this orientation and velocity integration is highly non linear, it may become necessary to use very small integration steps when motion becomes highly dynamic in order to maintain consistent accuracy.

Coning and sculling algorithms provide computation efficient ways to integrate accelerometers and gyroscopes signals at high frequency such as 1 kHz.

The Ellipse IMU computes a 1 KHz coning and sculling integration for best accuracy in dynamic environments.

Delta angle filters and delta velocity filters have been designed to provide an equivalent output delay.

1.3. Extended Kalman Filter

1.3.1. Overview

Thanks to a modern processing architecture, the Ellipse runs a real time loosely coupled Extended Kalman Filter (EKF). The loose coupling between GPS/GNSS and the Kalman Filter allows GPS data to improve inertial sensor performance, and on the other hand inertial data improve overall navigation performance.

More than just a direct EKF implementation, the Ellipse navigation algorithm includes advanced error models and wrong measurement rejection algorithms to ensure that best navigation performance is provided at any time.

A modular design allows a wide range of aiding sensors to be connected to the Ellipse INS. GNSS, Odometer, and other aiding sensors can be connected to further enhance navigation performance.

In addition, the Ellipse Kalman filter is able to estimate some user entered parameters to further improve accuracy, such as GPS lever arm, odometer's gain, and others.

Specialized motion profiles and error models provide optimal options and tuning for each application, and each aiding equipments.

1.3.2. Theory of operation

Inertial sensors (accelerometers and gyroscopes) provide very accurate short term motion measurements but suffer from drift when integration time becomes long. Some other systems such as GNSS receivers or magnetometers provide low frequency measurements that can be fooled by jamming, or magnetic interferences in a short term, but these sensors provide good performance over long term.

The basic idea behind the Kalman filter is to take the best of each sensor, without drawbacks. A high frequency prediction (also called propagation) step uses inertial sensors to precisely measure motion and navigation data. When aiding data (GPS position, Odometer data or Magnetometer reading for example) becomes available, the Kalman filter will use it to correct the current state and prevent drift.

As aiding measurements are made at a lower frequency than the prediction step, a small jump can be observed after a correction is applied. This jump should be really small in normal operating conditions.

A covariance matrix maintains up to date each estimated parameter error. When there is no measurement available, estimation error tends to increase; when a new measurement is received, this error will decrease. This covariance matrix is also used to handle the "link" between each estimated parameters.

Besides the EKF, a sensor manager is implemented to check aiding measurements and reject bad ones.

To summarize the Ellipse Extended Kalman Filter operation, the following diagram shows how IMU and external sensors are used inside the EKF to provide navigation and orientation data.

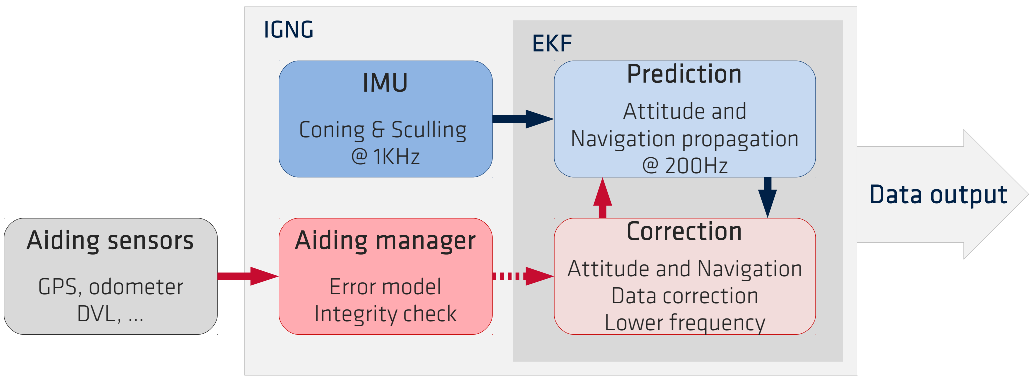


Figure 1.3: EKF simplified block diagram

1.3.2.1. Modes of operation

The Kalman filter inside the Ellipse INS will run into several computation modes depending on situations:

Initialization

This mode is observed at startup only and corresponds to the first attitude initialization using the internal accelerometer as vertical reference. It assumes low accelerations so best accuracy is achieved when the Ellipse is powered up stationary or at constant speed. If the INS is powered up during motion, the full accuracy will be reached within a few minutes after startup.

Vertical Gyro operation

Once roll and pitch angles are initialized, the Kalman filter is running in a limited mode, where only attitude (roll and pitch angles) is valid. This mode uses a vertical reference and internal gyroscopes to estimate orientation. Therefore, heading angle is freely drifting, as well as position and velocity. Ship motion data is provided accurately in this mode but is not velocity aided.

Heading alignment procedures

When operated in “vertical gyro” mode, the Ellipse will be able to align heading angle using different procedures. These procedures have some constraints and the following table explains how they are used and in which situations:

Method	Availability	Constraints – Remarks
GPS Course Heading	In Automotive, and Airplane motion profiles. Or, when GPS Course is used as aiding input.	This method is the default for most dynamic applications. It uses GPS course as an input for heading, considering that preferred direction of travel is forward. The device must drive/fly in forward direction, at least at 3.0 m/s.
GPS True Heading	When GPS True Heading is activated as an aiding input	This method uses input GPS true heading provided by dual antenna GPS. Open sky condition is preferred for initialization due to the dual antenna system sensitivity to multi-path effects. Device must be in static or constant heading condition.
GPS+accelerations	In Helicopter and General Purpose motion profiles	This method uses GPS and accelerations to define a heading. This allow any motion, in any direction. Due to higher sensitivity to GPS signal reflection, the sensor should be initialized in good GPS conditions. The device must be accelerated at more than $2.5 m/s^2$ during at least 2 seconds.
Magnetic Heading	Available when Magnetic heading aiding is enabled.	If magnetometers are enabled, this signal is available at startup. A good magnetic field must be available for proper operation.

As a result of heading alignment, several jumps on heading angle may be observed when the system is operated in vertical gyro mode.

AHRS mode

In this mode, a full orientation set is accurately estimated using a vertical reference and a heading input (magnetometer or other sensor input). Roll, Pitch and Yaw angles are accurate. Position and velocity are freely drifting and cannot be considered as valid.

Navigation modes (Ellipse N and E only)

- Navigation Velocity mode; In this mode a velocity input (GPS, or Odometer + vehicle constraints, or DVL) is provided to maintain accurate orientation and velocity data. Position output is unreferenced but should not drift as much as in AHRS mode.
- Full Navigation mode; In this mode, the Ellipse provides the full output set accurately: Orientation, absolute position and velocity are fully estimated.

The Kalman filter will always try to use the best or highest computation mode. In some situations such as long GPS drop outs, the computation mode may be downgraded from Full Navigation to Navigation Velocity or AHRS mode depending on outage duration. This makes it possible to maintain reliable orientation even during long GPS outages, with an accuracy similar to AHRS systems.

1.3.2.2. Heading observability with single antenna GPS

Depending on the device configuration, the Ellipse EKF will make use of all available measurements to estimate orientation and navigation parameters. GPS or odometers will be able to stabilize navigation data but also orientation data. Roll and pitch are always accurately estimated when GPS is available.

When the sensor is subject to acceleration, the EKF is also able to stabilize heading angle.

In some applications where the dynamics are too low for good heading observability, it may be necessary to find an alternative heading measurement, coming either from the internal magnetometer, a dual antenna GNSS system (providing true heading) or the GNSS Course (available when the device is in motion).

1.3.2.3. Heading observability with dual antenna GPS

The Ellipse E is able to connect to a dual antenna GNSS system. This type of GNSS receiver is able to provide a heading angle, even while stationary. This might be helpful in applications where magnetometers is denied and where the dynamics are low.

Compared to a stand-alone GNSS dual antenna system, the Ellipse will smooth GNSS heading measurements and reject wrong heading measurements in order to provide best output accuracy. The internal gyro will also provide reliable heading information during temporary GNSS drop outs.

1.3.2.4. Operation during long aiding outages

When there is no aiding measurement available (no GPS fix or between measurements), the propagation step maintains navigation and orientation data up to date, but navigation error will increase. This condition is also referred as "dead reckoning". After a long dead reckoning period, the first correction applied can generate large jumps depending on actual error.

After a long dead reckoning period (> 3 min), navigation data will still be computed but may contain a large error. Orientation behavior will become similar to AHRS version.

There are ways to limit dead-reckoning drift by using other sensors such as odometer, or by making stops (check out next section).

1.3.2.5. Automatic ZUPT detection

The Ellipse Kalman filter is able to automatically use "Zero Velocity Updates" (ZUPT) in some motion profiles. When the sensor stops moving, the Kalman filter detects the zero velocity and use that information to correct the states, and then limit the position drift.

1.3.2.6. Augmented state estimation (lever arms, alignments)

In most applications, measuring lever arms or misalignment angles can be very difficult tasks. That's why the Ellipse Extended Kalman filter is able to estimate several additional states that will ensure maximum accuracy:

- Lever arms (GPS, Odometer) estimation makes it possible to improve user measurements. It is still required to enter those lever arms, but with a reasonable accuracy of 5 cm, the Kalman filter will finish the adjustments with less than 1 cm accuracy.
- Alignments (Vehicle alignment, GPS True Heading) can also be estimated. User entered alignments angles can be performed with only 3° accuracy to ensure good operation using these algorithms.
- Odometer Gain is also constantly estimated to minimize dead reckoning errors when using this type of sensor.

Note: All these "augmented states" are only enabled when relevant with an application. In addition, most of these states require some dynamic motion, so for example GPS True heading alignment estimation can only be used in airborne or land applications.

1.3.3. Motion profiles and aiding sensors error models

Each application has specific requirements and constraints such as angular rate dynamics, vibrations, presence of long term accelerations, magnetic disturbances and others. Instead of having different products for each environment, SBG Systems has developed a cutting edge technology able to adapt the sensor to each situation.

The Motion Profile technology is tightly integrated with the embedded Kalman Filter and inertial sensors. It provides with a simple application selection a deep and fine Ellipse configuration. Different motion profiles have been designed to fit most typical applications and should provide optimal performance.

A similar technology is used to specialize error models for each aiding device. A single click allows the user to choose an aiding sensor model and everything will just work properly.

Note: Most applications should find a suitable motion profile and error models to obtain optimal performance. However, if a specific application requires fine tuning, it is still possible to design a specific motion profile for that application. Feel free to contact our SBG Systems support team that will assist you during this operation.

1.3.4. Ship motion computation (Heave)

Mainly used in marine applications, we refer here to ship motion computation. Vertical motion is called heave. Our Real Time Ship Motion algorithm provides instantaneous heave information for real time applications.

Aside from the EKF, the Ellipse computes at 50Hz ship motion data from accelerometers double integration. As this double integration generates drift due to orientation error or sensor bias, the best way to get a stable output is to use a high pass filter design that will remove any constant component in the motion.

SBG Systems has developed an advanced filter design that ensures very little phase and gain errors are generated. In addition, an automatic filter tuning ensures proper behavior is obtained with swell periods up to 15 seconds.

Due to high pass filter design, the heave data will always return to zero in static conditions. If a step is performed, the heave output will show the step and then will smoothly come back to zero. It may take a few minutes for the output to be stabilized after a step.

For best accuracy, the Ellipse E and N versions use GNSS receiver data to compensate accelerations that could disturb ship motion computations during turns or acceleration phases.

1.4. Aiding sensors

Many different aiding sensors can be used to aid the Ellipse INS.

1.4.1. Internal aiding sensors

1.4.1.1. Magnetometers

A set of three Anisotropic Magneto-resistive magnetometers is embedded within the Ellipse. This technology provides a very high sensitivity compared to coil based technologies.

Although part of the Ellipse internal IMU, the magnetometer is in fact considered as an “aiding sensor” and is not mandatory for proper operation.

Nevertheless, in many applications such AHRS applications, airborne or several marine applications, this magnetometer is still a reliable and efficient way to observe heading.

Note: Magnetometer use requires a specific in place calibration in order to compensate surrounding ferromagnetic materials and magnets. Please refer to the Ellipse Hard and Soft Iron Calibration Manual for more information about this.

Warning: Note that magnetometer sampling design makes it impossible to reject signal frequencies above 180Hz. User should ensure that high frequency noise is not disturbing magnetometers at the sensor's location.

	Specifications	Remarks
Full scale (Gauss)	8	
Scale factor stability (%)	0.5	
Linearity (% of FS)	0.1	
Noise (μGauss)	200	Over 1 to 25 Hz band
Bias stability (m Gauss)	0.5	
Bandwidth (Hz)	110	
Resolution (mGauss)	2	
Sampling rate (Hz)	220	
Orthogonality (°)	0.1	After user magnetic calibration

1.4.1.2. Ellipse N internal GNSS receiver

The Ellipse N embeds an industrial GNSS receiver (L1 GPS + GLONASS or GPS + BEIDOU), capable of DGPS positioning using either SBAS or third party base station. With a refresh rate of 10Hz, this receiver has an excellent sensitivity for continuous tracking under challenging environments.

	Specification		Remark
Channels	72		
Signal tracking	GPS L1 C/A GLONASS L10F QZSS L1 C/A BeiDou B1 SBAS L1 C/A: WAAS, EGNOS, MSAS		
Horizontal position accuracy	2.0 m CEP		GPS + GLONASS + SBAS or DGPS
Velocity accuracy	0.1 m/s RMS		
Sensitivity	Tracking & Navigation; Cold start:	-167dBm -148dBm	
Time to First Fix	Cold start	< 26 s	
	Hot start	< 1.5s	
Output frequency	10 Hz		
Operational limits	Dynamics: < 4*g* Velocity: 500 m/s Altitude: 50 000 m		

1.4.1.3. Internal barometric altimeter

The Ellipse N and E models embed a MEMS pressure sensor, used as altimeter. This pressure sensor is fully calibrated and temperature compensated making it ideal to measure accurately absolute pressure.

The Ellipse converts this absolute pressure into altitude using the Standard Atmosphere model, assuming a constant temperature gradient over altitude, and a sea pressure level of 1013,25 hPa.

1.4.2. External sensors

1.4.2.1. Third party GNSS receiver

The Ellipse-E model does not include a GNSS receiver, but can be connected to an external GNSS module. All GNSS receivers will provide velocity and position aiding. In some applications such as automotive ones, the GPS course can also be used as heading reference input.

Dual antenna systems can also provide a True Heading aiding. RTK GPS receivers can be used to improve positioning accuracy.

1.4.2.2. Odometer

In addition to the GNSS aiding, the Ellipse N and E versions includes an odometer input which can greatly improve performance in challenging environments such as urban canyons. The odometer provides a reliable velocity information even during GPS outages. This increases significantly the dead reckoning accuracy.

The Ellipse handles quadrature output or compatible odometers in order to support forward and backward directions.

> **Note:** Odometer integration is made really simple as the Kalman filter will finely adjust odometer's gain and will correct residual errors in the odometer alignment and lever arm.

1.5. System Performance

All specifications are rated to 1 σ, over -40°C to +85°C (-40 to 185°F) unless otherwise stated.

These specifications have been measured based on typical mission scenarios with simulated GPS outages and compared to post processed RTK data of a high end FOG based INS.

1.5.1. Ellipse A specifications

1.5.1.1. Orientation specifications

	Performance	Remarks
Measurement range	360° in all axes, no mounting limitation	
Roll / Pitch accuracy	< 0.2°	Medium dynamic conditions – No long term accelerations
Yaw Accuracy	0.8°	Clean magnetic environment – Magnetic calibration performed.

1.5.2. Ellipse E / N specifications

For each application, we present the measured accuracies for different positioning modes. You can find below a short description of each positioning mode:

- SP refers to Single Point mode and is the default L1 GPS / GLONASS fix quality
- RTK stands for Real Time Kinematics with a typical 1 cm accuracy position
- Odometer Aiding is specified when an odometer provides velocity (automotive applications)
- DVL aided is specified when a Doppler velocity Log sensor provides sub-water velocity information (bottom tracking)

1.5.2.1. Land applications

Outage Duration	Positioning Mode	Position Accuracy		Velocity Accuracy		Attitude Accuracy (°)	
		Horizontal	Vertical	Horizontal	Vertical	Roll / Pitch	Heading
No Outage	SP	2 m	2.5 m	0.1 m/s	0.1 m/s	0.2 °	0.4 °
	RTK	0.02 m	0.04 m	0.05 m/s	0.05 m/s	0.2 °	0.4 °
10 s	SP	2.5 m	3 m	0.2 m/s	0.2 m/s	0.2 °	0.5 °
	RTK	0.8 m	0.8 m	0.15 m/s	0.15 m/s	0.2 °	0.5 °
	Odometer aiding	0.15 % of DT	0.15 % of DT	0.1%	0.1%	0.6 °	0.6 °
60 s	SP	10 m	8 m	0.5 m/s	0.5 m/s	0.25 °	0.6 °
	RTK	8 m	6 m	0.4 m/s	0.4 m/s	0.25 °	0.6 °
	Odometer aiding	0.2 % of DT	0.2 % of DT	0.1%	0.1%	0.2 °	0.6 °

1.5.2.2. Marine & Subsea applications

Orientation and navigation performance

Outage Duration	Positioning Mode	Position Accuracy		Velocity Accuracy		Attitude Accuracy (°)	
		Horizontal	Vertical	Horizontal	Vertical	Roll / Pitch	Heading
No outage	SP	2 m	2.5 m	0.1 m/s	0.1 m/s	0.2 °	0.8 °
	RTK / Dual antenna GPS	0.02 m	0.04 m	0.05 m/s	0.05 m/s	0.2 °	0.2 °
10 s	SP	3 m	3.5 m	0.2 m/s	0.2 m/s	0.3 °	0.8 °
	RTK / Dual antenna GPS	1 m	1 m	0.15 m/s	0.15 m/s	0.3 °	0.3 °
	DVL aided	0.5% of DT	0.5% of DT	0.5 %	0.5 %	0.2 °	0.8 °

Note: In case of standalone dual antenna GNSS system use, heading accuracy parameters listed in "RTK / Dual antenna GPS" lines may apply.

Heave performance

	Real Time Heave	Remark
Range	50 meters	
Period	0 to 15 s	
Accuracy	10 cm or 10%	Whichever is greater; Velocity aided heave
Mode	Real time, auto tuning	

1.5.2.3. Airborne applications

Outage Duration	Positioning Mode	Position Accuracy		Velocity Accuracy		Attitude Accuracy (°)	
		Horizontal	Vertical	Horizontal	Vertical	Roll	Heading
No outage	SP	2 m	2.5 m	0.1 m/s	0.1 m/s	0.2 °	0.5 °
	RTK	0.02 m	0.04 m	0.05 m/s	0.05 m/s	0.2 °	0.5 °
10 s	SP	3 m	3.5 m	0.2 m/s	0.2 m/s	0.3 °	0.6 °
	RTK	1 m	1 m	0.15 m/s	0.15 m/s	0.3 °	0.6 °

1.6. Time and synchronization

When dealing with external devices, latency and synchronization can be important points to consider because of different calculation delays within each device and transmission times.

1.6.1. Output Latency

A specific design has been implemented to provide minimum latency for most important outputs. For good understanding, we must consider here the various sets of Logs (messages) provided by the Ellipse:

- Inertial sensor Logs coming from the Ellipse IMU are the most important Logs and they can be provided less than 1 ms after the actual sensor sample.
- EKF output Logs require some processing. These are sent once computed, 2 ms after sample time.
- Other output Logs have lower priority and can be sent afterward.

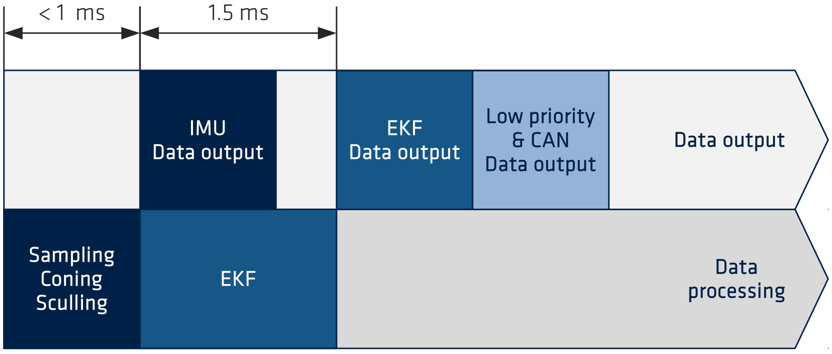


Figure 1.4: Timing and processing diagram

Note: CAN Logs are all sent with lower priority messages as the CAN protocol cannot guarantee in any case the output delay.

Note: A full description of output Logs is provided in the Ellipse Firmware Reference Manual.

The following graph explains how data is processed and delivered.

1.6.2. Event inputs

The Ellipse includes up to 4 synchronization inputs that can be used for different purposes:

- Event input: All pulses received generate events that can generate specific Logs output. Any output log can be triggered by an event pulse.
- Event Marker: An event marker log can be sent each time a pulse is received in order to time mark each event.
- PPS input: When the Ellipse E is connected to a GNSS system, the PPS signal is used to realign and synchronize internal clock to GPS clock.
- Aiding input time-stamping: If a specific aiding sensor generates pulses that time stamp the following output, the corresponding event input can be used for data synchronization.

1.6.2.1. Event triggered logs

The following example shows how event triggered logs are generated. In this example, three processing loops are shown, from N to N+3. Event received during loop N generates an output after N+1 computation. Event received during N+1 loop generates an output after N+2 computation.

The Ellipse handles up to 200Hz input. In case of higher frequency events, only the last received event will be taken into account.

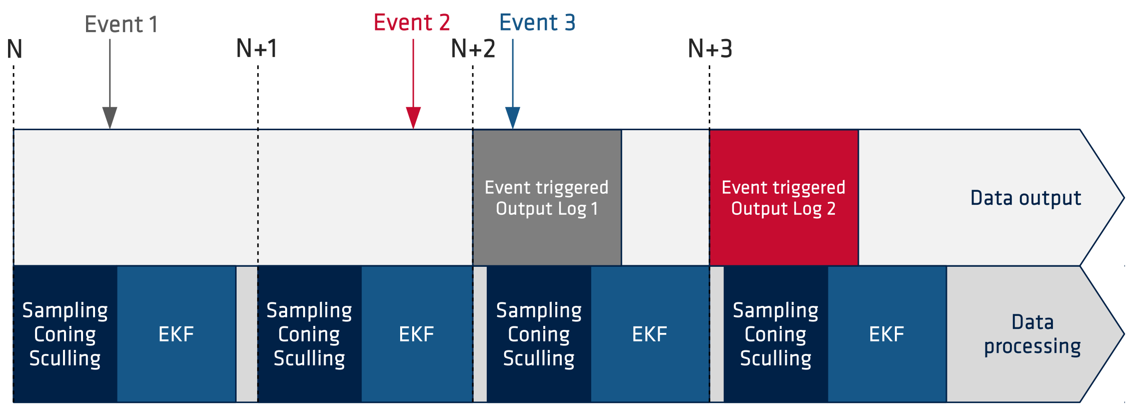


Figure 1.5: Event triggered log example

1.6.2.2. Event markers handling

Event marker handling is very similar to the event triggered logs. Events received are stacked in the system and an event marker message can be sent at each computation loop. This log will include all events details during previous loop.

The Ellipse handles up to 1kHz event Markers input. Sending more than 1KHz events may overload the internal CPU.

The following diagram explains this behavior:

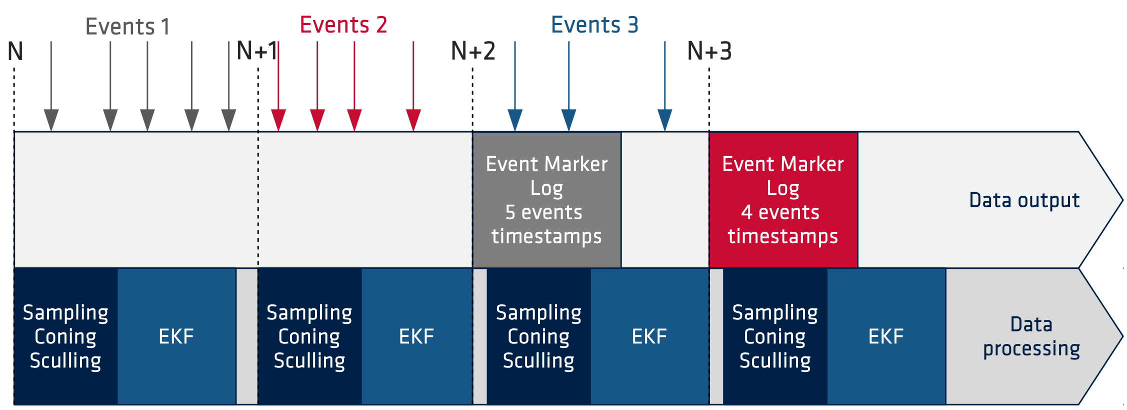


Figure 1.6: Event markers

1.6.3. Event Output

A synchronization output pin allows pulses generation in following conditions:

- Main loop divider: This event is activated at the sensor sample time, but its frequency is divided by the output divider. If the divider is set to 4, pulse output frequency will be 200Hz / 4 = 50Hz.
- PPS: This output will also be synchronized with the sample time, but it will be provided at 1Hz only when clock is correctly estimated. So this output is provided at each top of a second in UTC time.
- Virtual odometer: This outputs provide a sync pulse, each time the sensor travels the specified distance.

1.6.4. Clock bias and gain estimation with GPS

The Ellipse internal crystal has an accuracy of 40ppm over full temperature range. The Ellipse N will automatically improve this accuracy using internal GNSS receiver. In order to reduce this crystal error over time, the Ellipse E should be connected to the GNSS PPS signal.

This PPS signal also allows GPS data synchronization, required for good navigation accuracy, as well as internal clock bias and gain estimation.

It is generally sent at each top of a UTC time second.

Clock estimation is made in two steps:

- The first step is to realign the main loop to the PPS: each pulse received on the PPS must correspond to a new sample data.
- The second step is to finely adjust the clock gain by comparing the actual PPS time with internal clock time.

1.6.5. Internal time and UTC time

The Ellipse internal clock reference is always started at 0 when the sensor is powered on. During clock bias estimation, the internal time may slide up to +/- 2.5 ms in order to align internal time with UTC time. Once synchronized, the internal time keeps counting from power up without being affected by UTC.

When internal clock has been synchronized to PPS and UTC time is available from the GNSS system, the Ellipse will also provide a UTC time reference, with corresponding internal time. Thanks to the internal time and UTC offset, it is possible to recalculate a UTC time for each received log.

Note: Before GPS is available, the UTC time starts at the date configured in settings. When the GPS becomes available, a first value of UTC (based on GPS time) is provided but it can be a few seconds away from the actual UTC time. When "leap seconds" information becomes available, a jump can be observed to realign output on actual UTC time. A specific flag informs the user about the UTC time validity.

Fore more information, please search "GPS Leap Seconds" on the Internet to find some more details about this notion.

2. Conventions

2.1. Reference coordinate frames

Although this matter requires some mathematics skills, it may be important to take some time to fully understand how navigation and orientation are represented.

We remind that an inertial frame is a frame in which Newton's laws of motion apply. An inertial frame is therefore not accelerating, but can be in uniform linear motion.

All Inertial sensors (accelerometers, gyroscopes) produce measurements relative to an inertial frame.

2.1.1. Earth Centered Earth Fixed (ECEF) Coordinate frame

This coordinate frame has its origin placed at the center of Earth. The frame is rotating with Earth so that constant coordinates will point to a single point on Earth. The frame rotation rate ω_{ie} is 360° per day plus 360° per year.
Due to this frame rotation, the ECEF frame is not an inertial frame.

Note: The Ellipse algorithms take into account this frame rotation rate in order to ensure best navigation accuracy.

There are two main coordinate systems used to represent positions within this ECEF frame.

2.1.1.1. ECEF Cartesian coordinate system

The first is the Cartesian where the origin is placed at the Earth Center of mass; *X* axis is pointing to the equator and prime meridian intersection. *Z* axis is pointing to the North pole and *Y* axis complete the right hand rule.

This system is widely used inside GPS systems because of its easy and precise computations, but is not easily understood by human beings.

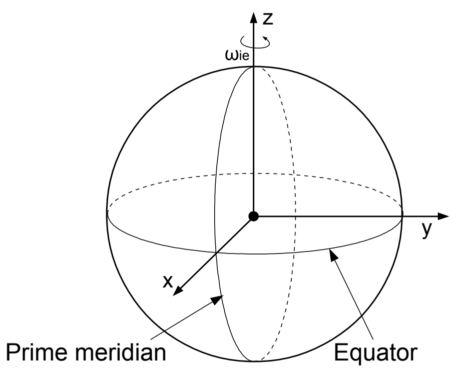


Figure 2.1: ECEF Coordinate system

2.1.1.2. Geodetic coordinate system (WGS84)

The second coordinate system is the most commonly used to represent positions relative to Earth. It uses an ellipsoid to represent the overall Earth shape.

Several geodetic models exist, but nowadays, the WGS84 ellipsoid is probably the most common one due to its use as the GPS standard. When talking about Geodetic coordinates, we will always refer to WGS84 referenced coordinates.

A geodetic coordinate is a set of three parameters: Latitude (Φ), Longitude (λ) and Altitude (h).

The Latitude is the angle in the meridian plane from the equatorial plane to the ellipsoid normal. Note that in most situations, the ellipsoid normal will not intersect the center of the Earth.

The Longitude is the angle in the equatorial plane from the prime meridian to the projection of the point of interest onto the equatorial plane.

The Altitude is the length, along the ellipsoid normal, from the ellipsoid surface to the point of interest.

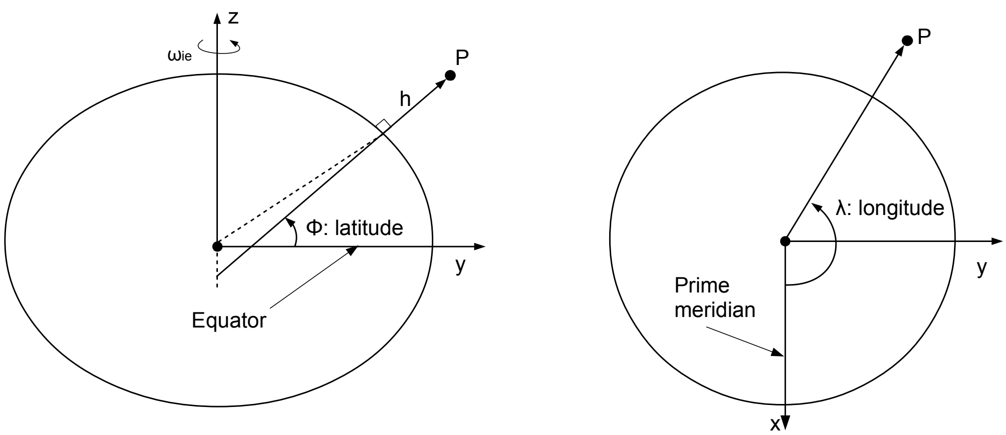


Figure 2.2: Latitude, Longitude, and Altitude definition

Altitude reference

As mentioned above, the WGS84 altitude reference is the ellipsoid surface. Unfortunately, this surface does not exactly match the actual Earth surface.

A geoid shape which is based on complex gravity models is often used to give a better Earth shape approximation than typical spherical or ellipsoidal models. The total variation between the WGS84 ellipsoid shape and a geoid is less than 200m.

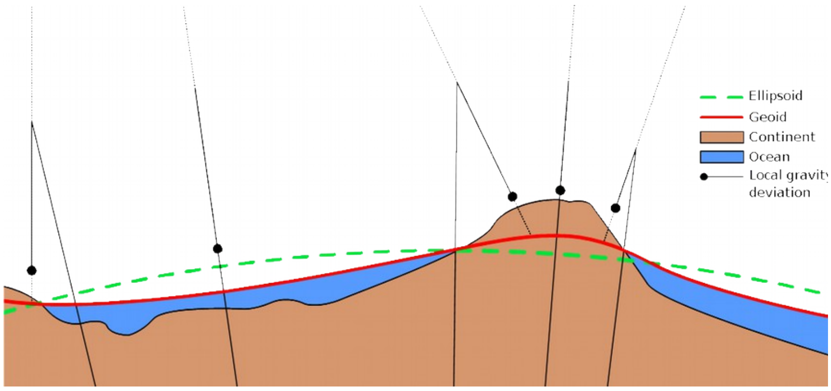


Figure 2.3: Geoid representation with ellipsoid and actual Earth shape

When an altitude is provided with respect to the geoid model, it becomes consistent with the Mean Sea Level (MSL). Geoid based altitude will then be called altitude above MSL.

The Ellipse INS allows providing altitude referenced to the Ellipsoid or to the Mean Sea Level.

2.1.2. Local Geodetic frame

The local Geodetic frame refers to the North, East, Down rectangular frame (NED).

This frame is obtained by fitting the local ellipsoid shape by a tangent plane at the current position. This coordinate frame is attached to a fixed point relatively to the Earth surface.

X axis is turned toward North, *Z* axis turned down, along the local ellipsoid normal, and *Y* axis completes the right hand rule, pointing East.

As it's impossible to perfectly fit the ellipsoidal shape by a plane, this frame is only suitable for local measurements.

Note: The Ellipse INS internally accounts for this frame rotation when the vehicle moves at high speed in order to ensure best navigation performance.

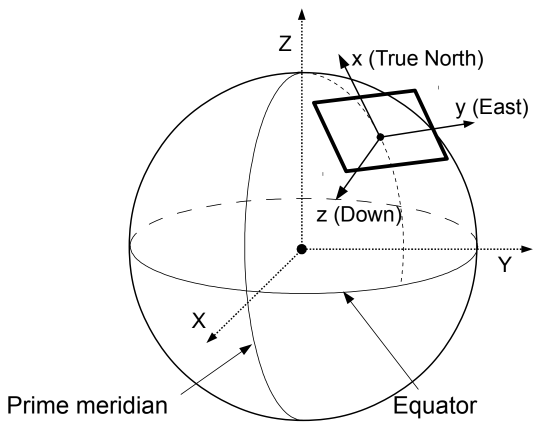


Figure 2.4: Local Geodetic coordinate frame representation

2.1.3. Vehicle coordinate frame

Depending on application, a vehicle coordinate frame is defined as follows: *X* axis is turned in Forward direction, *Z* axis is turned Down, and *Y* axis, thanks to right hand rule is turned to the right of vehicle.

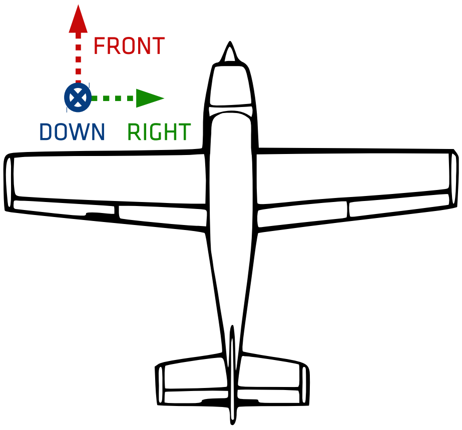


Figure 2.5: Vehicle coordinate frame

2.1.3.1. Ship motion conventions

According to the vehicle coordinate frame defined above, the ship motion conventions are the following:

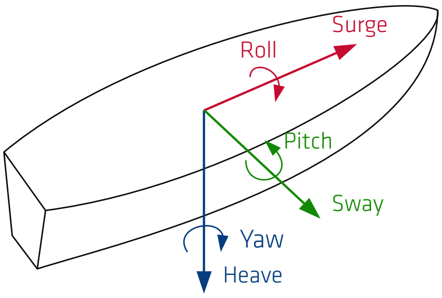


Figure 2.6: Ship motion conventions

2.1.4. Sensor (body) coordinate frame

This frame is attached to the Ellipse.

The following diagram shows the body coordinate frame as configured by default. In most situations, the body coordinate frame must be aligned with vehicle coordinate frame. Sensor alignment in vehicle can be rotated by software if the sensor coordinate frame cannot be aligned mechanically. Check section 2.3 Accounting for Misalignment for more details about this software alignment.

Figure 2.7: Default body coordinate frame

2.1.4.1. Origin of measurements

We have defined the Ellipse axes directions, but we also need to know where is the Origin of this coordinate frame. This coordinate frame origin is the intersection of the three accelerometers and corresponds to the center of velocity and position measurements.

This origin must be considered when measuring lever arms.

A ◕ symbol in the mechanical specifications defines and locates this Origin of measurements.

2.2. Rotations between two coordinate frames

2.2.1. Positive rotation direction

According to the "Right Hand Rule", the positive direction for rotations is clockwise in the axis direction:

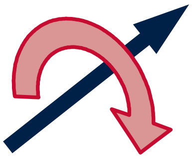


Figure 2.8: Positive rotation direction

2.2.2. Rotations representation

There are several ways to represent the orientation of the device that are provided by the Ellipse. Some are easy to understand, others are very efficient such as quaternion form.

2.2.2.1. Euler Angles

Euler angles are a commonly used representation of spatial orientation. Euler angles are in fact a composition of rotation from the Local Geodetic Coordinates System. This orientation is defined by the sequence of the three rotations around the Local Frame *X*, *Y* and *Z* axes.

Euler angles are widely used because they are easy to understand. The three parameters: Roll, Pitch and Yaw define rotations around the fixed frame's axes:

- Roll *(φ)*: Rotation around *X* axis. $\varphi \in [-\pi ; \pi]$
- Pitch *(θ)*: Rotation around *Y* axis. $\theta \in \left[-\frac{\pi}{2} ; \frac{\pi}{2}\right]$
- Yaw *(Ψ)*: Rotation around *Z* axis. $\psi \in [-\pi ; \pi]$

Note: As Euler angles suffer from a singularity called "Gimbal lock", when Pitch approaches ± π/2, we do not advise to use Euler angles if the device has to be used in a wide range of orientations. Quaternions and rotation matrices do not have any singularity.

2.2.2.2. Rotation matrix (Direction Cosine Matrix)

The Direction Cosine Matrix (DCM) is a rotation matrix that transforms one coordinate reference frame to another. Rotation matrices are a complete representation of a 3D orientation, thus there is no singularity in that model.

A DCM locates three unit vectors that define a coordinate frame. Here the DCM transforms the body coordinate frame to the Local NED coordinates. The DCM is the combination of the three rotation matrices RM_{φ} , RM_{θ} and RM_{ψ} respectively around Local Geodetic (NED) X, Y and Z axes.

Here is defined a DCM in terms of Euler Angles:

$$DCM = RM_{\psi} RM_{\theta} RM_{\phi}$$

$$DCM = \begin{pmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{pmatrix}$$

$$DCM = \begin{pmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{pmatrix}$$

As for any rotation matrix, the inverse rotation equals to the transposed matrix:

$$DCM^{-1} = DCM^{T}$$

In order to transform a vector expressed in the Body coordinate system into the NED frame, user will use the DCM as expressed below:

$$V_{NED} = DCM \cdot V_{body}$$

Reciprocally:

$$V_{body} = DCM^{T} \cdot V_{NED}$$

2.2.2.3. Quaternions

Quaternions are an extension of complex numbers as defined here:

$Q=q_0+i\cdot q_1+j\cdot q_2+k\cdot q_3$ Where i, j and k are imaginary numbers.

Particular quaternions such as $\|Q\|=1$ can represent, as DCMs, a complete definition of the 3D orientation without any singularity.

Quaternion algebra do not require a lot of computational resources, they are therefore very efficient for orientation representation.

The inverse rotation of Q is defined by the complex conjugate of Q , denoted $\overline{Q}$:

$$\overline{Q}=q_0-i\cdot q_1-j\cdot q_2-k\cdot q_3$$

Quaternion can be defined as a function of DCM coefficients:

$$q_0=\frac{1}{2}\sqrt{1+DCM_{11}+DCM_{22}+DCM_{33}}$$

$$q_1=\frac{1}{4q_0}\left(DCM_{32}-DCM_{23}\right)$$

$$q_2=\frac{1}{4q_0}\left(DCM_{13}-DCM_{31}\right)$$

$$q_3=\frac{1}{4q_0}\left(DCM_{21}-DCM_{12}\right)$$

Or as a function of Euler Angles:

$$q_0=\frac{1}{2}\sqrt{1+\cos\theta\sin\psi+\sin\phi\sin\theta\sin\psi+\cos\phi\cos\psi+\cos\phi\cos\theta}$$

$$q_1=\frac{1}{4q_0}\left(\sin\phi\cos\theta-\cos\phi\sin\theta\sin\psi+\sin\phi\cos\psi\right)$$

$$q_2=\frac{1}{4q_0}\left(\cos\phi\sin\theta\cos\psi+\sin\phi\sin\psi+\sin\theta\right)$$

$$q_3=\frac{1}{4q_0}\left(\cos\theta\sin\psi-\sin\phi\sin\theta\cos\psi+\cos\phi\sin\psi\right)$$

2.2.2.4. Other useful conversion formulas

Some other conversion formulas can be useful for many users, and are listed below:

Quaternion to DCM

It may be useful to compute a DCM based on the quaternion parameters:

$$DCM=\begin{pmatrix} 2q_0^2+2q_1^2-1 & 2q_1q_2-2q_0q_3 & 2q_0q_2+2q_1q_3 \\ 2q_1q_2+2q_0q_3 & 2q_0^2+2q_2^2-1 & 2q_2q_3-2q_0q_1 \\ 2q_1q_3-2q_0q_2 & 2q_2q_3+2q_0q_1 & 2q_0^2+2q_3^2-1 \end{pmatrix}$$

Quaternion to Euler

Here is quaternion translated into Euler angles.

$$\phi=\tan^{-1}\left(\frac{2q_2q_3+2q_0q_1}{2q_0^2+2q_3^2-1}\right)$$

$$\theta=-\sin^{-1}\left(2q_1q_3-2q_0q_2\right)$$

$$\psi=\tan^{-1}\left(\frac{2q_1q_2+2q_0q_3}{2q_0^2+2q_1^2-1}\right)$$

DCM To Euler

Finally, DCM matrix is converted into Euler Angles.

$$\phi=\tan^{-1}\left(\frac{DCM_{32}}{DCM_{33}}\right)$$

$$\theta=-\sin^{-1}\left(DCM_{31}\right)$$

$$\psi=-\tan^{-1}\left(\frac{DCM_{21}}{DCM_{11}}\right)$$

2.3. Accounting for Misalignment

The Ellipse alignment procedure involves two steps: an axis alignment, and a fine alignment. Some aiding sensors must also take into account misalignment, that will be measured like it has been done for the IMU, comparing the external sensor with vehicle coordinate frame.

2.3.1. Axis misalignment

The following example shows how to measure IMU axis misalignment. The Ellipse axes must be compared to the Vehicle axes as follows:

IMU Axis	Vehicle direction
X	LEFT
Y	FRONT
Z	DOWN

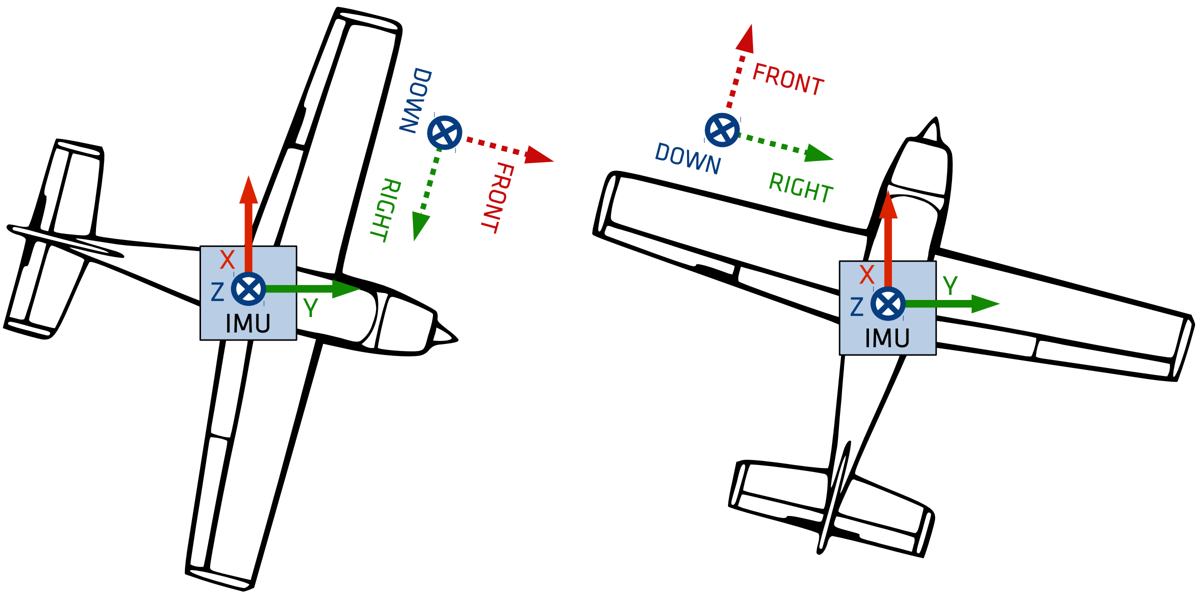


Figure 2.9: Axis alignment example.
Left: Initial mechanical installation. Right: Ellipse coordinate frame after axis alignment.

2.3.2. Fine misalignment

Once axes axis alignment is performed, the small residual angles must then be measured as follow. Misalignment angles correspond to the residual rotation required to pass from the IMU coordinate frame to the vehicle coordinate frame. In our example, alpha corresponds to the misheading and its sign is negative.

Most applications will only have low angles on roll and pitch misalignment. If large angles on roll and pitch are expected (> 5°), user must consider the rotation composition order: roll, then pitch, then yaw.

Mis Angles	Value
misroll	Not shown
mispitch	Not shown
misheading	- α (negative)

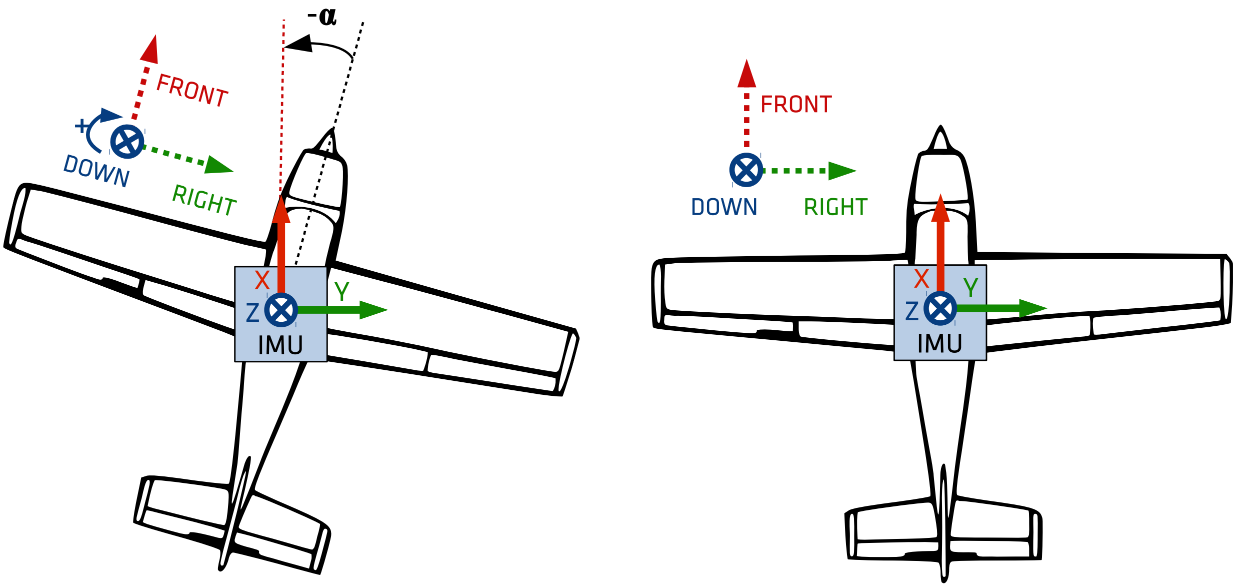


Figure 2.10: Misalignment residuals measurement
Left: Residual measurement. Right: Ellipse coordinate frame after fine alignment.

Once the fine misalignment angles are measured and entered into Ellipse configuration, the Ellipse coordinate frame is assumed to be aligned with the vehicle coordinate frame.

2.3.3. Instruments misalignment

Some aiding sensors will require a misalignment angle to be set.

The following diagram shows that instruments alignments with the Ellipse are measured in a similar way to the “fine misalignment” with the vehicle coordinate frame. We consider in this example a GPS true heading system that provides the direction from antenna 1 to antenna 2. The misalignment between the Ellipse and the antenna system is shown as the angle “mis yaw”. It is negative in this case.

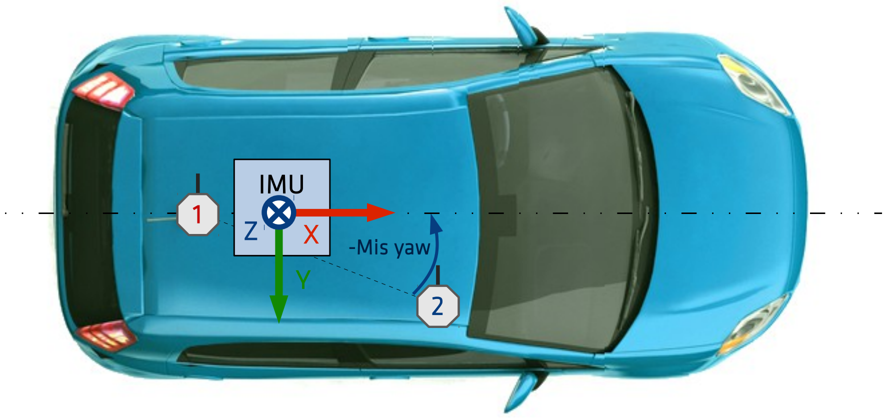


Figure 2.11: GPS Dual antenna misalignment measurement

2.4. Accounting for Lever arms

All lever arms are considered in the vehicle (body) coordinate frame, and are measured FROM the Ellipse, TO the point of interest.

Below is an example showing a GPS antenna lever arm measurement:

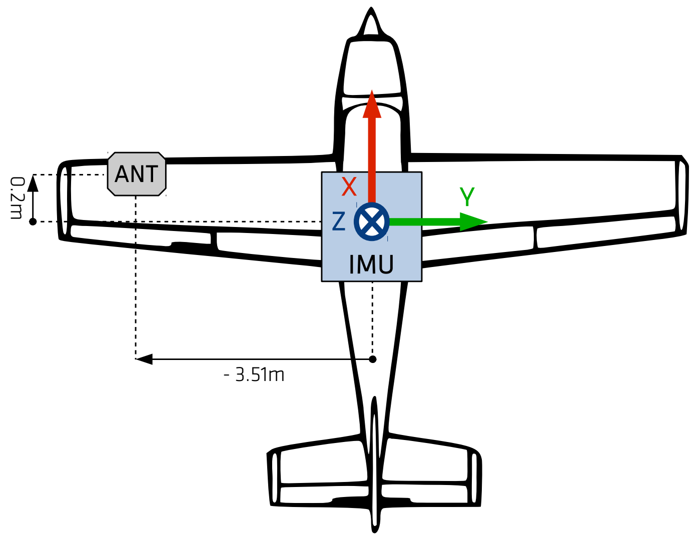


Figure 2.12: GPS antenna Lever Arm example

3. Mechanical and Electrical specifications

3.1. Mechanical specifications

All dimensions are expressed in millimeters using the International System of Units (SI) conventions.

3.1.1. Overview

The Ellipse enclosure is composed of two anodized aluminum parts, one for the cover and one for the base plate. The device uses high quality alloys and connectors to offer a full IP-68 enclosure and a good resistance to harsh environments.

The Ellipse N and E versions include a sophisticated venting system maintain IP-68 protection while allowing ambient pressure measurements to be performed.

The Ellipse connectors are high quality Ultimate Fischer connectors that offers IP-68 protection even unconnected. The Ellipse-N version also includes a SMA connector to connect the GPS antenna. When used with a waterproof GPS antenna cable, this connector offers an IP-68 protection.

Note 1: If you are planing to use Ellipse internal magnetometers, please make sure that you don't use ferromagnetic materials to mount the device.

3.1.2. Specifications

The table below summarizes all mechanical and environmental specifications.

Mechanical Specifications	
Size	46 x 45 x 24 mm (1.8 x 1.77 x 0.9 ")
Weight	A: 45 g / 0.1 lbs N: 47 g / 0.1 lbs E: 49 g / 0.1 lbs
Shocks	< 2 000 *g*
Operating Vibrations	3g RMS – 20Hz to 2 kHz as per MIL-STD-810G

Environmental Specifications	
Enclosure	Anodized Aluminum
IP rating	IP-68 (30min at 1 meter)
Operating temperature	-40 to 85°C (-40 to 185°F)
Storage	-40 to 85°C (-40 to 185°F)
Humidity	Sealed, no limit
MTBF (computed)	50.000 hours
Calibration interval	None required, maintenance free

3.1.3. Device mechanical alignment

For best measurement accuracy, a good mechanical alignment is required. During manufacturing, the Ellipse measurement frame has been carefully aligned to 0.05° with the base plate for roll, pitch and yaw angles.

To ease the yaw alignment (X axis), the base plate features two alignment holes Ø 2 mm H8 that guarantees with two taper pins Ø 2 mm h7 a yaw alignment better than ±0.05°.

3.1.4. Origin of measurements

The center of measurement for acceleration, velocity and position is represented on the mechanical outlines by the ◑ symbol. It is referenced to the base plate fine alignment hole.

3.1.5. Device label

SBG Systems manufacturing process is based on EN-9100 system with individual and full traceability of every component and operation. Each Ellipse is identified by a unique serial number that can be used to trace all operations during the product lifetime such as manufacturing, calibration, tests and repairs.

In addition to a unique serial number, a product code is used to define exactly the device type and options.

You can find on the back side of the Ellipse a laser printed label that hold all these identification information. This label also includes a data-matrix code that encodes the device unique serial number.

Figure 3.1: Ellipse device label sample

3.1.6. Ellipse-A mechanical outline

All dimensions are in mm.

3.1.6.1. Front view

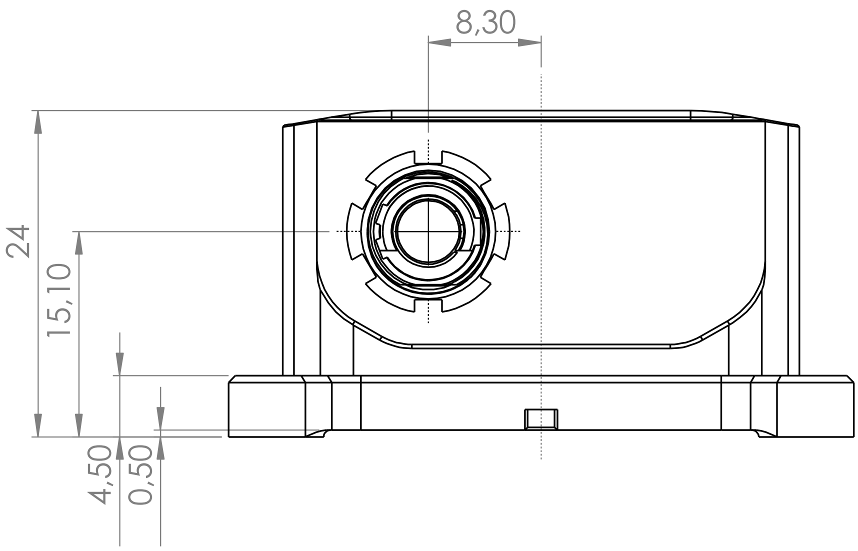


Figure 3.2: Ellipse A front view

3.1.6.2. Top view

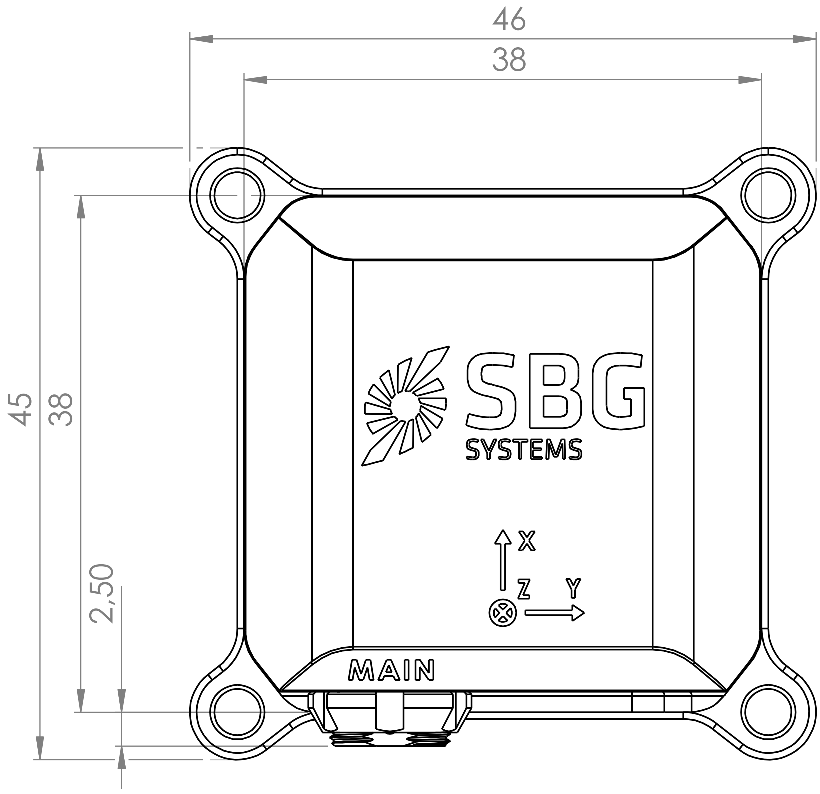


Figure 3.3: Ellipse A top view

3.1.6.3. Right view

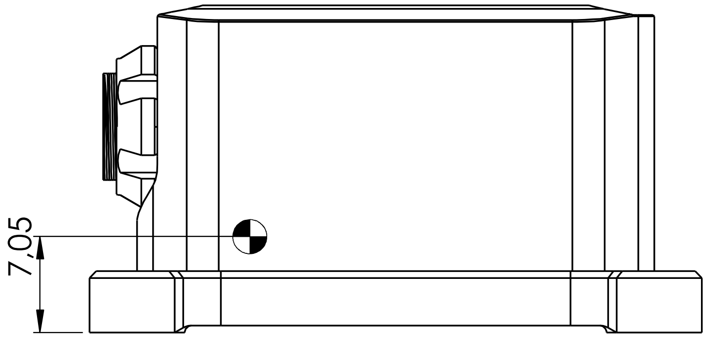


Figure 3.4: Ellipse A right view

3.1.6.4. Bottom view

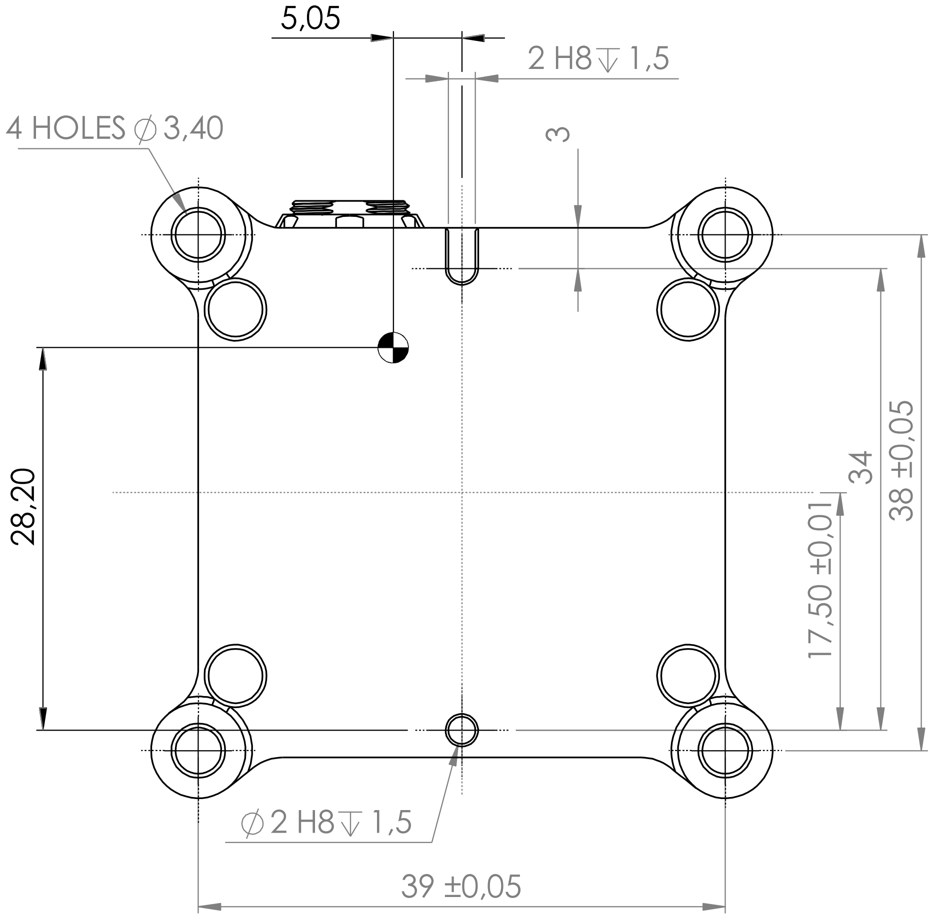


Figure 3.5: Ellipse A bottom view

3.1.7. Ellipse-E mechanical outline

All dimensions are in mm.

3.1.7.1. Front view

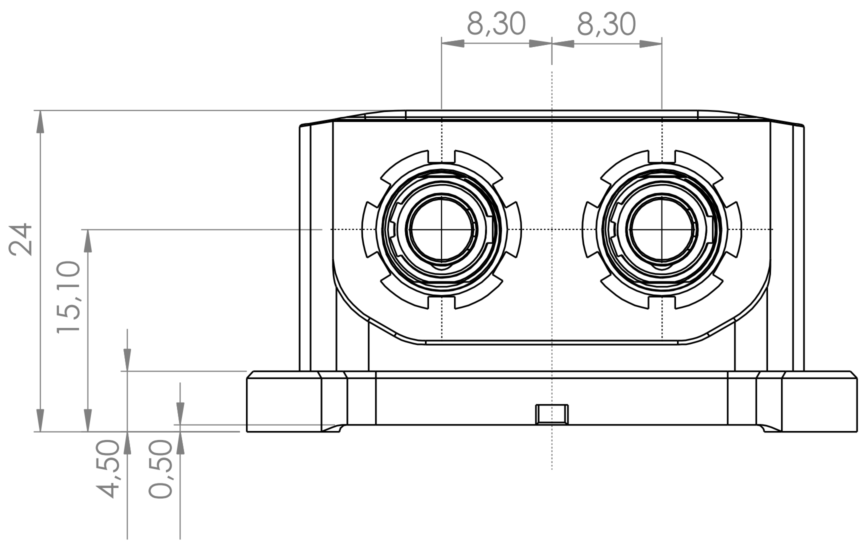


Figure 3.6: Ellipse E front view

3.1.7.2. Top view

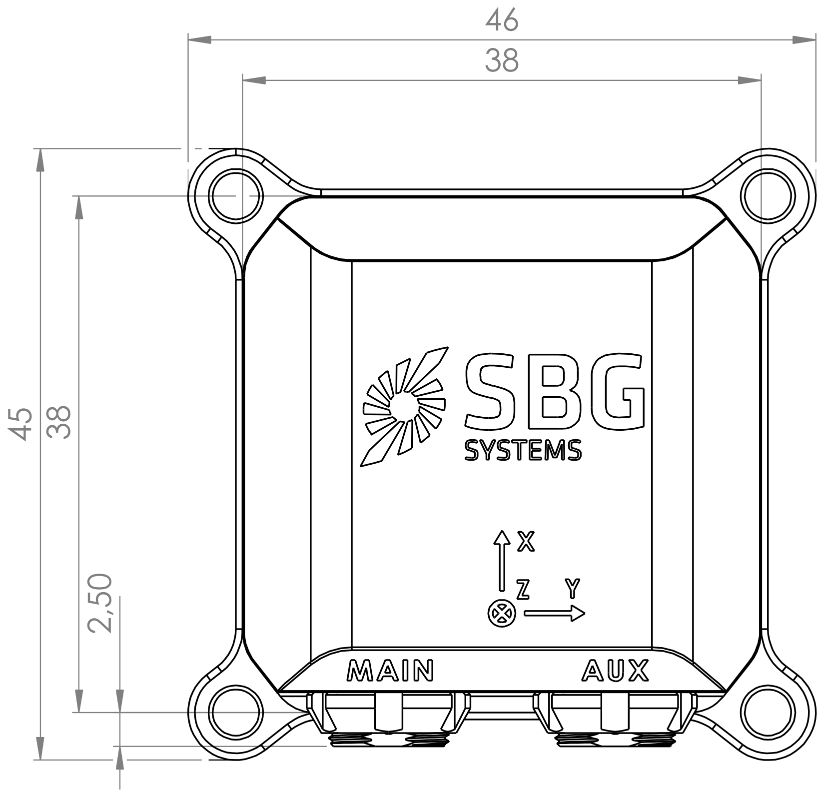


Figure 3.7: Ellipse E top view

3.1.7.3. Right view

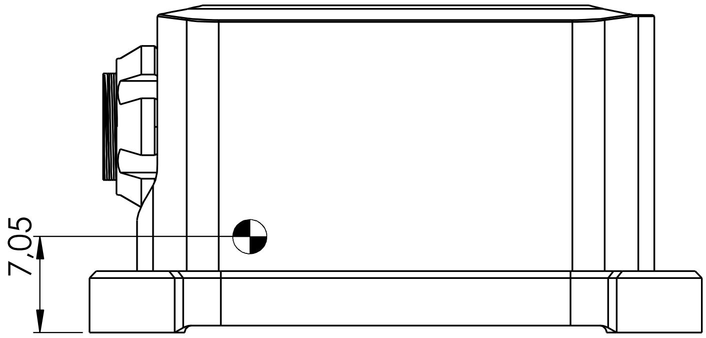


Figure 3.8: Ellipse E right view

3.1.7.4. Bottom view

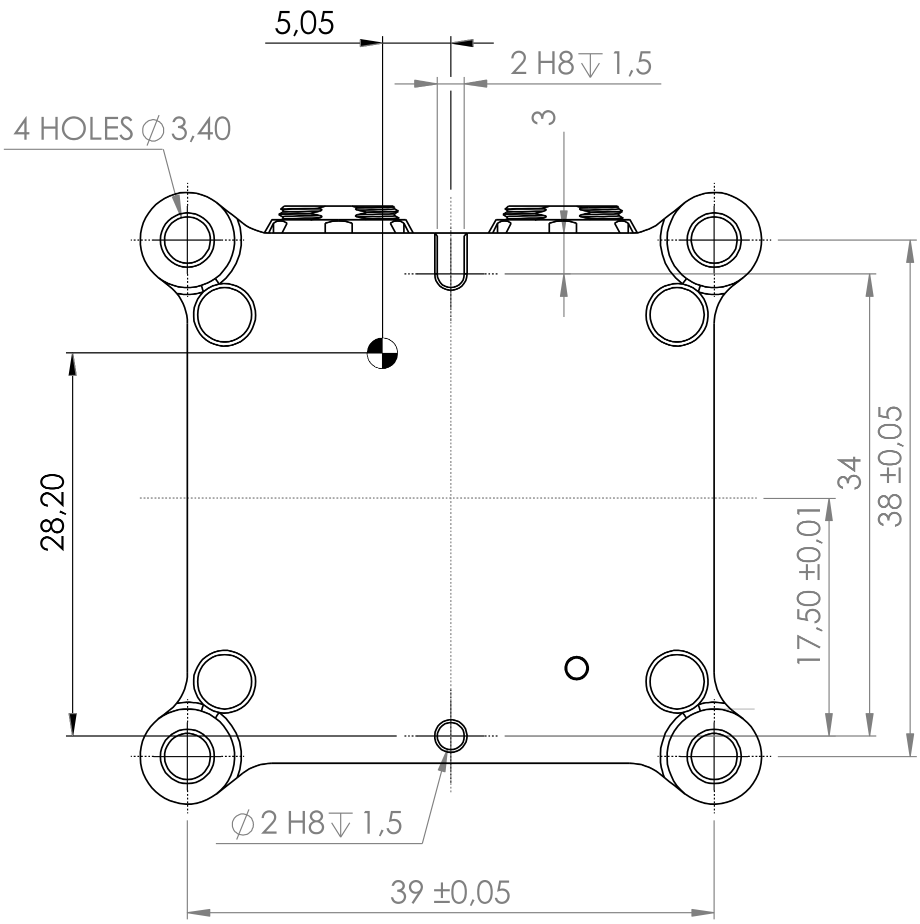


Figure 3.9: Ellipse E bottom view

3.1.8. Ellipse-N mechanical outline

All dimensions are in mm.

3.1.8.1. Front view

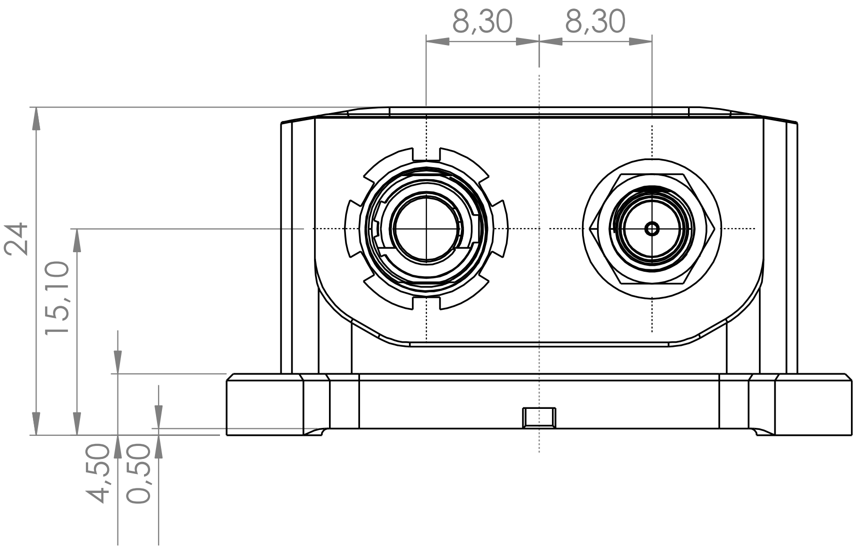


Figure 3.10: Ellipse N front view

3.1.8.2. Top view

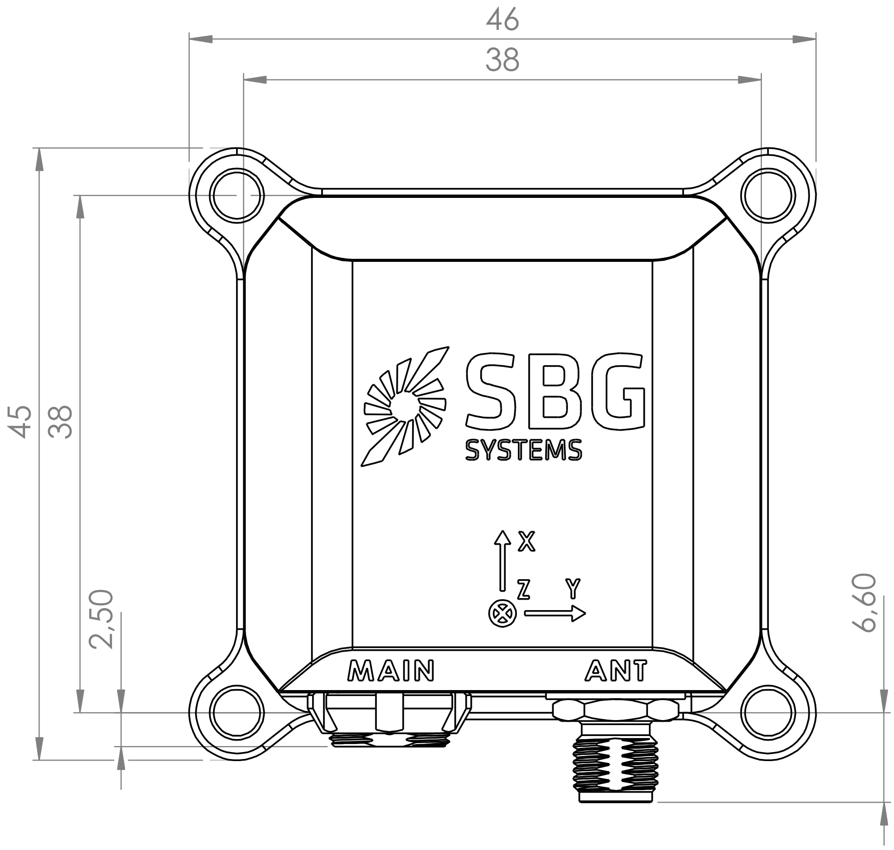


Figure 3.11: Ellipse N top view

3.1.8.3. Right view

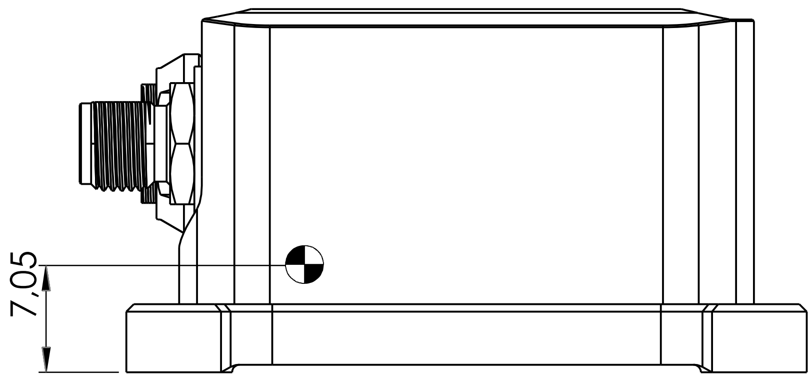


Figure 3.12: Ellipse N right view

3.1.8.4. Bottom view

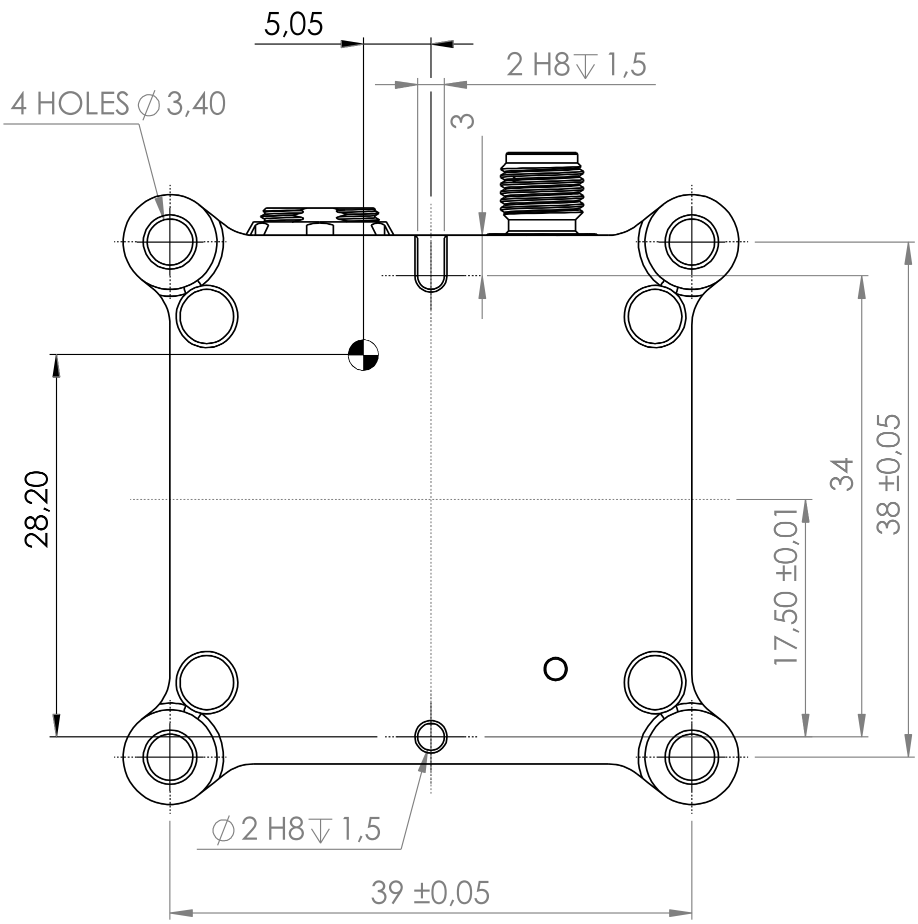


Figure 3.13: Ellipse N bottom view

3.2. Electrical specifications

The Ellipse connectors are all placed on the front panel. The connectors are referenced and identified by laser marking on the enclosure.

SBG Systems has selected high quality connectors designed for harsh environments. They offer an IP-68 protection when the plug is properly mounted.

> **Note:** The Ellipse development kit cables are not designed to offer an IP-68 protection. Contact SBG Systems to get further support about IP-68 protection.

3.2.1. Ellipse-A without GPS aiding

Figure 3.14: Ellipse AHRS

3.2.2. Ellipse-E with external aiding only

Figure 3.15: Ellipse INS without GPS (E version)

3.2.3. Ellipse-N with embedded GNSS

Figure 3.16: Ellipse INS with GNSS receiver (N version)

3.2.4. Main connector

The main connector provides access to most Ellipse features. It provides:

- One serial connection that supports full-duplex operations at up to 921 600 bps. It can be configured to operate as an RS-232 or RS-422 interface by pulling down the pin 5.
- One CAN 2.0A/B connection that supports up to 1 Mbit/s data rate used to output data.
- Two synchronization input / event marker signal for clock synchronization or to output data on a signal event. One of these logic inputs can be used as additional serial port for RTCM correction input. Those two pins can also be used as odometer signal input.
- A Synchronization output signal for time stamping and to trigger some equipments.

3.2.4.1. Connector specifications

The main connector uses a 10 ways UltiMate Fischer connector. The exact receptacle reference is: UR02W07 F010P BK1 E2AA.

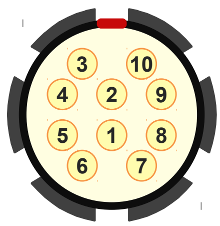


Figure 3.17: Main receptacle front view

The Ellipse connector will mate with the reference UP01L07 M010S BK1 Z2ZA. Don't forget that this reference don't include the cable clamp sets. Other plugs with right angle or other options may be found if required.

Figure 3.18: Main plug top view

3.2.4.2. Connector pin out for Ellipse B1 versions

Pin #	Name	Description
1	SYNC IN A – ODO B	Multi function input. May be used as clock/event, or odometer input
2	SYNC IN B – PORT B RX - ODO A	Multi function input. May be used as clock/event, odometer input, or RS-232 Rx line for RTCM correction input
3	VIN	Power supply input
4	GND	Ground return signal
5	PORT A RS-232/$\overline{\text{RS-422}}$	Port A RS-232 or RS-422 selector. Tie to GND to select RS-422
6	SYNC OUT A	Synchronization output signal.
7	PORT A RS422 TX+	Port A RS-422 Tx+. Not used in RS-232 connection.
8	PORT A RS232 TX – PORT A RS422 TX-	Port A RS-422 Tx- or RS-232 Tx line
9	PORT A RS232 RX – PORT A RS422 RX+	Port A RS-422 Rx+ or RS-232 Rx line
10	PORT A RS422 RX-	Port A RS-422 Rx-. Not used in RS-232 connection.

Note: By default, if you leave the RS-232/$\overline{\text{RS-422}}$ signal unconnected, the Port A will operate in RS-232 mode.

3.2.4.3. Connector pin out for Ellipse B2 versions

Pin #	Name	Description
1	SYNC IN A – ODO B	Multi function input. May be used as clock/event, or odometer input
2	SYNC IN B – PORT B RX - ODO A	Multi function input. May be used as clock/event, odometer input, or RS-232 Rx line for RTCM correction input
3	VIN	Power supply input
4	GND	Ground return signal
5	NC	Not used. Leave unconnected.
6	SYNC OUT A	Synchronization output signal.
7	CAN L	CAN Low
8	PORT A RS232 TX	Port A RS-232 Tx line
9	PORT A RS232 RX	Port A RS-232 Rx line
10	CAN H	CAN high

3.2.5. External aiding connector (Ellipse-E only)

The external aiding connector is mainly used to connect aiding equipments to the Ellipse-E. It features the following connections:

- A full duplex RS-232 / RS-422 port for GNSS aiding connection
- An additional RS-232 input for upward compatibility
- Two synchronization input signals used for internal clock synchronization, data time stamping and/or event markers
- A Synchronization output signal for time stamping and to trigger some equipments.

3.2.5.1. Connector specifications

Please refer to section 3.2.4.1 Connector specifications for more details as the same connector type is used for Main and Aux connectors.

3.2.5.2. Connector pin out

Pin #	Name	Description
1	SYNC IN C	May be used as clock/event input
2	SYNC IN D	May be used as clock/event input
3	PORT D RX	RS-232 input for miscellaneous applications
4	GND	Ground return signal
5	NC	Not internally connected
6	SYNC OUT B	Synchronization output signal.
7	PORT C RS422 TX+	Port C RS-422 Tx+. Not used in RS-232 connection.
8	PORT C RS232 TX – PORT C RS422 TX-	Port C RS-422 Tx- or RS-232 Tx line
9	PORT C RS232 RX – PORT C RS422 RX+	Port C RS-422 Rx+ or RS-232 Rx line
10	PORT C RS422 RX-	Port C RS-422 Rx-. Not used in RS-232 connection.

3.2.6. Electrical specifications

3.2.6.1. Electrical specifications

Recommended electrical specifications from -40°C to 85°C.

Item	Conditions	Min	Typical	Max	Unit
Power supply					
Input voltage range		5		36	V
Power consumption	Model A		440		mW
	Model E		460		mW
	Model N		650		mW
RS-232 Receivers, Sync In pins					
Input range		-25		25	V
Low level threshold		0.8			V
High level threshold				2.0	V
Input resistance		3	5	7	kΩ
RS-422 Receivers					
Input differential threshold		-200		-50	mV
Input hysteresis			30		mV
Input resistance		48			kΩ
RS-232 Transmitters					
Output range		+/-5	+/-5.4		V
RS-422 transmitters					
Differential output voltage		2			V
Common mode output voltage				3	V
CAN bus					
Recessive Bus Voltage		2	2.5	3	V
CAN H Output Voltage	dominant	2.75	3.5	4.5	V
CAN L Output Voltage	dominant	0.5	1.25	2.25	V
Absolute input voltage	CANH, CANL	-58		58	V
Differential input voltage	CANH, CANL	0.5	0.7	0.9	V

3.2.7. GPS antenna connector (Ellipse N only)

To connect an external GNSS antenna, the Ellipse N includes an IP-68 SMA connector. The internal GNSS receiver only supports active GNSS antennas.

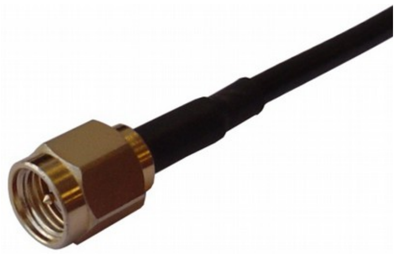


Figure 3.19: SMA antenna connector

Please be advise that the Ellipse doesn't implement any lightning protection. The GPS antenna and cable are very sensitive to strikes and a proper installation with lightning protection devices may be required.

Note: For best performance, the antenna(s) should be connected before the power is applied. The Ellipse GPS estimates the noise floor of the antenna during the startup sequence.

Warning: The SMA connector offers an IP-68 protection only when a waterproof GPS cable is connected. There is no IP rating when the SMA connector is not connected to an IP-68 dust cap or cable.

3.2.7.1. GPS antenna advices

The Ellipse N embeds a high performance GNSS receiver that supports L1 GPS and GLONASS signals. For best performances and robustness, please use low noise and high gain active GPS antennas that support the frequencies band you are planning to use.

Recommended electrical specifications from -40°C to 75°C.

Parameter	Specifications		Remark, conditions
Antenna connector	SMA female		IP-68 when connected
Input impedance	50 Ω		
LNA supply voltage	3.0 VDC		
LNA supply current	< 20 mA		
RF input frequencies	GPS L1: GLONASS L1: Beidou B1:	1575.42 MHz 1596 – 1610 MHz 1561.098 MHz	The GNSS module can track up to two constellations at a time
Minimum gain	15 dB		
Maximum gain	50 dB		
Maximum noise figure	<< 1.5 dB		

Table 1: GNSS antenna requirements

SBG Systems has selected some high quality GPS antennas for different applications. Please refer to the section 8.4 GNSS antennas to get more details on available antennas.

4. Interfaces specifications

4.1. Overview

The Ellipse features up to four serial interfaces (Port A to Port D) which provide all the main features of the Ellipse: Configuration, data input, data output.

In addition, the Ellipse supports CAN 2.0A/B connectivity to output log messages. Due to the CAN implementation and limitations (payload limited to 8 bytes), the CAN interface is not handled like the other interfaces.

4.2. Supported protocols

The Ellipse has been designed to be connected to a large range of aiding equipments and materials. In addition to the native sbgECom binary protocol, other third party or standard protocols are also supported such as NMEA, RTCM, TSS1, Ublox Binary protocol and others.

4.2.1. sbgECom binary protocol

The Ellipse binary protocol is the main and native protocol used to output log messages and to configure the device.

4.2.1.1. Log messages

All Ellipse binary output log messages are listed in the section 4.3-Log outputs overview below.

4.2.1.2. Commands

The sbgECom protocol provides a full set of configuration commands that can be used to tune every functionality of the device. In addition to the dedicated commands set, a global configuration can be performed through a settings import / export feature.

Some commands will be operated in real time, while most others will issue a device reset.

> **Note:** For a complete description of the sbgECom binary protocol, please refer to the Ellipse Firmware Reference Manual.

4.2.2. Legacy IG Devices Serial Protocol

For easy migration from previous IG-500 series, The Ellipse also supports the legacy IG Devices protocol continuous output mode. This mode provides regular sensor output.

Note that all previous IG Devices configuration commands are not supported in Ellipse series.

4.2.3. Ublox UBX protocol

The Ublox UBX binary protocol can be used to provide best performance when connecting an external Ublox GPS/GNSS receiver to an Ellipse-E.

- NAV PVT is used to handle the full Position, Velocity and Time solution (required)
- NAV SAT is used to get advanced signal tracking details such as constellations in use (optional).

4.2.4. NMEA protocol

The Ellipse implements NMEA 0183 standard protocol for both log outputs and aiding equipments input. A detailed list of NMEA output logs can be found in the section 4.3-Log outputs overview below.

The following NMEA messages are handled by the Ellipse to input aiding data:

- GGA for position and altitude
- RMC for horizontal velocity and course
- HDT for true heading
- ZDA for UTC time data

4.2.5. RTCM protocol

The Ellipse N version embed a high performance GNSS receiver that allows differential GPS data to be provided externally rather than using SBAS corrections. This can be done through the serial Port B. The embedded GNSS receiver supports the following RTCM 2.3 messages:

Message Type	Description
1	Differential GPS Corrections
2	Delta Differential GPS Corrections
3	GPS Reference Station Parameters
9	GPS Partial Correction Set

Note RTCM cannot be used together with SBAS.

4.3. Log outputs overview

The Ellipse can output log messages using different protocols on each interface that implements an output channel.

The CAN interface handles log outputs in a different manner than serial interfaces. For more details, please refer to the section 4.5-CAN 2.0 A/B interface below.

4.3.1. Logs configuration

For a particular interface, the user can configure how each log message should be outputted using the following options:

- Disabled, this log message is never generated
- Continuous, this log message is outputted according to the configured output frequency
- New data, this log message is sent each time a new data is available
- Event #, this log message is sent each time a signal is received on the Event # pin

4.3.1.1. Continuous mode

The continuous mode is recommended to output log data on a regular basis. It is usually used to output inertial data, computed attitude, velocity and position. When this mode is selected, a divider can be set for each log message to reduce the output rate from 200 Hz down to 1 Hz.

When the device is correctly fed with UTC data and a PPS signal, the device time is UTC aligned. In this case, configuring a log message in continuous mode to 1 Hz means that each time an UTC second elapses, the log message is sent.

This feature is very useful to ease data synchronization between multiple equipments.

4.3.1.2. New data

The new data mode is very useful to output aiding equipments data such as GPS position or odometer velocity.

With this mode, you are always sure to get the most recent data without logging duplicates.

4.3.1.3. Event input signals

The Ellipse can be configured to output log messages when an event input signal is detected. An input signal can be generated on a rising edge, falling edge or both rising and falling edges.

When an event signal is detected, a log message can be outputted using the last received or computed data.

4.3.2. NMEA Talker Id

A NMEA talker id can be defined for each output interface. The NMEA talker id is appended at the beginning of the NMEA frame to form a complete NMEA identifier.

For example if the Ellipse has to output the log message GGA and the NMEA talker id is set to GP, the resulting NMEA message name will be GPGGA.

This feature is useful to increase the NMEA log messages compatibility with external equipments.

4.3.3. Log messages list

The Ellipse output logs architecture is very versatile and powerful. For example, the device can output sbgECom binary logs and NMEA messages on the same output port.

As explained previously, each message can be triggered based on different conditions. For some logs, it makes sense to output them on a time basis such as 50 Hz. However, for other logs, it's much better to output them as soon as a new data is available (for example a GPS position).

For each available log, you can use the following color code to know it's recommended to output a log on a “New Data” event.

Color Code	Description
●	It's strongly recommended to output this log on a “New Data” trigger

4.3.3.1. Ellipse Binary Log messages

The Ellipse binary protocol offers the best security, latency and options to output log messages. You can find in the table below a summary of all available binary log messages that can be outputted by the Ellipse.

For a complete description of each log message, please refer to the Ellipse Firmware Reference Manual.

Output		Description
SBG_ECOM_LOG_STATUS		Output the system, solution, clock, aiding status
SBG_ECOM_LOG_IMU_DATA		Output accelerometers, gyroscopes, delta angle and delta velocity
SBG_ECOM_LOG_EKF_EULER		Output computed Euler angles attitude
SBG_ECOM_LOG_EKF_QUAT		Output computed quaternion attitude
SBG_ECOM_LOG_EKF_NAV		Output computed velocity and position
SBG_ECOM_LOG_SHIP_MOTION_0		Real time heave output at the main monitoring point
SBG_ECOM_LOG_UTC_TIME	●	Output the synchronized UTC date and time
SBG_ECOM_LOG_MAG	●	Output magnetometers and related accelerometers aiding data
SBG_ECOM_LOG_MAG_CALIB	●	Magnetometer calibration data (raw buffer)
SBG_ECOM_LOG_GPS1_VEL	●	Output GPS 1 velocity aiding data
SBG_ECOM_LOG_GPS1_POS	●	Output GPS 1 position aiding data
SBG_ECOM_LOG_GPS1_HDT	●	Output GPS 1 true heading aiding data
SBG_ECOM_LOG_GPS1_RAW	●	GPS 1 raw data for post processing.
SBG_ECOM_LOG_ODO_VEL	●	Output odometer velocity aiding data
SBG_ECOM_LOG_EVENT_A/B/C/D	●	Output the list of received event markers on Sync A/B/C/D/E pin
SBG_ECOM_LOG_PRESSURE	●	Internal pressure sensor output

4.3.3.2. NMEA log messages

The Ellipse supports some standard NMEA 0183 messages to ensure GPS drop in replacement and protocol compatibility with other hardware.

However, the NMEA standard offers only a very limited set of messages and generating, transmitting and parsing NMEA sentences requires a lot of computational resources and transmission bandwidth.

If you don't really need NMEA messages, please use binary logs instead to reduce data latency and reveal the full potential of the Ellipse device.

Output	Description
$##GGA	Output the computed position
$##RMC	Output the computed position, velocity and course
$##ZDA	Output the synchronized UTC date and time
$##HDT	Output true heading angle
$##GST	Output GNSS Pseudorange Error Statistics
$PRDID	RDI Proprietary Heading, Pitch, Roll

4.3.3.3. ASCII and Third Party Log messages

In this part, you will find all log messages that can be generated by the Ellipse to support third party materials such as echo sounders. In addition, the Ellipse can output some proprietary ASCII log messages for debug and ease of use.

Output	Description
TSS1	Output computed roll, pitch, heave and accelerations data

> **Note:** The Ellipse supports most common third party protocols and materials. However, If your equipment is not supported by the Ellipse, please feel free to contact SBG Systems at support@sbg-systems.com.

4.4. Serial interfaces

The Ellipse features up to 4 physical RS-232/RS-422 serial connections (Port A, B, C and D). These serial ports have different uses as described below:

- Port A is the main communication interface. It is used for both configuration and data output.
- Port B (which is shared with Sync In B) is dedicated on Ellipse N to RTCM data corrections input.
- Port C is available on Ellipse E for external GPS data input.
- Port D is available on Ellipse E as auxiliary input; reserved for future use.

The Ellipse Serial interfaces support the following baudrates:

- 9 600 bps
- 19 200 bps
- 38 400 bps
- 57 600 bps
- 115 200 bps
- 230 400 bps
- 460 800 bps
- 921 600 bps

Note: The Ellipse automatically limits the serial signals slew-rate to minimize EMI and reduce communication error when the baud rate is below 230 400 bps.

4.4.1.1. Main port A

The Port A is located on the main connector and has been designed to be the main serial connection between the device and a host system. The RS-232/RS-422 mode is hardware selected using the pin PORT A RS-232/RS-422 located on the main connector.

The Port A is the only port that accepts sbgECom binary Protocol commands. It can be used, for example, to output various real time data and to send device configurations.

The factory default configuration for the Port A is:

Parameter	Value
Baudrate	115200
Data Bits	8
Parity	None
Stop Bits	1
Flow Control	Disabled

4.4.1.2. Aiding ports B, C and D

The Port B is located on the Main connector (multiplexed with Sync In B), and Ports C and D are located on the auxiliary connector of the Ellipse E. These ports are intended to connect aiding external equipments.

4.5. CAN 2.0 A/B interface

The main port contains a CAN 2.0 A/B interface that supports transfer rate at up to 1 Mbits/s. This CAN interface is mainly used to output log messages. By default, the CAN interface is disabled.

The CAN bus implementation and especially timing settings complies with the CAN in Automation (CiA) DS-102 standard.

The Ellipse supports the following standard CAN bus bitrates:

- 1 000 kBit/s
- 500 kBit/s
- 250 kBit/s
- 125 kBit/s
- 100 kBit/s
- 50 kBit/s
- 20 kBit/s
- 10 kBit/s

Note: The Ellipse does not include any termination resistor, and it belongs to user to ensure that the CAN bus includes termination resistors in order to get proper communications.

4.5.1. Configuration

For each log message the user can define the CAN message identifier, the output mode (continuous, new data, event) and the output frequency. CAN log messages offer the same configurations options as log messages outputted on standard serial interfaces.

4.5.2. CAN messages logs

For each available log, you can use the following color code to know if a log will be interpolated when outputted on a “Sync In” signal and if it's recommended to output a log on a “New Data” event.

Color Code	Description
●	It's strongly recommended to output this log on a “New Data” trigger

Output	Description
SBG_ECAN_LOG_IMU_INFO	Time stamp and IMU status
SBG_ECAN_LOG_IMU_GYRO	3d rate or turn
SBG_ECAN_LOG_DELTA_ANGLES	Delta angle (coning output)
SBG_ECAN_LOG_IMU_ACCEL	3D Acceleration
SBG_ECAN_LOG_IMU_DELTA_VEL	Delta velocity (Sculling output)
SBG_ECAN_LOG_IMU_TEMP	IMU internal temperature
SBG_ECAN_LOG_EKF_INFO	Extended Kalman filter time and status

Output		Description
SBG_ECAN_LOG_EKF_QUAT		Quaternion output
SBG_ECAN_LOG_EKF_EULER		Euler Angles output
SBG_ECAN_LOG_EKF_ORIENTATION_ACC		Orientation standard deviation
SBG_ECAN_LOG_EKF_POS_1		Latitude and Longitude data
SBG_ECAN_LOG_EKF_POS_2		Altitude and Horizontal + vertical standard deviations
SBG_ECAN_LOG_EKF_VEL_1		North and East Velocities
SBG_ECAN_LOG_EKF_VEL_2		Down velocity and velocity standard deviation
SBG_ECAN_LOG_SHIP_MOTION_INFO		General information about ship motion status
SBG_ECAN_LOG_SHIP_MOTION_0_0		Real time surge, sway & heave at defined monitoring point
SBG_ECAN_LOG_SHIP_MOTION_0_1		Real time ship accelerations at defined monitoring point
SBG_ECAN_LOG_SHIP_MOTION_0_2		Real time ship velocity at defined monitoring point
SBG_ECAN_LOG_MAG_1	•	Magnetometer status and time stamp
SBG_ECAN_LOG_MAG_2	•	3D Magnetometer data
SBG_ECAN_LOG_GPS_1_VEL_1	•	Time of velocity and velocity status
SBG_ECAN_LOG_GPS_1_VEL_2	•	Velocity North and Velocity East
SBG_ECAN_LOG_GPS_1_VEL_3	•	Velocity Down
SBG_ECAN_LOG_GPS_1_VEL_4	•	Velocity accuracy North, East Down
SBG_ECAN_LOG_GPS_1_POS_1	•	GPS position status and internal time stamp
SBG_ECAN_LOG_GPS_1_POS_2	•	Altitude and GPS time of week
SBG_ECAN_LOG_GPS_1_POS_3	•	GPS Latitude, Longitude
SBG_ECAN_LOG_GPS_1_POS_4	•	GPS position accuracy
SBG_ECAN_LOG_GPS_1_TRUE_HEAD_1	•	Time stamp and GPS true Heading status
SBG_ECAN_LOG_GPS_1_TRUE_HEAD_2	•	GPS True heading and true heading accuracy
SBG_ECAN_LOG_UTC_TIME_1	•	Time since reset, UTC time status, Year and Month
SBG_ECAN_LOG_UTC_TIME_2	•	Day, Hour, Minutes, Seconds, Nanoseconds
SBG_ECAN_LOG_ODOMETER_VELOCITY_0	•	Time stamp, Odometer status
SBG_ECAN_LOG_ODOMETER_VELOCITY_1	•	Odometer velocity
SBG_ECAN_LOG_EVENT_INFO_A/B/C/D	•	Output the list of received event markers on Sync A/B/C/D/E pin
SBG_ECAN_LOG_EVENT_TIME_A/B/C/D	•	Output the list of received event markers on Sync A/B/C/D/E pin

5. Installation

5.1. Ellipse installation

5.1.1. General rules

In nominal use, the Ellipse INS does not require to be placed at a special location for proper operation. However, for best reliability in harsh environments where the Ellipse cannot rely on GNSS for extended periods, best performance will be obtained in the vehicle center of rotations.

5.1.2. Airborne applications

The Ellipse INS should be placed in the aircraft coordinate frame, which is defined as follows: Ellipse *X* axis should be turned in aircraft Front direction, *Y* axis should be turned in aircraft Right direction, and *Z* axis should be turned to the aircraft bottom direction.

When this mechanical alignment is not possible, the Ellipse misalignment with respect to the vehicle coordinate frame must be measured, as described in section 2.3–Accounting for Misalignment.

Hence it is not required, the Ellipse should be placed at the center of rotations for best performance.

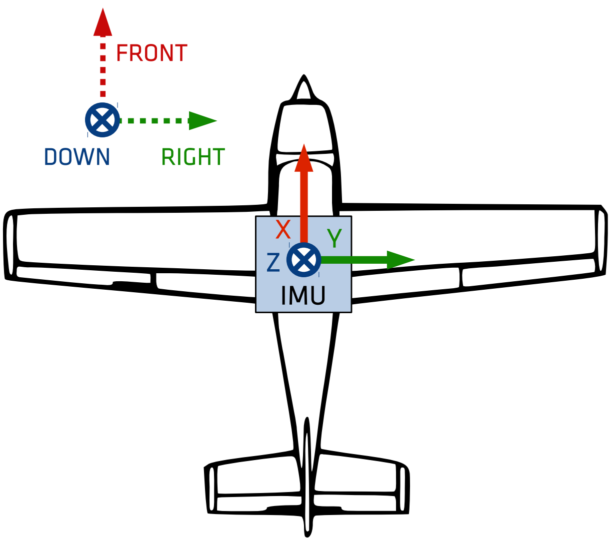


Figure 5.1: Ellipse placement in airborne applications

Note: Please consider the installation restrictions that may apply: Highly vibrating applications should consider vibration isolation as explained in section 5.1.5.1-Vibration considerations.

In addition, magnetometer use will also generate some placement restrictions, explained in section 5.1.5.2-Magnetic field influence.

5.1.2.1. Main lever arm

In some applications, mechanical constraints make it difficult to place the Ellipse exactly where we want to get navigation data. For most applications, this monitoring point would be the actual vehicle center of rotations.

The "main lever arm" has to be measured from the Ellipse to the desired monitoring point.

Note: The primary lever arm will affect navigation data. IMU data will be provided at the actual IMU location.

5.1.3. Marine applications

The Ellipse INS should be placed in the vessel coordinate frame, which is defined as follows: Ellipse *X* axis should be turned in vessel Front direction, *Y* axis should be turned in vessel Right direction, and *Z* axis should be turned to the vessel bottom direction.

When this mechanical alignment is not possible, the Ellipse misalignment with respect to the vehicle coordinate frame must be measured, as described in section 2.3–Accounting for Misalignment.

Hence it is not required, the Ellipse should be placed at the center of rotations for best performance.

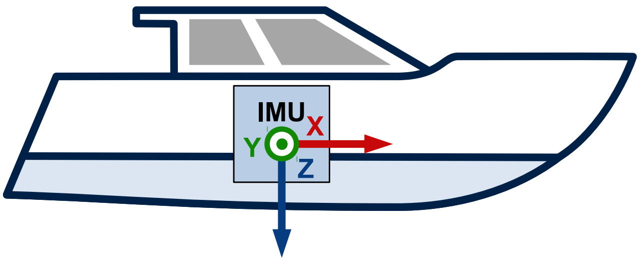


Figure 5.2: Ellipse Placement in a marine application

Note: Please consider the installation restrictions that may apply: Highly vibrating applications should consider vibration isolation as explained in section 5.1.5.1-Vibration considerations.

In addition, magnetometer use will also generate some placement restrictions, explained in section 5.1.5.2-Magnetic field influence.

5.1.3.1. Main lever arm

In some applications, mechanical constraints make it difficult to place the Ellipse exactly where we want to get navigation data. For most applications, this monitoring point would be the actual vehicle center of rotations but it can be another point of interest.

The “main lever arm” has to be measured from the Ellipse to the desired monitoring point.

Note: The primary lever arm will affect navigation and heave data. IMU data will be provided at the actual IMU location.

5.1.4. Land applications

The Ellipse INS should be placed in the vehicle coordinate frame, which is defined as follows: Ellipse *X* axis should be turned in vehicle Front direction, *Y* axis should be turned in vehicle Right direction, and *Z* axis should be turned to the vehicle bottom direction.

When this mechanical alignment is not possible, the Ellipse misalignment with respect to the vehicle coordinate frame must be measured, as described in section 2.3–Accounting for Misalignment.

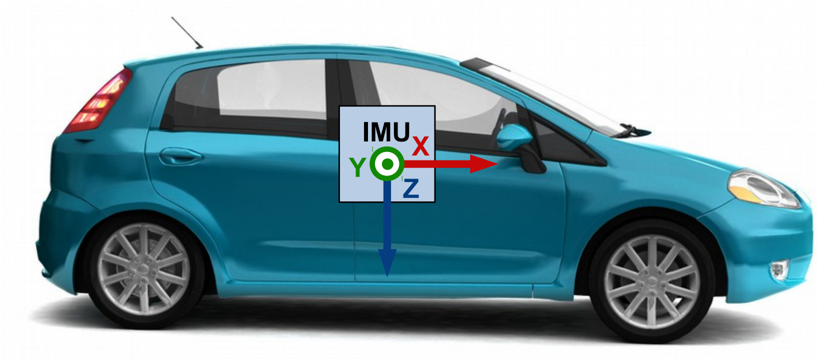


Figure 5.3: Ellipse axes in land vehicle application

Note: Please consider the installation restrictions that may apply: Highly vibrating applications should consider vibration isolation as explained in section 5.1.5.1-Vibration considerations.

5.1.4.1. Main lever arm (Non steering Axle)

When a non steering axle is present in the vehicle, the distance from the Ellipse to the Non-steering axle center should be measured as the Main lever arm.

This axle center corresponds to the vehicle's center of rotation and must be correctly measured in the vehicle coordinate frame, from the Ellipse to the Axle center, within at least 5 cm accuracy.

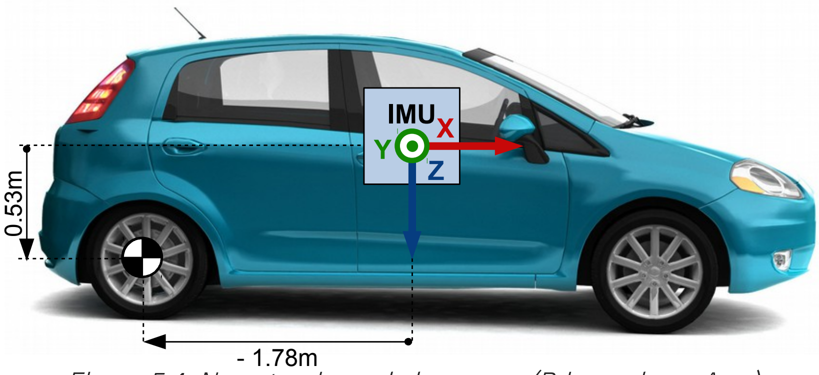


Figure 5.4: Non steering axle lever arm (Primary lever Arm)

5.1.5. Restrictions

5.1.5.1. Vibration considerations

SBG Systems has designed the Ellipse with a high quality MEMS sensors combined with high sampling frequency as well as efficient anti aliasing FIR filters to limit vibration issues as much as possible. Nevertheless, a good mechanical isolation will ensure getting the full sensor performance:

High amplitude vibrations can cause a bias in accelerometer reading. Thanks to a superior factory calibration, this effect is limited. Nevertheless it cannot be fully avoided. This effect is called the VRE (Vibration Rectification Error) and comes from the internal accelerometer non-linearity.

Ultimately, very high amplitude vibrations cause the sensor to saturate. The bias observed will be drastically increased, leading to a huge error on orientation.

> **Note:** If proper mechanical isolation cannot fully prevent high amplitude vibrations, consider using a 16*g* accelerometers unit, which has a lower VRE than the standard 8*g* accelerometers.

5.1.5.2. Magnetic field influence

When the internal magnetometer is used as heading reference, care should be taken with ferromagnetic environment.

Ferromagnetic materials or magnets that are placed in the vicinity of the device can generate error in the magnetometers readings by distorting the magnetic field. High current power supplies or the associated wires may also generate magnetic fields.

The Ellipse INS should be placed as far as possible from ferromagnetic materials, particularly those who can be moved independently with respect to the Ellipse INS. In practice placing the device more than 2 meter away from disturbing materials is enough to avoid generating error.

In most cases, a calibration procedure can be performed to map the magnetic distortions and therefore get the full performance of the unit. The Ellipse INS can compensate both Hard and Soft iron interferences.

Note 1: See Ellipse Hard & Soft Iron Calibration Manual for more information about the magnetometers calibration procedure.

Note 2: Some disturbances of the magnetic field cannot be predicted: a magnet passing suddenly near the device or a cell phone communication for example.

The internal Kalman filter is able to cope with short term magnetic disturbances. Ultimately if magnetic field direction changed for a long period, the Ellipse INS will realign itself to the new magnetic field direction.

Note 3: When the internal magnetometers are not in use, the magnetic influence on performance is weak but very strong magnetic fields can affect gyroscopes performance and such high amplitude magnetic fields should be avoided.

5.2. Aiding sensors installation

5.2.1. GNSS antenna placement

5.2.1.1. Single GNSS antenna

The GNSS antenna placement requirements are not always compatible with the Ellipse placement. Therefore, user can set a 3D offset defining where is placed the GPS antenna. Offset is expressed in meters, in the vehicle coordinate frame. Accurate lever arm measurement ensures optimal output accuracy.

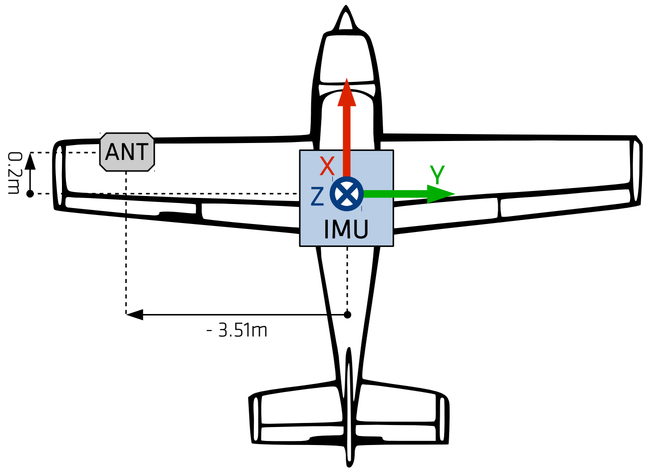


Figure 5.5: GNSS antenna lever arm measurement

5.2.1.2. Dual GNSS antenna

For optimal performance, dual antenna systems require some extra considerations during installation. When dealing with a third party GNSS receiver, these recommendations should apply, but please refer to manufacturer recommendations for other specific requirements.

- The primary antenna is the one used for position computation. Therefore, the GPS Lever arm should be measured from this antenna to the Ellipse. The GPS lever arm is the signed distance, expressed in the vehicle coordinate frame, from the GPS antenna to the Ellipse.
- The secondary antenna (also called sometimes the rover) should be placed in front of the primary antenna. This antenna is only used for True Heading measurements. If a specific alignment is made between the two antennas, a misalignment angle between antennas and vehicle coordinate frame must be measured.
- The (unsigned) distance between the two antennas should be measured.
- The same type of antenna must be used for primary and secondary antennas. In addition, these antennas must be placed in the same orientation, as shown in the figure below. Finally, the cables used for both antennas must have the same type and same length.
- Both antennas must be placed on a ground plane, and ideally, more than 20cm away from the ground plane edges.

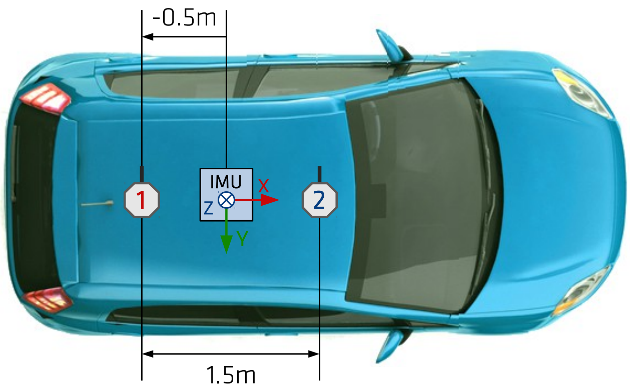


Figure 5.6: Dual GNSS antennas installation in the vehicle

5.2.2. External GNSS receiver electrical installation (Ellipse E)

When using an external GNSS receiver with the Ellipse E, the following electrical connections must be performed:

- RS-232 or RS-422 GPS data output has to be connected on a dedicated Ellipse port.
- GPS PPS signal must be connected to a Sync In X pin on the Ellipse.

5.2.3. Odometer installation

5.2.3.1. Mechanical installation

As for the GPS or external navigation sensor, the odometer requires a lever arm (signed distance between the Ellipse and the odometer) to be set for optimal use.

You can find below an example of how to setup the odometer lever Arm.

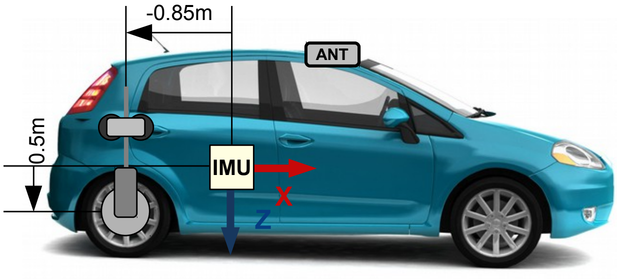


Figure 5.7: Odometer lever arm measurement

5.2.3.2. Electrical installation

The Ellipse supports pulse output odometers, and for direction finding, quadrature and direction output odometers. The following pictures show the connections for each type of odometer:

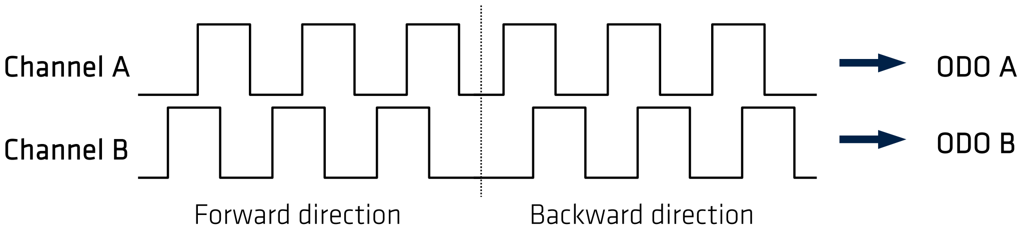


Figure 5.8: Quadrature output connection example

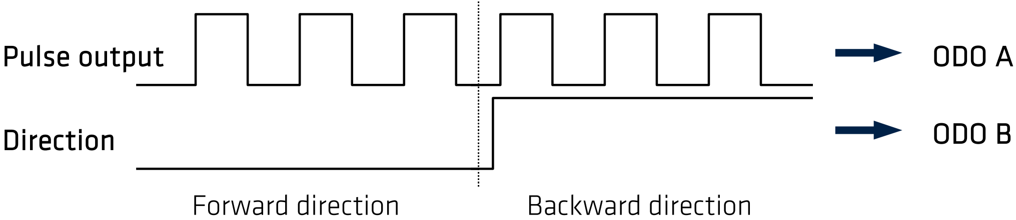


Figure 5.9: Direction output connection example

Note: In case of single channel odometer, only the ODO A input can be used as Odometer input. This would let the Sync In A pin available for another synchronization input.

6. Operation

This section describes the basic operation scenario and provides some performance checking information. We consider previous User Manual sections were followed: The Ellipse AHRS/INS is correctly installed and configured.

6.1. Initialization

When powered ON, the Ellipse will first initialize to an approximated attitude (roll / pitch angles), based on accelerometers used as a vertical reference. Initial heading and velocity are set to 0, and initial position is defined as set in configuration. During this time, the Kalman filter runs in a “vertical gyro” mode.

Once reasonable roll/pitch angles are estimated, heading alignment procedures are tried until a first heading guess is found. As soon as an alignment procedure has been successful, the Kalman filter will start full AHRS computations.

As navigation aiding data becomes available (Odometer, GNSS, ...) the Ellipse will make use of it to initialize velocity, position, and to improve orientation accuracy.

All outputs are provided but may not be valid until all parameters are initialized.

Once all estimated parameters (attitude, heading, velocity, position) are initialized, the navigation phase start, but with sub-optimal accuracy. The system is estimating sensors error parameters continuously to improve performance. It may take 15 minutes to improve performance.

It is possible to use the navigation and orientation data before those 15 minutes are elapsed.

6.2. Orientation tracking / Navigation

After the first 15 minutes of operation, outputs provided are considered as nominal performance. The Ellipse can be used as required.

Data provided by the Ellipse is sent in real time through the different interfaces (serial, CAN).

6.3. Performance monitoring

During initialization and navigation phases, it may be necessary to check that provided data are consistent. The Ellipse provides deep status information that allows a good interpretation.

6.3.1. Checking External devices data reception

In order to check proper operation with external sensors, the first thing to check is whether consistent data are retrieved from those external devices or not.

For each aiding data, a status flag indicates if data were received in the last seconds or not. Data may be valid or invalid, but the main thing here is that we want to know if the device is well connected to the Ellipse.

6.3.2. Checking aiding data use in Kalman filter

Once External devices connection has been checked, it's then possible to check if the Kalman filter is able to use incoming data. Each aiding data has a dedicated status flag indicating:

“OK” when the corresponding aiding data could be used by the Kalman filter in the last seconds

“NO” when the Kalman filter was not able to use the aiding data. Possible reasons can be:

- Invalid data is provided (e.g. no GNSS fix is available)
- Kalman filter rejected the data (data is currently not consistent with current estimated state)

6.3.3. Checking sensor status

Internal sensor provides useful status information, and it is important to keep an eye on this information in order to check output accuracy.

Gyroscopes include a built in test that continuously checks if each gyro channel is performing in a correct way. A gyro over-range error status informs about the orientation integrity: In case of over-range, orientation accuracy is degraded in an unlimited way until normal gyro operation is recovered.

Accelerometers include an over-range status that informs about navigation integrity. In case of high acceleration or strong vibrations, this status may be in error, informing about what's wrong.

Magnetometers include a start-up self test that makes it possible to check the sensor behavior at each power up. A magnetic field range checking is also provided for measurement integrity check.

6.3.4. Checking orientation and navigation accuracy

Once aiding data were checked to be good, it is still possible to have another accuracy indication. In each EKF Log message, an accuracy parameter provides the 1σ estimated accuracy for the corresponding output.

6.4. Ending operation

Once a log session is finished, simply disconnect the power supply to turn off the sensor.

7. Important notices

7.1. Absolute maximum ratings

Stresses above those listed under the Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Rating
VDD – GND	+/- 36 V
Rx+, Rx-, Logic inputs pins input voltage to signal GND	±25V
Logic output Max current	150 mA
CANH, CANL	±80 V
ESD protection (Tx, Rx, Input & Output pins, CANH, CANL)	15 kV
Shock	2000 g for 0.3ms
Operating temperature range	-40 to 85°C (-40 to 185°F)
Storage temperature range	-40 to 85°C (-40 to 185°F)

Table 2: Absolute maximum ratings

7.2. Maintenance

The Ellipse will not require any specific maintenance when properly used. In the case you observe sub-optimal performance, please contact SBG Systems support.

Nevertheless, if you would like to maintain your sensor performance to the highest level, SBG Systems can provide a maintenance service with regularly planned checkups and calibrations.

7.2.1. Cleaning

Disconnect the Ellipse from the power supply as well as other connections. Use damp cloth to clean the enclosure. Do not use any solvent or abrasive materials for cleaning.

7.3. Support

Our goal is to provide the best experience to our customers. If you have any question, comment or problem with the use of your Ellipse, we would be glad to help you, so please feel free to contact us. Please do not forget to mention your Ellipse Device ID, (written on your Ellipse' label) as well as your firmware version.

You can contact us by:

- Email: support@sbg-systems.com
- Phone: +33 1 80 88 45 00

7.4. Warranty, liability and return procedure

SBG Systems provides a warranty covering this product against any defect in materials or manufacture for a period of one (1) year from the date of shipment. In the event that such a defect becomes obvious during the stipulated warranty period, SBG Systems will undertake, at its sole discretion, either to repair the defective product, bearing the cost of all parts and labor, or to replace it with an identical product.

In order to avail itself of this warranty, Customer must notify SBG Systems of the defect before expiry of the warranty period and take all steps necessary to enable SBG Systems to proceed. Upon reception of required information (Sensor serial number, defect description), SBG Systems will issue an RMA and will provide return instructions. Customer shall be responsible for the packaging and the shipment of the defective product to the repair center notified by SBG Systems, the cost of such shipment being borne by Customer.

This warranty shall not be construed as covering defects, malfunctions or damages caused by improper use or inadequate maintenance of the product. Under no circumstances shall SBG Systems be due to provide repair or replacement under this warranty in order a) to repair damage caused by work done by any person not representing SBG Systems for the installation, repair or maintenance of the product; b) to repair damage caused by improper use or connection to incompatible equipment, and specifically, the opening of the housing of the equipment under warranty shall cause the warranty to be automatically canceled.

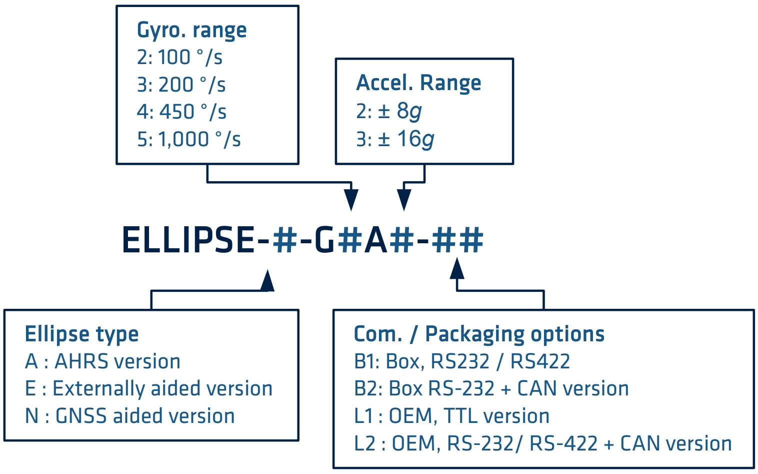
This warranty covers the product hereunder and is provided by SBG Systems in place of all and any other warranty whether expressed or implied. SBG Systems does not guarantee the suitability of the product under warranty for sale or any specific use.

SBG Systems' liability is limited to the repair or replacement of defective products, this being the sole remedy open to Customer in the event the warranty becomes applicable. SBG Systems cannot be held liable for indirect, special, subsequent or consequential damage, irrespective of whether SBG Systems has or has not received prior notification of the risk of occurrence of such damage.

8. Appendix A: Ordering codes and Accessories

8.1. Ellipse ordering codes

The following diagram showing the different sensors and interfaces options available, might help you ordering an Ellipse module.



8.2. Development kits

8.2.1. DK-ELI-[B, L]

The Development Kit is an essential accessories that should be used along with the Ellipse series. The Development kit provides the following items:

- Small sized transport case
- USB cable to quickly connect the Ellipse sensor
- A USB Stick that contains the SDK:
  - sbgCenter analysis software suite
  - Magnetic calibration tools and C library
  - sbgECom C library and C code examples
- Unlimited software upgrades
- Unlimited phone and email support.

Figure 8.1 : DK-ELLIPSE-B

The following development kits are available:

Ordering code	Description
DK-ELI-B	Development kit for Ellipse A, E and N in Box versions (B1 or B2)
DK-ELI-L	Development Kit for Ellipse series, OEM, versions (L1 or L2)

8.3. Cables

8.3.1. CA-ELI-USB-3M

This 3meters long cable provides an easy connection of an Ellipse device to any PC.

It includes in the USB plug a RS-232 to USB converted, and provides power to the Ellipse sensor.

Figure 8.2 : CA-ELI-USB

8.3.2. CA-ELI-RS232-CAN-3M

This cable provides access to the Ellipse Main and Aux connectors. It's designed to communicate in RS-232 with the Ellipse B1 versions, but can also be used with the Ellipse B2 versions and Aux connectors. It has the following characteristics:

- 1x UP01L07 M010S BK1 Z2ZA connector
- 1x open end
- 3 meters long
- Water proof

Figure 8.3 : CA-ELI-RS232-CAN-3M

Cable wiring is the following:

Pin on Fischer connector	Color	Main connector signal (B1 version)	Main connector signal (B2 version)	Aux connector signal
1	GREEN	SYNC IN A – ODO B	SYNC IN A – ODO B	SYNC IN C
2	BLUE	SYNC IN B – PORT B RX ODO A	SYNC IN B – PORT B RX ODO A	SYNC IN D
3	RED	VIN	VIN	PORT D RX
4	BLACK	GND	GND	GND
5	N/A	NC	NC	NC
6	BROWN	SYNC OUT A	SYNC OUT A	SYNC OUT B
7	WHITE	N/A	CAN L	PORT C RS422 TX+
8	YELLOW	PORT A RS232 TX	PORT A RS232 TX	PORT C RS232 TX PORT C RS422 TX-
9	ORANGE	PORT A RS232 RX	PORT A RS232 RX	PORT C RS232 RX PORT C RS422 RX+
10	GREY	N/A	CAN H	PORT C RS422 RX-

8.3.3. CA-ELI-RS422-3M

This cable provides access to the Ellipse Main and Aux connectors. It's designed to communicate in RS-422 with the Ellipse B1 versions, but can also be used with the Ellipse B2 versions and Aux connectors. It has the following characteristics:

- 1x UP01L07 M010S BK1 Z2ZA connector
- 1x open end
- 3 meters long
- Water proof

Figure 8.4 : CA-ELI-RS422-3M

Cable wiring is the following:

Pin on Fischer connector	Color	Main connector signal (B1 version)	Main connector signal (B2 version)	Aux connector signal
1	GREEN	SYNC IN A – ODO B	SYNC IN A – ODO B	SYNC IN C
2	BLUE	SYNC IN B – PORT B RX ODO A	SYNC IN B – PORT B RX ODO A	SYNC IN D
3	RED	VIN	VIN	PORT D RX
4	BLACK	GND	GND	GND
5	N/A	Internally connected to GND for RS-422 comm.	Internally connected to GND	Internally connected to GND
6	BROWN	SYNC OUT A	SYNC OUT A	SYNC OUT B
7	WHITE	PORT A RS422 TX+	CAN L	PORT C RS422 TX+
8	YELLOW	PORT A RS422 TX-	PORT A RS232 TX	PORT C RS232 TX PORT C RS422 TX-
9	ORANGE	PORT A RS422 RX+	PORT A RS232 RX	PORT C RS232 RX PORT C RS422 RX+
10	GREY	PORT A RS422 RX-	CAN H	PORT C RS422 RX-

8.4. GNSS antennas

8.4.1. ANT-TAL-TW-32-2410-00-3000 and ANT-TAL-TW-32-2710-00-3000

These high performance antennas have been especially chosen for their excellent performance/size compromise.

The TW2410 provides GPS L1 + GLONASS tracking, while the TW2710 provides additionally BEIDOU B1 and GALLILEO E1 signals tracking.

Those two antennas share the same specifications as defined below:

Figure 8.5 : Tallysman TW2410 & TW2710 antennas

8.4.1.1. Performance specifications

Parameter	Specification
Architecture	Dual, Quadrature Feeds One LNA per feed line, mid section High rejection SAW filter
LNA Gain	> 28 dB
Noise figure	< 1dB
VSWR (at LNA output)	< 1.5:1
Power consumption	15 mA
Antenna gain (100mm ground plane)	4,25 dBic
Dimensions	Diameter: 57mm Height: 15mm
Cable length, Connector	3m, SMA
Environmental	-40 to +85°C IP-67 housing

8.4.1.2. Mechanical drawing

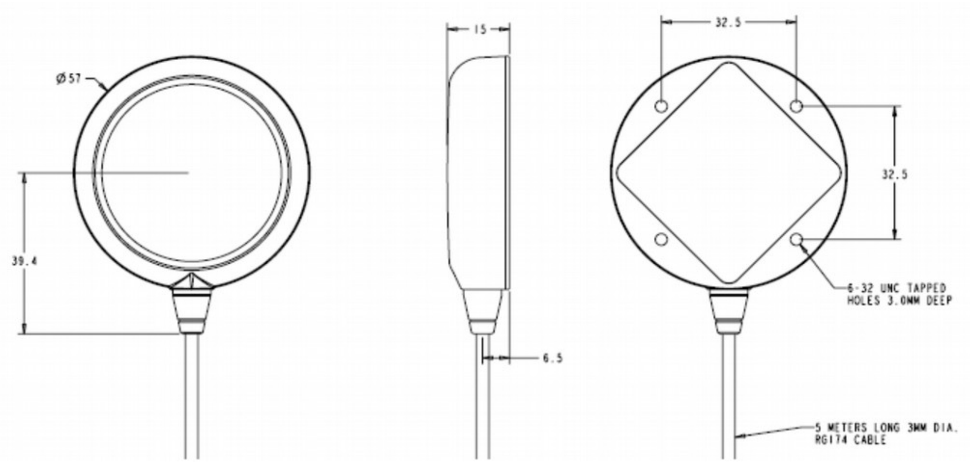


Figure 8.6: Tallysman TW2410 / TW2710 mechanical drawing