Spatial OEM Reference Manual

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1 Revision History

Version	Date	Changes
2.7	27/03/2013	Added additional magnetic information, section 7.6 Added 1PPS input, section 8.3.29 Updated detailed satellites packet, section 9.8.12 Corrected geoid height packet, section 9.8.35
2.6	29/01/2013	Added heave information, section 7.13 Added RTCM corrections packet, section 9.8.36 Added external pitot pressure packet, section 9.8.37 Added wind estimation packet, section 9.8.38 Added heave packet, section 9.8.39 Updated GPIO3 functions, section 9.9.8.3 Updated GPIO4 functions, section 9.9.8.4 Added heave configuration packet, section 9.9.14
2.5	07/12/2012	Added underwater navigation information, section 7.12 Added Linkquest DVL input, section 8.3.25 Added pressure depth transducer input, section 8.3.26 Added left wheel speed sensor input, section 8.3.27 Added right wheel speed sensor input, section 8.3.28 Added external time packet, section 9.8.33 Added external depth packet, section 9.8.34 Added geoid height packet, section 9.8.35 Updated GPIO functions tables, section 9.9.8
2.4	06/12/2012	Yaw terminology changed to heading for increased clarity Reworded installation magnetics for increased clarity, section 6.4 Reworded initialisation for increased clarity, section 7.2 Reworded operation magnetics for increased clarity, section 7.6 Added vehicle profiles information, section 7.9 Updated NMEA output, section 8.3.7 Added Tritech USBL input, section 8.3.24
2.3	19/11/2012	Installation magnetics changed, section 6.4 Heading source added, section 7.5 Disabling magnetometers changed, section 7.6.3 GPIOs information updated, section 8.3 Added NMEA input GPGLL support, section 8.3.6 Added NMEA input GPHDT support, section 8.3.6 Added NMEA input HEHDT support, section 8.3.6 Updated NMEA output, section 8.3.7 Added RTCM corrections input, section 8.3.19 Added Trimble GNSS input, section 8.3.20 Added u-blox GNSS input, section 8.3.21 Added Hemisphere GNSS input, section 8.3.22 Added Teledyne DVL input, section 8.3.23 Updated GPIO functions table, section 9.9.8
2.2	30/10/2012	Sensor specifications updated, section 4.3 Blurry recommended footprint fixed, section 5.4

Version	Date	Changes
2.1	28/10/2012	Regrouped integration information into section 5 Updated mechanical mounting, section 5.1 Added basic electrical connection, section 5.3.3 Updated recommended footprint information, section 5.4 Added pin protection, section 5.7 Fixed error in odometer state packet, section 9.8.32
2.0	18/10/2012	Added information on sensor calibration, section 4.9 Added odometer installation information, section 6.3 Updated filter description to clarify instability, section 7.1 Added hot start information, section 7.3 Added time information, section 7.4 Added odometer pulse length information, section 7.10 Added RAIM information, section 7.11 Updated Odometer input, section 8.3.3 Updated NMEA output, section 8.3.7 Added disable magnetometers GPIO function, section 8.3.13 Added disable GNSS GPIO function, section 8.3.14 Added disable pressure GPIO function, section 8.3.15 Added set zero alignment GPIO function, section 8.3.16 Added system state packet trigger GPIO function, section 8.3.17 Added raw sensors packet trigger GPIO function, section 8.3.18 Updated acknowledge packet, section 9.7.1 Added running time packet, section 9.8.30 Added local magnetic field packet, section 9.8.31 Added odometer state packet, section 9.8.32 Updated installation alignment packet, section 9.9.5 Fixed error in filter options packet, section 9.9.6 Updated GPIO configuration packet, section 9.9.8 Added odometer configuration packet, section 9.9.12 Added set zero orientation alignment packet, section 9.9.13
1.0	16/09/2012	1PPS description updated, section 8.3.1 Corrected reset packet, section 9.7.6 Corrected external body velocity packet, section 9.8.28 Revised alignment packet, section 9.9.5 Grammar and spelling corrections
0.6	31/08/2012	Grammar corrections throughout Spelling corrections throughout Updated 3D magnetic calibration, section 7.6.2 Updated cover page photo
0.5	28/08/2012	Corrected satellite indexes, section 9.8.12.1 Added navigation specifications, section 4.2 Added sensor specifications, section 4.3 Added GNSS specifications, section 4.4 Added communication specifications, section 4.5 Added hardware specifications, section 4.6
0.3	23/08/2012	Clarified anti aliasing, section 7.8

Version	Date	Changes
		Added external data, section 8.2 Added GPIO information, section 8.3 Added GPIO configuration packet, section 9.9.8
0.2	11/08/2012	Magnetic calibration values packet corrected Incorrect length fixed on several packets Grammar corrections
0.1	31/07/2012	First Draft. Please email support@advancednavigation.com.au if you notice any mistakes or anything is not explained clearly.

2 Foundation Knowledge

This chapter is a learning reference that briefly covers knowledge essential to understanding Spatial and the following chapters. It explains the concepts in simple terms so that people unfamiliar with the technology may understand it.

2.1 GNSS

GNSS stands for global navigation satellite system. A GNSS consists of a number of satellites in space that broadcast navigation signals. These navigation signals can be picked up by a GNSS receiver on the earth to determine that receiver's position and velocity. For a long time the only operational GNSS was the United States GPS. However the Russian GLONASS is now fully operational with similar performance to GPS. The Chinese COMPASS is in the process of becoming operational and the European Union's GALILEO should be operational within ten years.

GNSS is excellent for navigational purposes and provides fairly accurate position (2.5 metres) and velocity (0.03 metres/second). The main drawback of GNSS is that the receiver must have a clear signal from at least 4 satellites to function. GNSS satellite signals are very weak and struggle to penetrate through buildings and other objects obstructing view of the sky. GNSS can also occasionally drop out due to disturbances in the upper atmosphere.

2.2 INS

INS stands for inertial navigation system. An inertial navigation system can provide position and velocity similar to GNSS but with some big differences. The principle of inertial navigation is the measurement of acceleration. This acceleration is then integrated into velocity. The velocity is then integrated into position. Due to noise in the measurement and the compounding of that noise through the integration, inertial navigation has an error that increases exponentially over time. Inertial navigation systems have a very low relative error over short time periods but over long time periods the error can increase dramatically.

2.3 GNSS/INS

By combining GNSS and INS together in a mathematical algorithm, it is possible to take advantage of the benefits of GNSS long-term accuracy and INS short-term accuracy. This provides an overall enhanced position and velocity solution that can withstand short GNSS drop outs.

2.4 AHRS

AHRS stands for attitude and heading reference system. An AHRS uses accelerometers, gyroscopes and magnetometers combined in a mathematical algorithm to provide orientation. Orientation consists of the three body angles roll, pitch and heading.

2.5 The Sensor Co-ordinate Frame

Inertial sensors have 3 different axes: X, Y and Z and these determine the directions around which angles and accelerations are measured. It is very important to align the axes correctly in installation otherwise the system won't work correctly. These axes are marked on the top of the device as shown in Illustration 1 below with the X axis pointing in the direction of the connectors, the Z axis pointing down through the base of the unit and the Y axis pointing off to the right.

Illustration 1: Bird's eye view of Spatial showing axes marked on top

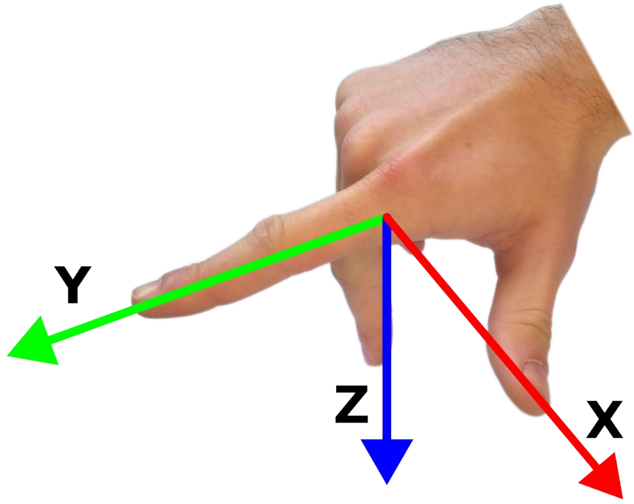

Illustration 2: First right hand rule

When installed in an application the X axis should be aligned such that it points forwards and the Z axis aligned so that it points down when level. A good way to remember the sensor axes is the right hand rule, which is visualised in Illustration 2. You take your right hand and extend your thumb, index and middle. Your thumb then denotes the X axis, your index denotes the Y axis and your middle denotes the Z axis.

2.6 Roll, Pitch and Heading

Orientation can be described by the three angles roll, pitch and heading, these are known as the euler angles. They are best described visually through the Illustrations below.

2.6.1 Roll

Roll is the angle around the X axis. See Illustration 3 for the positive direction of roll and Illustration 4 for an example of a roll of 90 degrees.

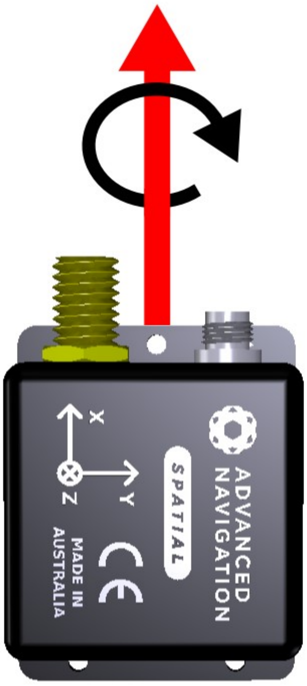

Illustration 3: Spatial with black arrow indicating positive direction of roll

Illustration 4: Spatial after a roll of 90 degrees

2.6.2 Pitch

Pitch is the angle around the Y axis. See Illustration 5 for the positive direction of pitch and Illustration 6 for an example of a pitch of 90 degrees.

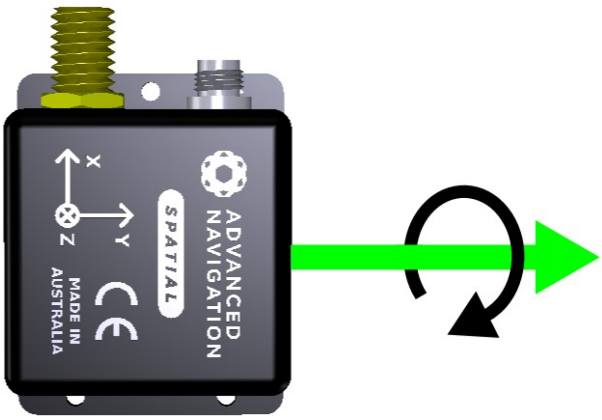

Illustration 5: Spatial with with black arrow indicating positive direction of pitch

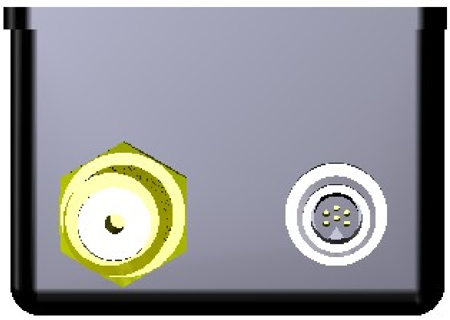

Illustration 6: Spatial after a pitch of 90 degrees

2.6.3 Heading

Heading is the angle around the Z axis. See Illustration 7 for the positive direction of heading and Illustration 8 for an example of a heading change of 90 degrees. 0 degrees heading is when the positive X axis points North and 180 degrees heading is when the positive X axis points South.

Illustration 7: Spatial with black arrow indicating positive direction of heading

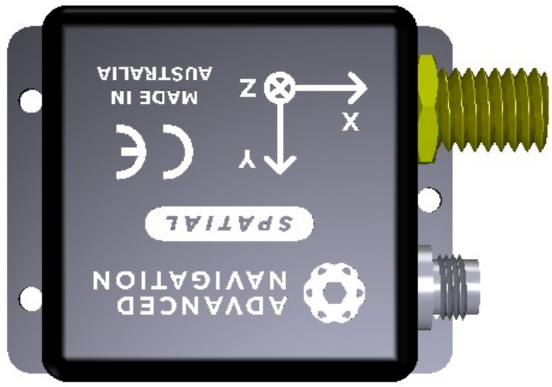

Illustration 8: Spatial after a heading change of 90 degrees

2.6.4 Second Right Hand Rule

The two right hand rules are often the best way to memorise the sensor axes and directions of positive rotation. The first right hand rule gives the positive axis directions and is described in section 2.5. The second right hand rule shown in Illustration 9 provides the direction of positive rotation. To use it, point your thumb in the positive direction of that axis, then the direction that your fingers curl over is the positive rotation on that axis.

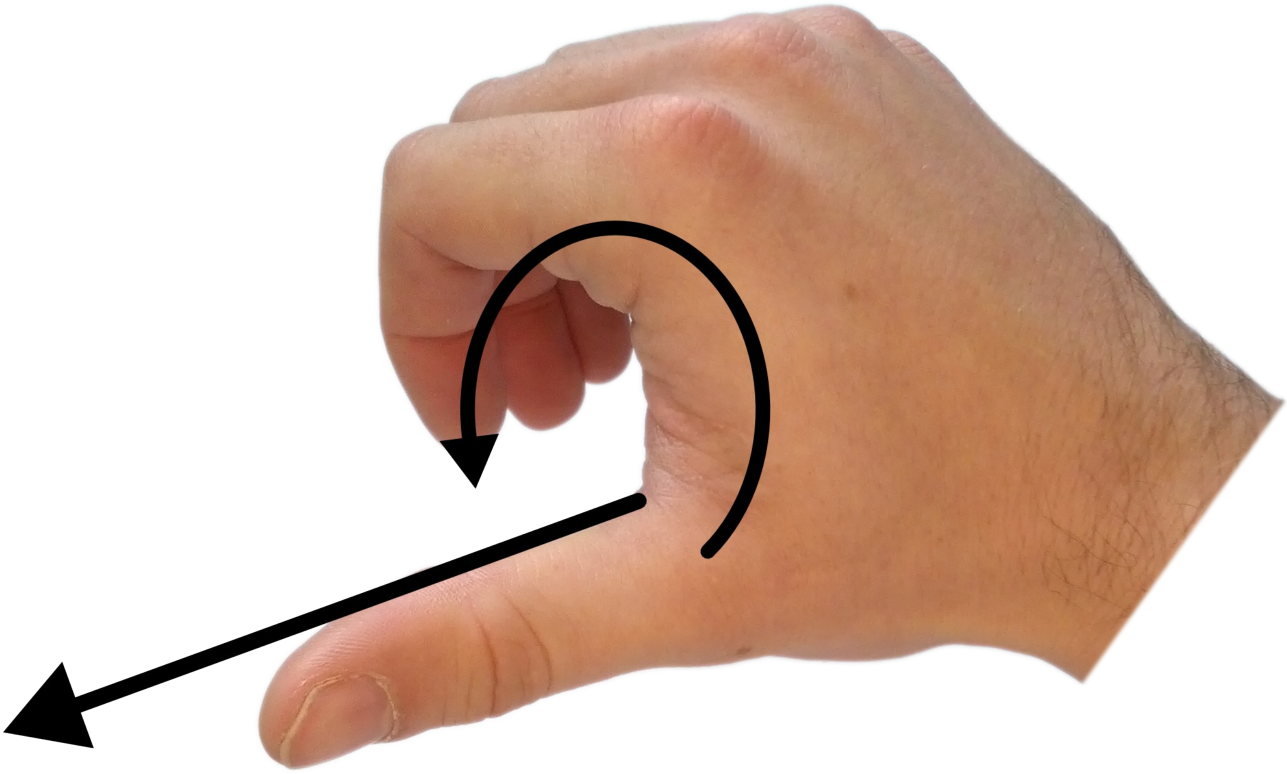

Illustration 9: Second right hand rule

2.6.5 Rotation Order

When multiple axes are rotated, to imagine the final orientation the three rotations must be performed in the order heading first, then pitch and then roll. To deduce the final orientation the unit should first be considered level with the X axis pointing north and the Z axis pointing down. Heading is applied first, then pitch is applied and finally roll is applied to give the final orientation. This can be hard for some people to grasp at first and is often best learned experimentally by rotating spatial with your hand whilst watching the orientation plot in real time on the computer.

2.7 Geodetic Co-ordinate System

The geodetic co-ordinate system is the most popular way of describing an absolute position on the Earth. It is made up of the angles latitude and longitude combined with a height relative to the ellipsoid. Latitude is the angle that specifies the north to south position of a point on the Earth's surface. Longitude is the angle that specifies the east to west position of a point on the Earth's surface. The line of zero latitude is the equator and the line of zero longitude is the prime meridian. Illustration 10 shows how latitude and longitude angles are used to describe a position on the surface of the Earth.

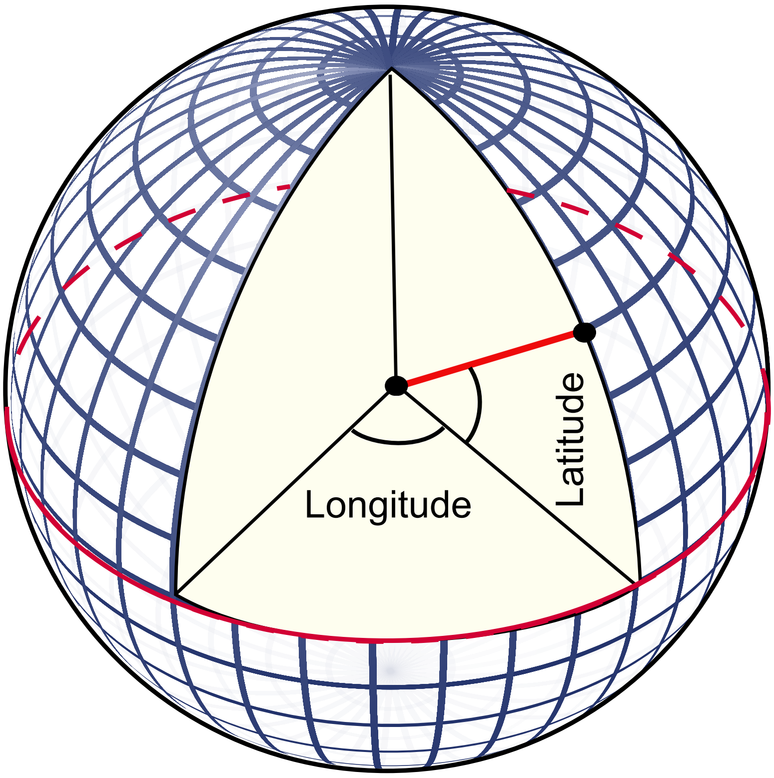

Illustration 10: Latitude and longitude represented visually to describe a position

Illustration 11 below shows latitude and longitude on a map of the world.

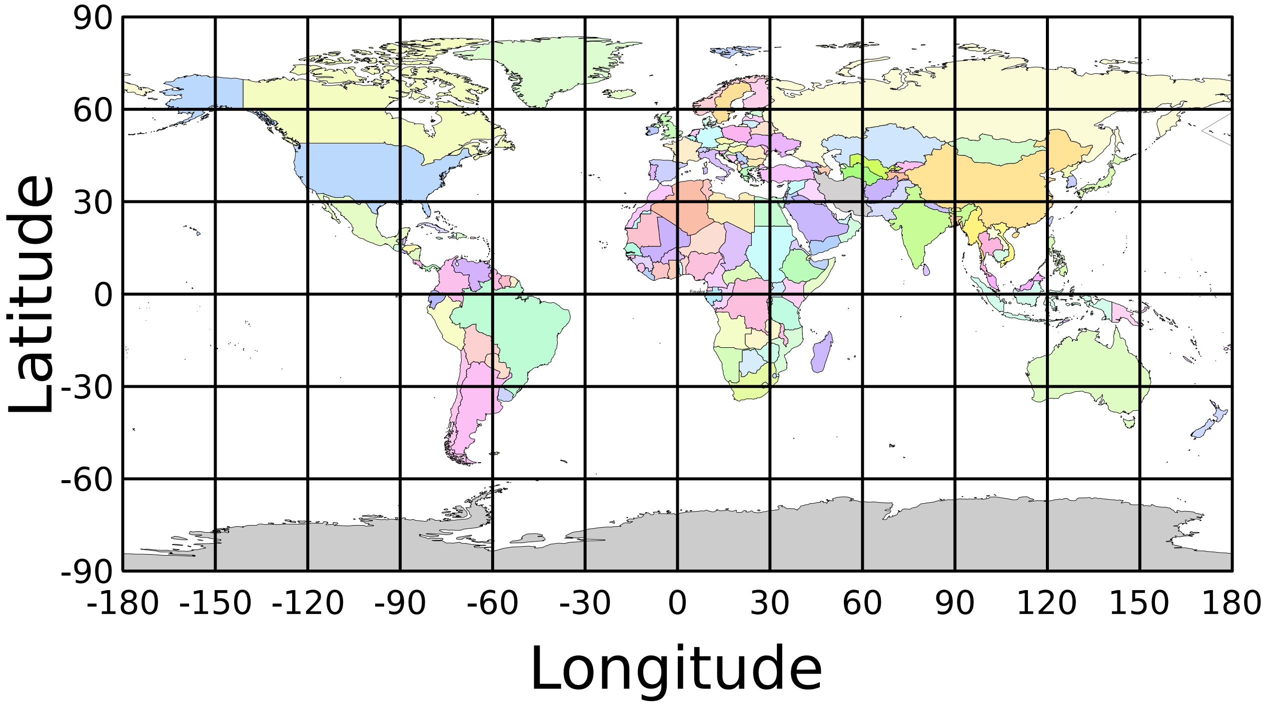

Illustration 11: World map showing latitudes and longitudes

Latitude and longitude give the 2D point on the surface of the Earth. These are combined with height to give the 3D position on the Earth.

Height is the height above the WGS84 reference ellipsoid. The WGS84 reference ellipsoid is a model used to approximate sea level across the Earth. Therefore the height should be considered approximately relative to sea level. Due to the approximate nature of the WGS84 model, the WGS84 height will not be the same as the actual sea level. For example, in Australia, the WGS84 height at sea level is 9 metres at some points.

2.8 NED Co-ordinate Frame

The NED (North East Down) co-ordinate frame is used to express velocities and relative positions. The origin of the co-ordinate frame can be considered the current position. From that origin, the north axis points true north and parallel to the line of latitude at that point. The east axis points perpendicular to the north axis and parallel to the line of longitude at that point. The down axis points directly down towards the centre of the Earth. See Illustration 12 for a graphical representation of the NED co-ordinate frame at a position on the Earth.

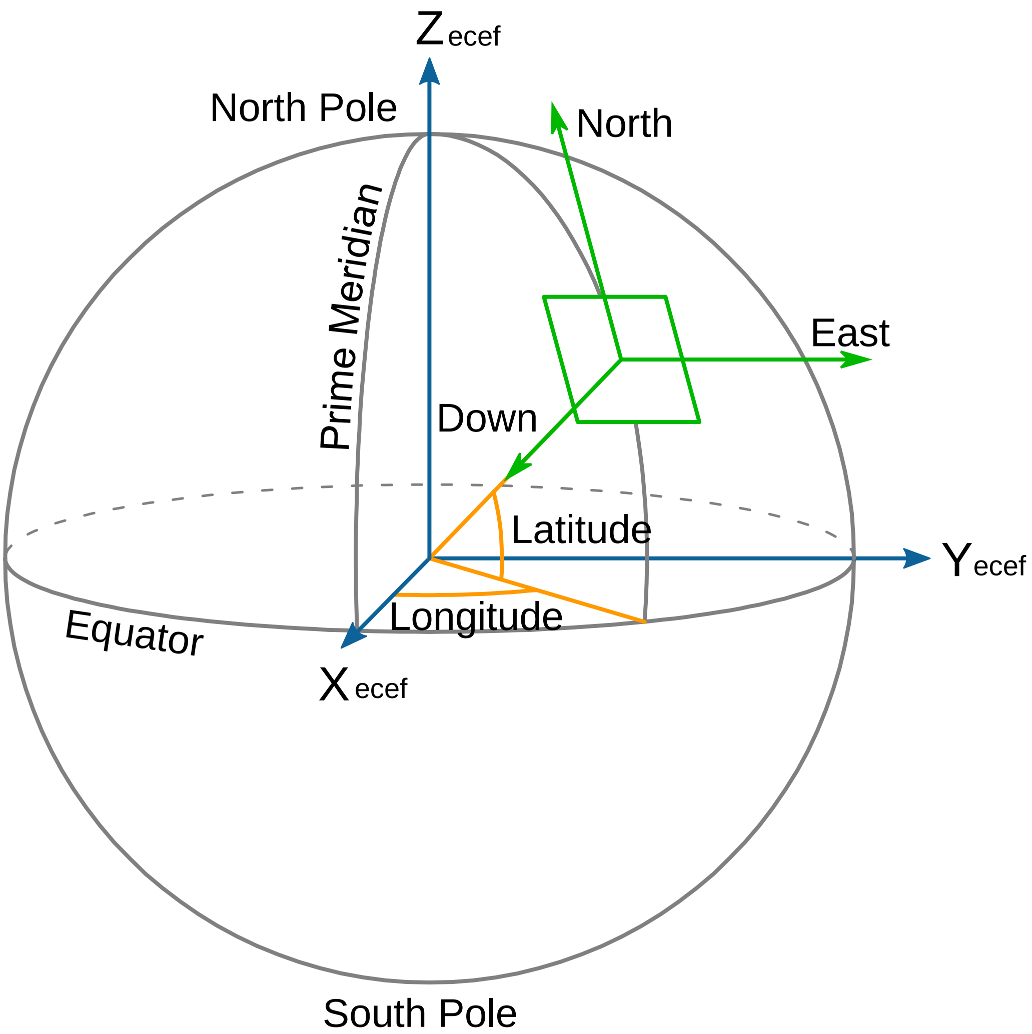

Illustration 12: Graphic showing geodetic, NED and ECEF co-ordinates

2.9 ECEF Co-ordinate Frame

The ECEF (Earth-centred earth-fixed) co-ordinate frame is a Cartesian co-ordinate frame used to represent absolute positions on the Earth. It's origin is at the centre of the Earth. ECEF is an alternative to the geodetic co-ordinate frame. It is represented by the three axes X, Y and Z which are presented graphically in Illustration 12. ECEF positions can be retrieved from Advanced Navigation products however the geodetic system is used as the default.

3 Introduction

Spatial is a miniature GNSS/INS & AHRS system that provides accurate position, velocity, acceleration and orientation under the most demanding conditions. It combines temperature calibrated accelerometers, gyroscopes, magnetometers and a pressure sensor with an advanced GNSS receiver. These are coupled in a sophisticated fusion algorithm to deliver accurate and reliable navigation and orientation.

Spatial can provide amazing results but it does need to be set up properly and operated with an awareness of it's limitations. Please read through this manual carefully to ensure success within your application.

The Spatial Manager software is downloadable from the software section. It allows Spatial to be easily configured and tested. It is referenced throughout this manual.

If you have any questions please contact support@advancednavigation.com.au.

Attention
Spatial OEM is an Electrostatic Sensitive Device and must be handled with care. Precautions against static must be taken when handling Spatial OEM.

4 Specifications

4.1 Mechanical Drawings

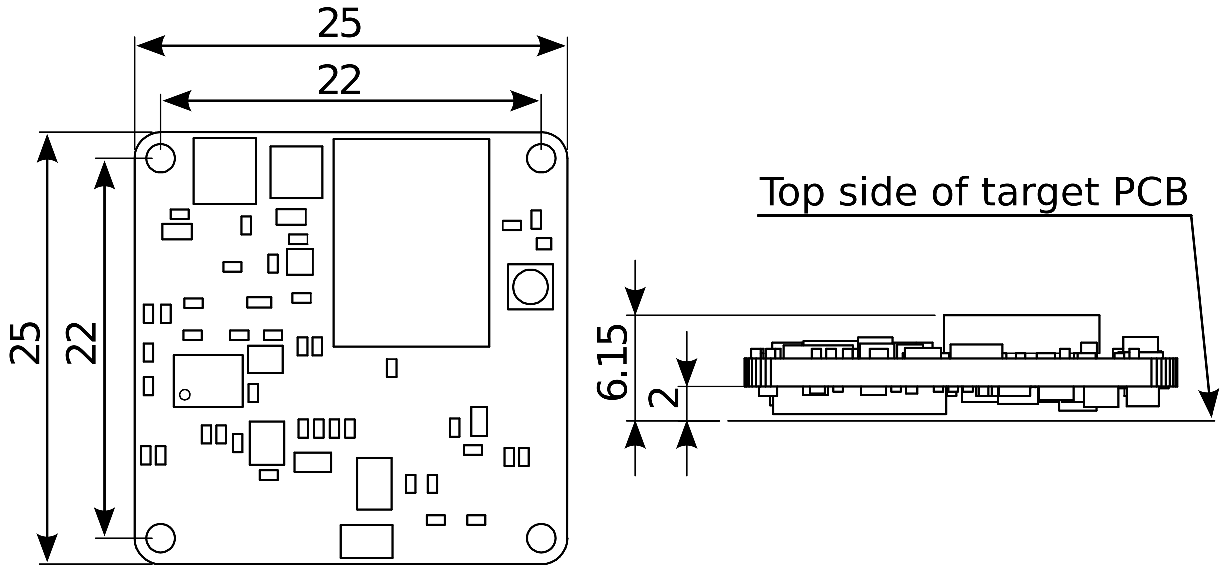

Illustration 13: Mechanical drawings of Spatial OEM

4.2 Navigation Specifications

Parameter	Value
Horizontal Position Accuracy	2.0 m
Vertical Position Accuracy	3.0 m
Horizontal Position Accuracy (with DGNSS)	0.6 m
Vertical Position Accuracy (with DGNSS)	1.0 m
Velocity Accuracy	0.05 m/s
Roll & Pitch Accuracy (Static)	0.1 °
Heading Accuracy (Static)	0.5 °
Roll & Pitch Accuracy (Dynamic)	0.2 °
Heading Accuracy (Dynamic with GNSS)	0.2 °
Heading Accuracy (Dynamic, magnetic only)	0.8 °
Orientation Range	Unlimited
Hot Start Time	500 ms
Internal Filter Rate	1000 Hz
Output Data Rate	Up to 1000 Hz

Table 1: Navigation specifications

4.3 Sensor Specifications

Parameter	Accelerometers	Gyroscopes	Magnetometers	Pressure
Range (dynamic)	2 g 4 g 16 g	250 °/s 500 °/s 2000 °/s	2 G 4 G 8 G	10 to 120 KPa
Noise Density	150 ug/√Hz	0.008 °/s/√Hz	210 uG/√Hz	0.56 Pa/√Hz
Non-linearity	< 0.05 %	< 0.05 %	< 0.05 %	-
Bias Stability	60 ug	3 °/hr	-	100 Pa/yr
Scale Factor Stability	< 0.05 %	< 0.05 %	< 0.05 %	-
Cross-axis Alignment Error	< 0.05 °	< 0.05 °	0.05 °	-
Bandwidth	400 Hz	400 Hz	110 Hz	50 Hz

Table 2: Sensor specifications

4.4 GNSS Specifications

Parameter	Value
Supported Navigation Systems	GPS L1 GLONASS L1 GALILEO L1 COMPASS L1
Supported SBAS Systems	WAAS EGNOS MSAS GAGAN QZSS
Update Rate	10 Hz
Cold Start Sensitivity	-143 dBm
Tracking Sensitivity	-160 dBm
Hot Start First Fix	3 s
Cold Start First Fix	30 s
Horizontal Position Accuracy	2.5 m
Horizontal Position Accuracy (with SBAS)	2 m
Velocity Accuracy	0.05 m/s
Timing Accuracy	25 ns

Table 3: GNSS Specifications

4.5 Communication Specifications

Parameter	Value
Interface	UART
Speed	4800 to 16M baud
Protocol	AN Packet Protocol
Peripheral Interface	6x GPIO
GPIO Level	5V

Table 4: Communication specifications

4.6 Hardware Specifications

Parameter	Value
Operating Voltage	4.2 to 36 V
Input Protection	± 40 V
Power Consumption	95 mA @ 5 V (typical)
Backup Battery Capacity	> 24 hrs
Backup Battery Charge Time	30 mins
Backup Battery Endurance	> 10 years
Operating Temperature	-40 °C to 85 °C
Shock Limit	2000 g
Dimensions	25 x 25 x 6 mm
Weight	4 grams

Table 5: Hardware specifications

4.7 Electrical Specifications

Parameter	Minimum	Typical	Maximum
Power Supply			
Input Supply Voltage	4.2 V		36 V
Input Protection Range	-40 V		40 V
GPIO			
Output Voltage Low	0 V		0.4 V
Output Voltage High	2.4 V		3 V
Input Threshold Low			0.8 V
Input Threshold High	2 V		
Input Voltage	0 V		5.5 V
Output Current			10 mA
GNSS Antenna			
Active Antenna Supply Voltage	2.5 V	2.65 V	2.8 V
Antenna Supply Current			57 mA

Table 6: Electrical specifications

4.8 Power Consumption

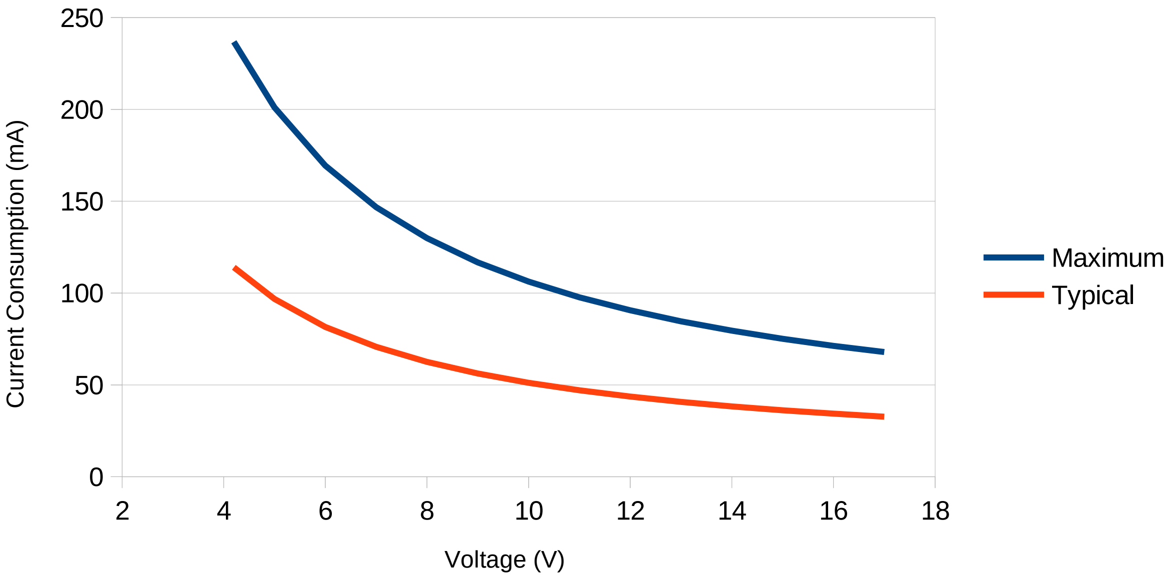

Illustration 14: Maximum and typical current consumption across operating voltage

4.9 Sensor Calibration

Spatial's sensors are calibrated for bias, sensitivity, misalignment, cross-axis sensitivity, non-linearity and gyroscope linear acceleration sensitivity across the full operating temperature range and for each of the three sensor ranges.

5 PCB Design and Integration

Spatial OEM has been designed to allow for quick and easy integration into the customer's own PCB design through the use of a board to board connector and specially designed SMD stand-offs.

5.1 PCB Mechanical Mounting

Spatial OEM mounts to its target PCB through the use of four precision 2mm high stand-offs that are supplied with every Spatial OEM. The stand-offs have been specially designed to be soldered to the target PCB during board assembly and are provided on pick and place tape to allow automated board assembly. Once the Spatial OEM is connected to the target PCB, four M1.6 x 4mm screws are used to hold Spatial OEM in place. Because the stand-offs are threaded, no extra nut is required on the reverse side of the user's target PCB and no part of the the screw should protrude through to the opposite side of the user's PCB. Please see Illustration 15 and Illustration 16 for a visual understanding of Spatial's mounting.

Please note that when mounting Spatial, the screws should be tightened evenly and only just tight enough to hold the board down. Over tightening the screws can place stress on the board and impact performance. For permanent installations thread locker should be used on the screws.

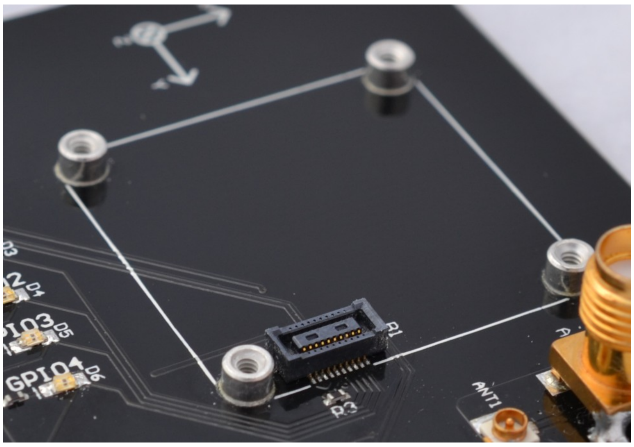

Illustration 15: Photo of Spatial OEM's mounting hardware on target PCB

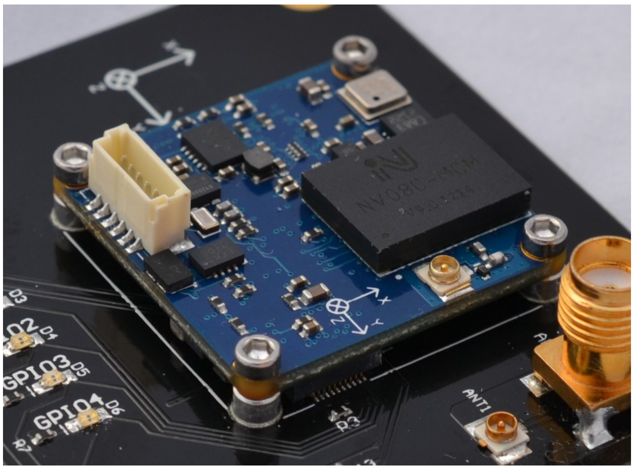

Illustration 16: Photo of Spatial OEM mounted on target PCB

5.2 Electrical Connector

The electrical connection to the Spatial OEM PCB is through a Hirose DF40 series 20 pin micro pitch board to board connector. These connectors have shock absorbing features, a large self-alignment distance and high contact reliability. A positive click should be felt when successful mating occurs between Spatial OEM and the target board. It should be noted that this connector is not designed for the Spatial OEM to be plugged in whilst power is applied to the user's PCB and connector mating cycles should not exceed 50 cycles to ensure connector reliability.

The manufacturers part number for the required PCB connector is
Hirose Part #: DF40C(2.0)-20DS-0.4V(51)

The connector can be ordered from the following distributors using the following numbers:

Digikey Part #: H11905CT-ND
Mouser Part #: 798-DF40C20DS0.4V51

To prevent damage to the connector during mating please follow the mounting advice in Illustration 17 and Illustration 18.

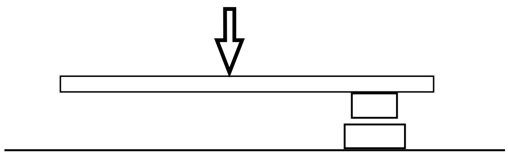

Illustration 17: Correct mounting of Spatial OEM

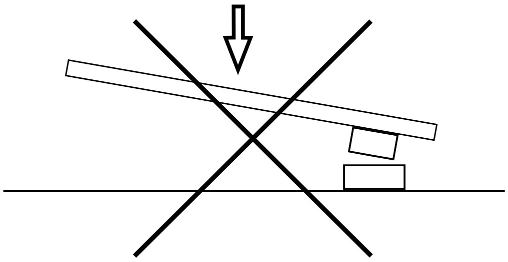

Illustration 18: Incorrect mounting of Spatial OEM

5.3 Connector Pin-out

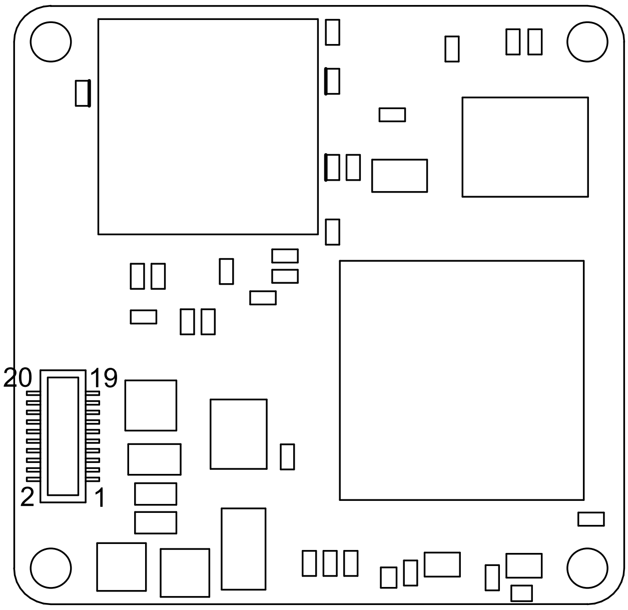

Illustration 19: Bottom view of Spatial OEM showing connector pin numbering

Pin	Function
1	Supply Voltage
2	Ground
3	Supply Voltage
4	Ground
5	Supply Voltage
6	Ground
7	3V translator supply, see section 5.3.1
8	Ground
9	Primary UART receive
10	Reset line, see section 5.3.2
11	Primary UART transmit
12	GPIO1
13	GPIO5
14	GPIO2
15	GPIO6
16	GPIO3
17	Do not connect
18	GPIO4
19	Do not connect
20	Do not connect

Table 7: Pin allocation table

5.3.1 Interoperability with Different Voltage Systems

All signals are 3 volt level, however inputs are tolerant to 5 volt signals from the target interface. If you require a different voltage level to be compatible with your target system it is recommended that you install a voltage level translator between the signals of each device. To power the translator 3V is provided on pin 7 of the Spatial OEM connector. This supply is only capable of driving up to 50mA and should be appropriately decoupled when powering a circuit.

5.3.2 Reset Line

The reset line is internally pulled high on Spatial OEM. This pin must be left floating for normal operation. If a user wishes to reset Spatial OEM the pin can be pulled low externally to force a reset. It is important that this signal is not driven high under any circumstances as it will prevent the Spatial OEM from functioning correctly. Please keep the reset line track length to a minimum to avoid noise.

5.3.3 Basic Connection

Please see Illustration 20 for the basic electrical connections required by Spatial OEM.

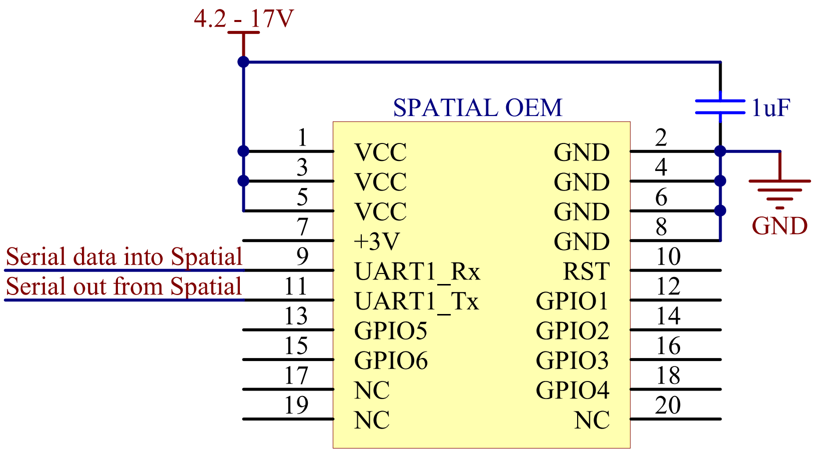

Illustration 20: Spatial OEM basic electrical connections

5.4 Recommended Footprint

The footprint for Spatial OEM incorporates four through-hole pads for the soldering of the four 2mm stand-offs and 20 additional SMD pads for the board to board connector. The through-hole pads are designed to allow solder paste to be applied before component placement so that the PCB can be assembled using pick and place machines.

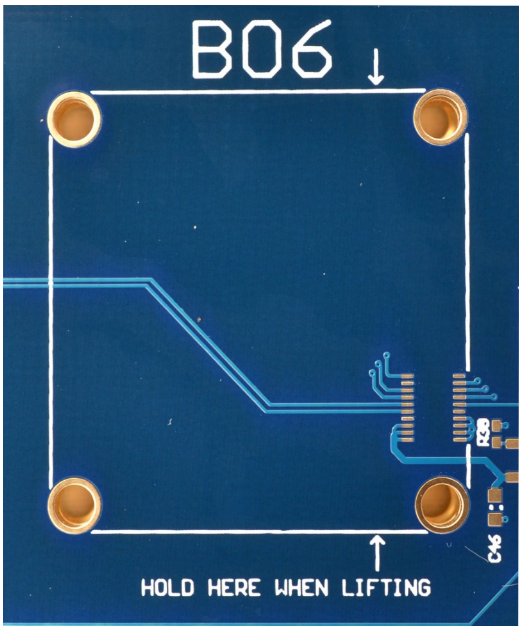

Illustration 21: Photo of Spatial OEM footprint

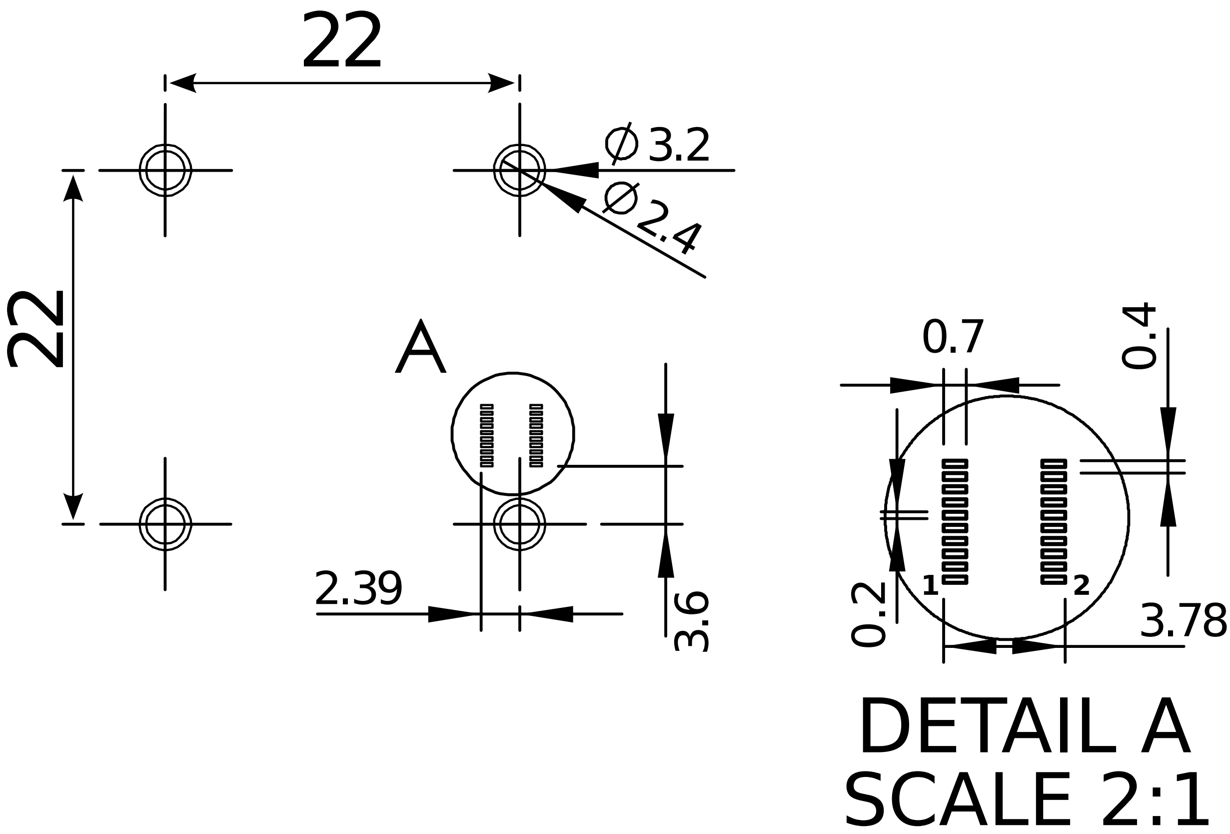

Illustration 22: Recommended footprint for Spatial OEM

PCB footprint files are provided in the documentation section of the website. Please contact Advanced Navigation support if you have any issues or to verify your footprint is correct.

5.5 Power Supply

A high level of power supply filtering has been built into Spatial, however it is still recommended that the power supply be free of significant noise. As the communications ground is shared with the supply ground it is important to ensure that ground wiring is routed to avoid power supply noise from other systems corrupting data communications.

A power supply should be selected that can provide at least the maximum current calculated from the graph in Illustration 14.

Spatial contains an active protection circuit on the power supply input that protects the unit from under-voltage, over-voltage and reverse polarity events. The protection circuit shuts off power and automatically recovers the unit to full operation once the fault is removed. Take care when running the unit close to its under-voltage lockout of 4.2 V because small voltage drops can engage the under-voltage shutdown and potentially oscillate between the on and off state. It is recommended that the unit is always run at 4.7 V or more to avoid issues associated with this.

On start-up of the Spatial OEM the device will initially draw an increased impulse current (~400mA for 2 microseconds) whilst it charges on board capacitors. It is important that the user's circuit is tolerant to these small impulses on start-up to avoid unsuccessful power up. It is recommended that a supply is selected that can provide a maximum current of 0.5A. Switch-mode supplies are suitable as Spatial OEM has on-board filters to remove any supply noise and ripple.

5.6 U.FL RF Connector

Spatial OEM's antenna connection is through a U.FL connector on the board. It is recommended to use a U.FL to SMA adapter cable to allow connection to standard GNSS antennas. The U.FL connector on Spatial is fragile and should be handled with care. It is not designed for repeated connection and disconnection.

5.7 Pin Protection

Users should ensure that any signals that are connected externally from the PCB, including GPIO and UART pins, are adequately protected. The use of a 5V zener diode and 1k resistor should provide enough protection for the majority of use cases, see Illustration 23.

External interface pins on Spatial have on board pull-up/pull-down resistors enabled to avoid signals oscillating when not connected. The user shouldn't need to place any pull-up or pull-down resistors on their PCB.

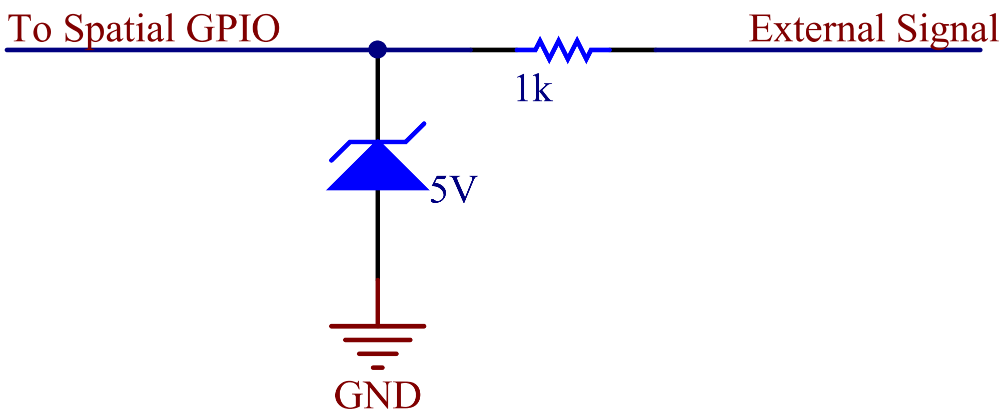

Illustration 23: Spatial OEM external protection circuit

6 Installation

6.1 Position and Alignment

When installing Spatial into a vehicle, correct positioning and alignment are essential to achieve good performance. There are a number of goals in selecting a mounting site in your application, these are:

1. Spatial should be mounted close to the centre of gravity of the vehicle.
2. Spatial should be mounted as far from sources of dynamic magnetic interference as possible i.e. high current wiring, large motors.
3. Spatial should be mounted within several metres of the GNSS antenna where possible.
4. Spatial should be mounted away from vibration where possible.
5. Spatial should be mounted in an area that is not going to exceed it's temperature range.
6. The two vents on the sides of Spatial must not be obstructed.

6.1.1 Alignment

The easiest way to align Spatial is by installing it with the sensor axes aligned with the vehicle axes. This means that the X axis points forward towards the front of the vehicle and the Z axis points down towards the ground. Examples of this are shown below in Illustration 24, Illustration 25 and Illustration 26.

If aligning Spatial with the vehicle axes is not possible or not optimal, it may be mounted in a different alignment and the alignment offset must be configured using either the Spatial Manager software or the Installation Alignment Packet. For precise alignment, the Set Zero Orientation Alignment Packet can be used to set the current orientation as the zero orientation alignment.

For more information on setting the alignment please see the Spatial Manager software manual or the alignment packet in section 9.9.5.

Illustration 24: Spatial axes aligned with car axes

Illustration 25: Spatial axes aligned with boat axes

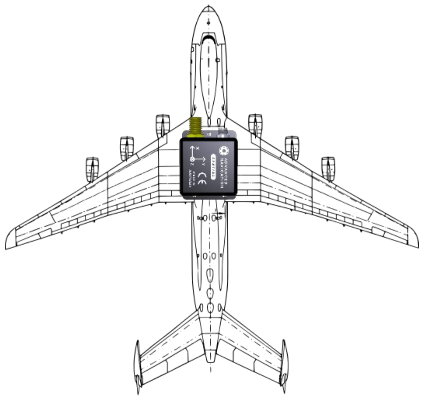

Illustration 26: Spatial axes aligned with plane axes

6.2 GNSS Antenna

The GNSS antenna should be installed level with a clear view of the sky and as close to the Spatial unit as possible. The antenna cable should be routed away from high energy noise sources. The optimum mounting configuration is above the Spatial unit. If the antenna has to be installed more than 1 metre away from the Spatial unit, this antenna offset should be configured in the Spatial unit by using either the Spatial Manager software or the packet protocol, see section 9.9.5. It is very important to set the antenna offset accurately as Spatial corrects for lever arm velocities. Incorrect GNSS antenna offset will lead to performance degradation under turning and angular rotations.

It is important to note that most GNSS antennas contain magnets for mounting. If you are using an antenna with magnets you will need to either keep it a minimum distance away from Spatial or remove the magnets to ensure that it doesn't interfere with Spatial's magnetometers.

If you are supplying your own antenna it is important to ensure that the antenna is able to receive all constellations and not just GPS, otherwise you will not achieve full performance. It is also important to select an IP67 antenna with an IP67 SMA connector, otherwise the system will not be environmentally sealed.

It is recommended to use an antenna with the following characteristics:

- Centre frequency of 1590 MHz and a bandwidth of 35 MHz
- Gain of 20 dB
- Antenna noise factor of < 2 dB
- Out of band rejection of 35 dB @ ±70 MHz

6.3 Odometer

On ground vehicles, the use of an odometer input can greatly improve Spatial's navigation and orientation solution during GNSS dropouts. With a high resolution wheel encoder Spatial can be used to navigate indoors with GNSS disabled altogether.

Most road cars since 1980 contain a VSS (vehicle speed sensor) signal that can be wired directly into one of Spatial's GPIO pins. Cars that do not feature a VSS signal may require additional circuitry to make the signal compatible with Spatial, please contact Advanced Navigation support for assistance with this.

To setup the odometer, the appropriate GPIO pin should be set to odometer input using either Spatial Manager or the GPIO Configuration Packet. The odometer pulse length must then be set either manually or automatically, please see section 7.10 for more information.

For more information on the GPIO signal and it's requirements please see section 8.3.3. Whilst Spatial contains protection on it's GPIO pins, Spatial OEM does not. The odometer signal needs to be connected through a protection circuit with a zener diode and resistor, please see section 5.7.

6.4 Magnetics

Spatial contains magnetometers which it uses to measure the Earth's magnetic field in order to determine it's heading. The principle is the same as that of a compass. Sources of magnetic interference can degrade Spatial's solution if not compensated for. There are two types of magnetic interference, these are static and dynamic.

Static magnetic interference is caused by steel and other magnetic materials mounted in the vehicle. Static disturbances are easily compensated for by running a magnetic calibration, see section 7.6. A magnetic calibration should always be run after installation into a vehicle.

Dynamic magnetic interference is generally a much bigger issue. Sources of dynamic magnetic interference include high current wiring, electric motors, servos, solenoids and large masses of steel that don't move with Spatial. Spatial should be mounted as far as possible from these interference sources.

Spatial contains a special algorithm to remove the effects of dynamic magnetic interference. This is able to compensate for most typical interference sources encountered, however certain types of prolonged dynamic interference cannot be compensated for. The best way to check for dynamic magnetic interference is to use the raw sensors view in Spatial Manager and watch the magnetometer outputs whilst the vehicle is operating but stationary. The values should be constant, if the values are fluctuating there is dynamic magnetic interference present.

If dynamic magnetic interference is causing performance problems and there is no way to mount Spatial away from the interference source, the magnetometers should be disabled, see section 7.6.3.

6.5 Vibration

Spatial is able to tolerate a high level of vibration compared to other inertial systems. This is due to a unique gyroscope design and a special filtering algorithm. There is however a limit to the amount of vibration that Spatial can tolerate and large levels of vibration will cause Spatial's accuracy to degrade.

When mounting Spatial to a platform with vibration there are several options. It is recommended to first try mounting Spatial and see whether it can tolerate the vibrations. The raw sensor view in the

Spatial Manager software can give you a good idea of how bad the vibrations are. If the vibrations are causing the sensors to go over range you will need to increase the sensors range, see section 7.7.

If Spatial is unable to tolerate the vibrations there are several options:

1. Try to find a mounting point with less vibration.
2. Spatial can be mounted with 3M foam rubber double sided tape or a small flat piece of rubber.
3. Spatial can be mounted to a plate which is then mounted to the platform through vibration isolation mounts.

7 Operation

7.1 Filter

Spatial contains a very sophisticated filter which it uses to fuse all it's sensors into a state estimation. The filter is a set of custom algorithms that have similar principles to a kalman filter, but operate differently. Spatial's custom filter makes decisions based upon context and history which greatly improves performance and makes it more resilient to error sources than a standard kalman filter.

Under rare conditions, when there are large errors present that Spatial's filter cannot compensate for, it can become unstable. If Spatial's filter does become unstable a monitoring process will immediately reset the filter to the last known good state. The filter initialised flag will remain reset until the filter stabilises again. In real time control applications it is very important to monitor Spatial's filter status, so that data can be ignored if a situation occurs causing the filter to reset.

7.2 Initialisation

When Spatial starts up, it assumes that it can be in any orientation. To determine it's orientation it uses the accelerometers to detect the gravity vector. Whilst this is occurring, if there are random accelerations present these can cause an incorrect orientation to be detected. To prevent this, Spatial monitors the accelerometers and gyroscopes and restarts the orientation detection if there are sudden movements. It is however still possible under some circumstances for it to miss movements and start with a bad orientation. In this scenario Spatial will progressively correct the orientation error over a period of several seconds.

After orientation detection, Spatial's filter takes several minutes to achieve it's full accuracy. It is recommended to wait two minutes after power on for applications requiring high accuracy.

7.3 Hot Start

Spatial is the first GNSS/INS on the market with hot start functionality. This allows Spatial to start inertial navigation within 500 milliseconds and obtain a GNSS fix in as little as 3 seconds. Spatial's hot start is always on and fully automatic.

A next generation backup battery system within Spatial provides the hot start ability for more than 24 hours without power. When Spatial hot starts it assumes that it is in the same position it was when it lost power and begins navigating from that position. The hot start also provides ephemeris, almanac and time information to the GNSS receiver which allows it to achieve a fix far more quickly than it otherwise would. When the GNSS achieves it's first fix, if this position deviates from the hot start position, Spatial will jump to the new position without causing any side effects to the filter.

Whilst Spatial is without power it keeps track of the time accurately to within 1 second so that the time is immediately valid on a hot start.

Spatial's hot start is of particular benefit to vehicle tracking and robotics applications. The primary benefits are immunity and fast recovery from power failure as well as fast startup time.

7.4 Time

Spatial was designed to provide a highly accurate time reference. When a GNSS fix is available

Spatial's time is accurate to within 50 nanoseconds. When a GNSS fix is lost, Spatial's time accuracy typically remains within 10 microseconds over extended time periods. When Spatial hot starts the time accuracy is typically within 1 second immediately on startup and corrected to within 50 nanoseconds as soon as a GNSS fix is achieved. To synchronise with Spatial's high accuracy time, both the packet protocol and a 1PPS line must be used.

7.5 Heading Source

There are three different heading sources available for Spatial. The heading source can be selected using the filter options dialog in Spatial Manager or the Filter Options Packet. It is possible to use multiple heading sources and this can often provide performance benefits.

7.5.1 Magnetic Heading

This is the default heading source and works well in the majority of cases. When using magnetic heading, calibration is required every time Spatial's installation changes. The downside of magnetic heading is that prolonged dynamic magnetic interference sources can cause heading errors.

7.5.2 Velocity Heading

Velocity heading works by deriving heading from the direction of velocity and acceleration. Velocity heading works well with cars, boats, fixed wing aircraft and other vehicles that don't move sideways. Velocity heading does not work with helicopters and other 3D vehicles. The downside of velocity heading is that heading can not be measured until the vehicle moves at a horizontal speed of over 2 metres/second with a GNSS fix. The benefits of velocity heading are that it is immune to magnetic interference and no calibration is required when Spatial's installation changes.

7.5.3 External Heading

This can be used if there is some other way to derive heading that is external to Spatial. Examples include dual antenna GNSS systems, north seeking gyroscopes, reference markers and SLAM systems. The heading must be fed into Spatial using the External Heading Packet or through NMEA into a GPIO pin.

7.6 Magnetics

Static magnetic interference is resolved through magnetic calibration and dynamic magnetic interference is compensated by a filter algorithm but should be minimised where possible through installation location. Please see section 6.4 for more information on magnetic interference. To compensate for static magnetic interference, magnetic calibration should be performed any time Spatial's installation changes.

Spatial contains a dynamic magnetic compensation filter that is able to mitigate the effects of short term magnetic interference sources while in operation. For example if Spatial is installed in a car and the car drives over a large piece of magnetised steel, this will be compensated for. Another example is driving through a tunnel which is built from heavily reinforced concrete. It is important to note that for Spatial's dynamic magnetic compensation filter to operate correctly, Spatial needs to get a GNSS fix at least once every time it is moved more than 50km. Each time Spatial moves more than 50km the new position is stored permanently and allows Spatial to update it's world magnetic model values.

There are two types of magnetic calibration available, these are 2D calibration and 3D calibration.

2D calibration involves three level rotations about the Z axis and is designed for vehicles that cannot easily or safely be turned upside down, such as full size cars, planes and boats. 3D calibration involves rotating through all orientations and is designed for vehicles that can easily and safely be rotated upside down, such as model size vehicles. 3D calibration offers slightly better performance and is recommended where possible.

Please note that if Spatial is going to be used in a vehicle, the calibration should be performed while Spatial is mounted in and fixed to that vehicle. This means that the whole vehicle must be moved to perform the calibration. The calibration needs to be performed in an area away from sources of magnetic interference. For example if Spatial is installed in a car, the calibration should not involve driving over steel drains or reinforced concrete etc. If Spatial is being calibrated to operate standalone, the calibration should not be done on a desk with a steel frame.

7.6.1 2D Magnetic Calibration

The following procedure should be used to perform a 2D magnetic calibration.

7.6.1.1 Using the Spatial Manager Software

1. The unit should be powered in a level orientation and kept stationary.
2. After power on wait 5 minutes for the temperature and filter to stabilise.
3. Open Spatial Manager and connect to the device. Ensure that the device has a GNSS fix before proceeding.
4. In the Tools menu, open Magnetic Calibration. Click the 2D Calibration button.
5. Whilst keeping as level as possible, rotate the unit in either direction through three full rotations.
6. Check the status in the Magnetic Calibration window to ensure that the calibration completed successfully. If not successful click Cancel, wait 2 minutes and repeat from step 4.

7.6.1.2 Using the Packet Protocol

1. The unit should be powered in a level orientation and kept stationary.
2. After power on wait 5 minutes for the temperature and filter to stabilise.
3. Ensure that the device has a GNSS fix before proceeding
4. Send the Magnetic Calibration Configuration Packet with the action Start 2D Magnetic Calibration.
5. Whilst keeping as level as possible, rotate the unit in either direction through three full rotations.
6. Read the Magnetic Calibration Status Packet to ensure that the calibration completed successfully. If not successful, send the Magnetic Calibration Configuration Packet with the action Cancel, wait 2 minutes and repeat from step 4.

7.6.2 3D Magnetic Calibration

The following procedure should be used to perform a 3D magnetic calibration.

7.6.2.1 Using the Spatial Manager Software

1. The unit should be powered in a level orientation and kept stationary.
2. After power on wait 5 minutes for the temperature and filter to stabilise.
3. Open Spatial Manager and connect to the device. Ensure that the device has a GNSS fix before proceeding.
4. In the Tools menu, open Magnetic Calibration. Click the 3D Calibration button.
5. From a level orientation, slowly rotate the unit twice around the X axis (roll).
6. From a level orientation, slowly rotate the unit twice around the Y axis (pitch).
7. From a level orientation, slowly rotate the unit through as many orientations as possible.
8. Check the status in the Magnetic Calibration window to ensure that the calibration completed successfully. If not successful click Cancel, wait 2 minutes and repeat from step 4.

7.6.2.2 Using the Packet Protocol

1. The unit should be powered in a level orientation and kept stationary.
2. After power on wait 5 minutes for the temperature and filter to stabilise.
3. Ensure that the device has a GNSS fix before proceeding
4. Send the Magnetic Calibration Configuration Packet with the action Start 3D Magnetic Calibration.
5. From a level orientation, slowly rotate the unit twice around the X axis (roll).
6. From a level orientation, slowly rotate the unit twice around the Y axis (pitch).
7. From a level orientation, slowly rotate the unit through as many orientations as possible.
8. Read the Magnetic Calibration Status Packet to ensure that the calibration completed successfully. If not successful, send the Magnetic Calibration Configuration Packet with the action Cancel, wait 2 minutes and repeat from step 4.

7.6.3 Disabling Magnetometers

In situations where there is strong dynamic magnetic disturbances present that cannot be avoided, it is recommended to disable the magnetometers. When the magnetometers are disabled a secondary heading source is required otherwise the heading will slowly drift. Please see section 7.5 for information on alternative heading sources. The magnetometers can be disabled using the filter options dialog in Spatial Manager or the Filter Options Packet.

7.7 Sensors Range

Spatial supports dynamic ranging on it's sensors. Each of the three sensors have three different range levels. At lower ranges the sensor performance is better, but at higher ranges Spatial can be used in more extreme dynamics. It is important to choose a range that your application won't exceed.

Sensor over range events can be detected through the Filter Status. In Spatial manager the status indicator will go orange indicating that a sensor has gone over range. When a sensor goes over range this causes the filter to become completely inaccurate and in some cases it can cause the filter to reset.

By default Spatial comes configured in the lowest sensor ranges. In this configuration it is possible to send the gyroscopes over range by quickly rotating the unit in your hand. It is recommended to watch what happens in Spatial Manager when you do this.

The sensor range can be set through the sensors option in the configuration menu in Spatial Manager or through the Sensor Ranges Packet.

7.8 Data Anti Aliasing

Internally Spatial's filters update at 800 Hz. When Spatial outputs data, most applications require the data at a much lower rate (typically < 100 Hz). This causes a problem for time based data such as velocities and accelerations where aliasing will occur at the lower rate. To prevent this problem, if the output rate is lower than 800 Hz, Spatial will low pass filter the values of the time dependent data between packets to prevent aliasing. This is only the case when a packet is set up to output at a certain rate. If the packet is simply requested no anti aliasing will occur. Additionally there is no anti aliasing for non time dependent fields such as position.

7.9 Vehicle Profiles

Spatial supports a number of different vehicle profiles. These vehicle profiles impose constraints upon the filter that can increase performance. If your application matches one of the available vehicle profiles, it is recommended to select it for use in the filter options dialog in Spatial Manager or the Filter Options Packet. For a list of the different vehicle profiles please see section 9.9.6.1. Please note that if the wrong vehicle profile is selected it can cause a significant decrease in performance.

7.10 Odometer Pulse Length

For Spatial to use a wheel speed sensor or odometer input, it must know the pulse length of the signal. The pulse length is the distance in metres between low to high transitions of the signal. The odometer pulse length can either be entered manually or automatically calibrated by Spatial. To enter the pulse length manually, please use the odometer configuration dialog in Spatial Manager or the Odometer Configuration Packet. To automatically calibrate the odometer pulse length please use the procedure listed below in section 7.10.1. By default the odometer will automatically calibrate itself.

7.10.1 Odometer Automatic Pulse Length Calibration Procedure

1. Ensure that the signal is connected correctly and that the GPIO pin is configured as an odometer input using the GPIO configuration dialog or the GPIO Configuration Packet.
2. Open Spatial Manager, connect to Spatial and open the odometer configuration dialog. In the odometer configuration dialog tick the automatic pulse length calibration check box and press the write button. If using the packet protocol this can be done using the Odometer Configuration Packet.
3. Wait until Spatial has a continuous GNSS fix and then drive 1000 metres over flat terrain with as little turning as possible.
4. If Spatial loses a GNSS fix for any extended period of time during the calibration, the

distance travelled will be reset. The distance travelled can be checked in the odometer configuration dialog to ensure that it has passed 1000m.

5. Once 1000 metres has been driven, press the read button and check that the automatic pulse length check box becomes un-ticked and the pulse length value is read.

7.11 RAIM

RAIM stands for receiver autonomous integrity monitoring. It allows a GNSS receiver to detect and exclude both faulty and fraudulent satellite signals. Spatial's internal GNSS is equipped with RAIM and it is enabled by default.

7.12 Underwater Navigation

Spatial is able to provide accurate absolute navigation underwater when combined with appropriate peripherals. There are several options for underwater navigation detailed below.

7.12.1 DVL (Doppler Velocity Log) Peripheral

DVLs provide 3D velocity underwater and allow Spatial to provide positional accuracy of approximately 0.3% of distance travelled.

A DVL works by tracking velocity relative to the sea floor. They typically have a range of approximately 100m. When the sea floor is beyond this range, the DVL provides velocity relative to the water layer, however this is unable to account for water currents which can cause positional accuracy to degrade faster.

When operating with a DVL, Spatial must have a starting position to navigate from. This can be achieved by either allowing Spatial to get a GNSS fix while the underwater vehicle is on the surface, or by manually entering the starting co-ordinates using the External Position Packet. The typical setup for obtaining a GNSS fix is a waterproof glass dome housing the GNSS antenna, mounted on the top of the vehicle.

Spatial contains built in support for DVLs from Teledyne and Linkquest and these systems can be directly connected to Spatial using the GPIO pins. Advanced Navigation recommends Teledyne DVL systems.

7.12.2 USBL (Ultra-short Baseline) Peripheral

USBLs provide relative 3D positioning underwater and allow Spatial to provide positional accuracy of approximately 4m.

A USBL setup consists of a surface transponder, an underwater responder and two Spatial units. The surface transponder is typically mounted on a ship and is connected to a Spatial unit. Another Spatial unit is mounted on the underwater vehicle along with the responder. The surface Spatial unit communicates with the underwater Spatial unit over a serial connection through a tether. Please see Illustration 27. USBL systems typically have a maximum range from transponder to responder of approximately 500 metres.

Spatial contains built in support for USBLs from Tritech and these systems can be directly connected to Spatial using the GPIO pins.

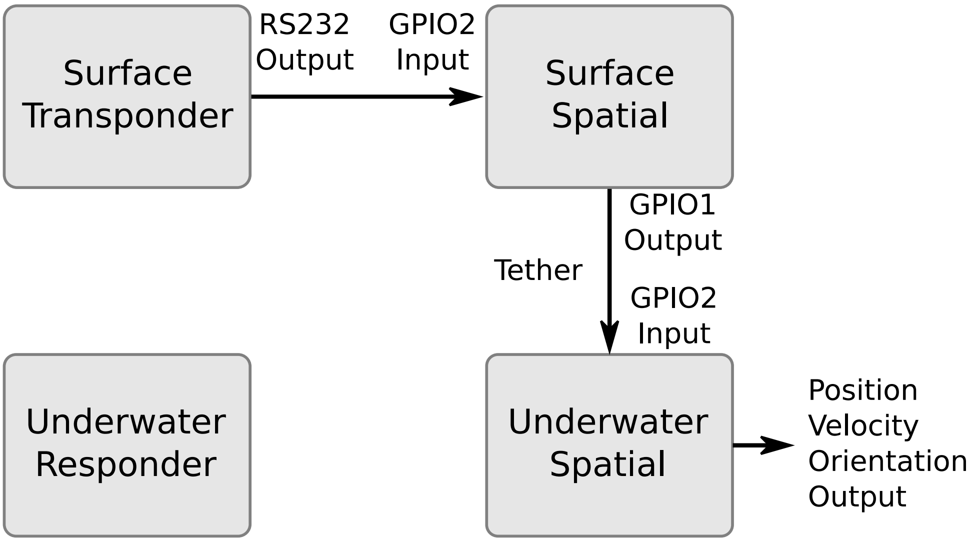

Illustration 27: Spatial USBL Setup

7.12.3 Depth

For Spatial's intelligent filter to operate correctly and provide maximum performance, Spatial requires continuous updates of depth information. This can be achieved by adding a pressure depth transducer to Spatial. Spatial supports frequency output pressure depth transducers using the GPIO pins, please see section 8.3.26. Alternatively if depth is already known, it can be fed into Spatial using the External Depth Packet. Some Teledyne DVLs feature a built in pressure sensor, in this case Spatial will automatically use the DVL pressure to determine depth.

7.12.4 DVL and USBL Combined Systems

For systems that require the highest accuracy, Spatial can be combined with both a DVL and USBL. By using both the DVL velocity and USBL position, Spatial is able to provide very accurate underwater navigation.

7.13 Heave

Spatial can provide vertical heave position at four different points on a ship. Spatial's heave filter is always on and fully automatic. After power on, Spatial requires approximately 5 minutes for it's heave filter to converge upon an accurate solution. Heave works without a GNSS fix, however best heave performance is achieved when Spatial has a GNSS fix.

By default Spatial provides heave from the point at which the Spatial unit is mounted, however it can provide heave at four different offset points on the ship. To set the heave offsets, either use the heave configuration dialog in Spatial Manager or the Heave Offset Packet.

7.14 Temperature

Spatial should not be subjected to temperature's outside of it's operating range. If the temperature rises above 90 degrees Celsius, Spatial will automatically shut off power to it's sensors and GNSS in an attempt to prevent damage, this will also send the filters into reset. Subjecting Spatial to temperature's outside of the storage range can effect the factory sensor calibration which will cause a permanent performance degradation.

8 Interfacing

8.1 Communication

All communication to the Spatial module is over the serial interface in the Advanced Navigation packet protocol. The serial format is fixed at 1 start bit, 8 data bits, 1 stop bit and no parity. See section 9 for details on the protocol.

8.1.1 Baud Rate

The default baud rate of Spatial is 115200. The baud rate can be set anywhere from 100 to 1000000 baud and can be modified using the Spatial Manager software or the baud rate packet, see section 9.9.3. It is important to select a baud rate that is capable of carrying the amount of data that Spatial is set to send. See packet rates in section 9.5 for more details on data output calculation. The data rate in bytes per second can be calculated by dividing the baud rate by 10. For example if the baud rate is 115200, then the data rate is 11520 bytes per second.

8.2 External data

External sources of position, velocity and/or orientation can be integrated into Spatial's filter solution. The data can be sent to Spatial in the ANPP format over the main serial port or through one of the GPIOs in a number of different formats. If using the ANPP, please use Table 8 below to find the relevant section. If using the GPIO pins, please see section 8.3.

Packet	Section
External Position and Velocity	9.8.25
External Position	9.8.26
External Velocity	9.8.27
External Body Velocity	9.8.28
External Heading	9.8.29

Table 8: ANPP External Data Reference

8.3 GPIO Pins

Spatial contains six general purpose input output pins on the main connector. These pins are multi function and can be used to extend Spatial with additional peripherals, sensors and data formats. All pins have digital input, digital output, frequency input and frequency output functionality. Additionally GPIO1 and GPIO3 can function as TTL serial transmit lines and GPIO2 and GPIO4 can function as TTL serial receive lines. The GPIO serial baud rate can be configured anywhere from 1200 to 1000000 baud by using the baud rate configuration dialog in Spatial Manager or the Baud Rates Packet.

The GPIO pin functions available are listed below. The function of a GPIO pin can be changed at any time using the GPIO configuration dialog in Spatial Manager or the GPIO Configuration Packet.

Function	Type	GPIOs
Inactive	Tristate	All
1PPS Output	Digital Output	All
GNSS Fix Output	Digital Output	All
Odometer Input	Frequency Input	All
Stationary Input	Digital Input	All
Pitot Tube Input	Frequency Input	All
NMEA Input	Serial Receive	2
NMEA Output	Serial Transmit	1
Novatel GNSS Input	Serial Receive	2
Topcon GNSS Input	Serial Receive	2
Motec Output	Serial Transmit	1
ANPP Input	Serial Receive	2
ANPP Output	Serial Transmit	1
Disable Magnetometers	Digital Input	All
Disable GNSS	Digital Input	All
Disable Pressure	Digital Input	All
Set Zero Orientation Alignment	Digital Input	All
System State Packet Trigger	Digital Input	All
Raw Sensors Packet Trigger	Digital Input	All
RTCM Differential GNSS Corrections Input	Serial Receive	2
Trimble GNSS Input	Serial Receive	2
u-blox GNSS Input	Serial Receive	2
Hemisphere GNSS Input	Serial Receive	2
Teledyne DVL Input	Serial Receive	2
Tritech USBL Input	Serial Receive	2
Linkquest DVL Input	Serial Receive	2
Pressure Depth Transducer Input	Frequency Input	All
Left Wheel Speed Sensor	Frequency Input	All
Right Wheel Speed Sensor	Frequency Input	All
1PPS Input	Digital Input	All

Table 9: GPIO pin functions

8.3.1 1PPS Output

In this function, the pin is normally low and pulses high for 50 milliseconds to signal the precise second. The 1PPS line starts pulsing approximately 100 milliseconds after power up and always fires irrespective of whether Spatial has accurate time or not. It is important to note that when Spatial acquires time corrections from it's GNSS receiver, the 1PPS signal may fire at an interval of less than 1 second. This typically only occurs the first time the GNSS receiver obtains a fix after startup. The time initialised status flag can be used to determine whether the time and 1PPS line is accurate or not.

8.3.2 GNSS Fix Output

In this function, the pin is low when there is no GNSS fix or a 2D fix and high when there is a 3D, SBAS, Differential or RTK GNSS fix.

8.3.3 Odometer Input

This function is designed for wheel speed sensors and vehicle speed sensors. It expects a normally low input with a transition from low to high for the trigger. Please contact Advanced Navigation support for help integrating with your speed sensor.

Parameter	Value
Voltage Level	0 – 5V
Trigger	Low → High
Maximum Frequency	600 Khz
Maximum Pulse Rate	4,000,000 pulses/metre

Table 10: Odometer Specifications

8.3.4 Stationary Input

In this function, a high state indicates to Spatial that the vehicle is stationary. The low state indicates that the vehicle could be moving. This can significantly improve performance when a GNSS signal is not available.

8.3.5 Pitot Tube Input

This function is designed for fixed wing aircraft to enhance navigation through the use of a pitot tube to measure airspeed. It requires a differential pressure sensor that has a frequency output such as the Kavlico P992 (frequency output option) or the Paroscientific series 5300. Please contact Advanced Navigation support for help integrating with a pitot tube.

8.3.6 NMEA Input

This function accepts external data in the NMEA format. Advanced Navigation recommends against using NMEA where possible due to the inefficiency, inaccuracy and poor error checking of the format. All NMEA messages received must have a valid checksum. Supported messages are listed below.

Message ID	Description
GPGGA	3D position
GPGLL	2D position
GPRMC	2D position, 2D velocity and coarse time
GPVTG	2D velocity
GPHDT	Heading
HEHDT	Heading

Table 11: Supported NMEA messages

8.3.7 NMEA Output

This function outputs the NMEA messages GPGGA, GPRMC and GPHDT at 10 Hz. Advanced Navigation recommends against using NMEA where possible due to the inefficiency, inaccuracy and poor error checking of the format. An example output is shown below.

$GPGGA,072202.63,3159.8633,S,11548.1786,E,1,12,1.5,12.7,M,0.0,M,,*73

$GPRMC,072202.63,A,3159.8633,S,11548.1786,E,0.3,164.4,051212,1.7,E,A*2E

$GPHDT,164.4,T*32

8.3.8 Novatel GNSS Input

This function is designed for interfacing Spatial with a Novatel GNSS receiver. It can be used to interface with a Novatel RTK GNSS receiver for high positional accuracy. It accepts data in the Novatel binary format and requires messages BESTPOS and BESTVEL at rates higher than 1 Hz.

8.3.9 Topcon GNSS Input

This function is designed for interfacing Spatial with a Topcon GNSS receiver. It can be used to interface with a Topcon RTK GNSS receiver for high positional accuracy. It accepts data in the GRIL TPS binary format and expects messages PG and VG at rates higher than 1 Hz.

8.3.10 Motec Output

This function is designed to output Spatial's data to Motec motor sport logging units. Please contact Advanced Navigation support for information on this function.

8.3.11 ANPP Input

This function accepts data in the ANPP format as specified in section 9.

8.3.12 ANPP Output

This function outputs data in the ANPP format as specified in section 9. For packets to be sent out they must be requested through another GPIO functioning as ANPP input.

8.3.13 Disable Magnetometers

This function accepts a digital input with a low state enabling the magnetometers and a high state disabling the magnetometers.

8.3.14 Disable GNSS

This function accepts a digital input with a low state enabling the GNSS and a high state disabling the GNSS.

8.3.15 Disable Pressure

This function accepts a digital input with a low state enabling the atmospheric pressure sensor and a high state disabling the atmospheric pressure sensor.

8.3.16 Set Zero Orientation Alignment

This function accepts a digital input. The input is normally low and a transition from low to high causes Spatial to set it's alignment so that the current orientation is zero. Due to the risk of exhausting the flash cycles, the change is not permanent and will disappear on reset. To make it permanent the Installation Alignment Packet must be read and then sent back to Spatial with the permanent flag set. This function requires de-bouncing if attached to a switch.

8.3.17 System State Packet Trigger

This function accepts a digital input. The input is normally low and a transition from low to high causes Spatial to send the system state packet. This function requires de-bouncing if attached to a switch.

8.3.18 Raw Sensors Packet Trigger

This function accepts a digital input. The input is normally low and a transition from low to high causes Spatial to send the raw sensors packet. This function requires de-bouncing if attached to a switch.

8.3.19 RTCM Differential GNSS Corrections Input

This function accepts RTCM differential GPS corrections. This allows for Differential GNSS with Spatial's internal GNSS receiver to increase positional accuracy.

8.3.20 Trimble GNSS Input

This function is designed for interfacing Spatial with a Trimble GNSS receiver. It can be used to interface with a Trimble RTK receiver for high positional accuracy. It accepts data in the Trimble binary format and expects packet 0x57 with record type 29 (enhanced position) at rates higher than 1Hz.

8.3.21 u-blox GNSS Input

This function is designed for interfacing Spatial with a u-blox GNSS receiver. It accepts data in the u-blox binary format and expects message NAV-PVT or NAV-SOL at rates higher than 1Hz.

8.3.22 Hemisphere GNSS Input

This function is designed for interfacing Spatial with a Hemisphere GNSS receiver. It accepts data in the Hemisphere binary format and expects message Bin1 at rates higher than 1Hz. For Hemisphere receivers that provide heading using two antennas, NMEA should be used instead as the binary format does not allow for transmission of heading information.

8.3.23 Teledyne DVL Input

This function is designed for interfacing with Teledyne DVL systems. This allows Spatial to navigate underwater. It accepts data in the PD0 output data format at rates 10Hz or higher. Please see section 7.12 for more information on underwater navigation using Spatial.

8.3.24 Tritech USBL Input

This function is designed for interfacing with a Tritech micronnav USBL system. This allows Spatial to navigate underwater. It accepts data in the Raw XYZ format. Please note that the setup with a Tritech USBL requires two Spatial units. Please see section 7.12 for more information on underwater navigation using Spatial.

8.3.25 Linkquest DVL Input

This function is designed for interfacing with Linkquest DVL systems. This allows Spatial to navigate underwater. It accepts data in the NQ1 output data format at rates 1Hz or higher. Please see section 7.12 for more information on underwater navigation using Spatial.

8.3.26 Pressure Depth Transducer Input

This function is designed for interfacing with frequency output pressure depth transducers. It requires a pressure transducer with a frequency output such as the AST4700 from American Sensor Technologies. Please see section 7.12 for more information on underwater navigation using Spatial.

8.3.27 Left Wheel Speed Sensor

This function is designed for the left wheel of a vehicle with dual wheel speed sensors.

8.3.28 Right Wheel Speed Sensor

This function is designed for the right wheel of a vehicle with dual wheel speed sensors.

8.3.29 1PPS Input

This function is designed to allow external GNSS receivers to synchronise time with Spatial. It triggers on a transition from low to high.

9 Advanced Navigation Packet Protocol

The Advanced Navigation Packet Protocol (ANPP) is a binary protocol designed with high error checking, high efficiency and safe design practices. It has a well defined specification and is very flexible. It is used across all existing and future Advanced Navigation products.

9.1 Data Types

The following data types are used in the packet protocol. All data types in the protocol are little endian byte ordering.

Abbreviation	Bytes	Also known as
u8	1	unsigned char, unsigned byte, uint8_t
s8	1	char, byte, int8_t
u16	2	unsigned short, uint16_t
s16	2	short, int16_t
u32	4	unsigned int, unsigned long, uint32_t
s32	4	int, long, int32_t
u64	8	unsigned long long, uint64_t
s64	8	long long, int64_t
fp32	4	float
fp64	8	double

Table 12: Data type abbreviations used in the ANPP

9.2 Packet Structure

The ANPP packet structure is shown in Table 13 and the header format is shown in Table 14. Example code can be downloaded from the software section.

Header				
Header LRC	Packet ID	Packet Length	CRC16	Packet Data

Table 13: ANPP Packet Structure

ANPP Header Format				
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Header LRC, see section 9.2.1
2	1	u8	1	Packet ID, see section 9.2.2
3	2	u8	1	Packet Length, see section 9.2.3
4	3	u16	2	CRC16, see section 9.2.4

Table 14: ANPP header format

9.2.1 Header LRC

The header LRC (Longitudinal Redundancy Check) provides error checking on the packet header. It also allows the decoder to find the start of a packet by scanning for a valid LRC. The LRC can be found using the following:

LRC = ((packet_id + packet_length + crc[0] + crc[1])^0xFF) + 1

9.2.2 Packet ID

The packet ID is used to distinguish the contents of the packet. Packet IDs range from 0 to 255.

Within this range there are three different sub-ranges, these are system packets, state packets and configuration packets.

System packets have packet IDs in the range 0 to 19. These packets are implemented the same by every device using ANPP.

State packets are packets that contain data that changes with time, i.e. temperature. State packets can be set to output at a certain rate. State packets are packet IDs in the range 20 to 179.

Configuration packets are used for reading and writing device configuration. Configuration packets are packet IDs in the range 180 to 255.

9.2.3 Packet Length

The packet length denotes the length of the packet data, i.e. from byte index 5 onwards inclusive. Packet length has a range of 0 – 255.

9.2.4 CRC

The CRC is a CRC16-CCITT. The starting value is 0xFFFF. The CRC covers only the packet data.

9.3 Packet Requests

Any of the state and configuration packets can be requested at any time using the request packet. See section 9.7.2.

9.4 Packet Acknowledgement

When configuration packets are sent to Spatial, it will reply with an acknowledgement packet that indicates whether the configuration change was successful or not. For details on the acknowledgement packet, see section 9.7.1.

9.5 Packet Rates

The packet rates can be configured either using Spatial Manager or through the rate configuration packet, see section 9.9.3. By default Spatial is configured to output the System State Packet at 50Hz. When configuring packet rates it is essential to ensure the baud rate is capable of handling the data throughput. This can be calculated using the rate and packet size. The packet size is the packet length add five to account for the packet overhead. For example to output the system state packet at 50Hz the calculation would be:

Data throughput = (100 (packet length) + 5 (fixed packet overhead)) * 50 (rate)

Data throughput = 5250 bytes per second

Minimum baud rate = data throughput x 11 = 57750 Baud

Closest standard baud rate = 115200 Baud

When multiple packets are set to output at the same rate, the order the packets output is from lowest ID to highest ID.

9.6 Packet Summary

Packet ID	Length	R/W	Name
System Packets			
0	4	R	Acknowledge Packet
1	-	W	Request Packet
2	1	R/W	Boot Mode Packet
3	24	R	Device Information Packet
4	4	W	Restore Factory Settings Packet
5	4	W	Reset Packet
State Packets			
20	100	R	System State Packet
21	8	R	Unix Time Packet
22	14	R	Formatted Time Packet
23	4	R	Status Packet
24	12	R	Position Standard Deviation Packet
25	12	R	Velocity Standard Deviation Packet
26	12	R	Euler Orientation Standard Deviation Packet
27	16	R	Quaternion Orientation Standard Deviation Packet

Packet ID	Length	R/W	Name
28	48	R	Raw Sensors Packet
29	36	R	Raw GNSS Packet
30	13	R	Satellites Packet
31	-	R	Detailed Satellites Packet
32	24	R	Geodetic Position Packet
33	24	R	ECEF Position Packet
34	25	R	UTM Position Packet
35	12	R	NED Velocity Packet
36	12	R	Body Velocity Packet
37	12	R	Acceleration Packet
38	16	R	Body Acceleration Packet
39	12	R	Euler Orientation Packet
40	16	R	Quaternion Orientation Packet
41	36	R	DCM Orientation Packet
42	12	R	Angular Velocity Packet
43	12	R	Angular Acceleration Packet
44	60	R/W	External Position & Velocity Packet
45	36	R/W	External Position Packet
46	24	R/W	External Velocity Packet
47	16	R/W	External Body Velocity Packet
48	8	R/W	External Heading Packet
49	8	R	Running Time Packet
50	12	R	Local Magnetic Field Packet
51	20	R	Odometer State Packet
52	8	R/W	External Time Packet
53	8	R/W	External Depth Packet
54	4	R	Geoid Height Packet
55	-	W	RTCM Corrections Packet
56	8	R/W	External Pitot Pressure Packet
57	12	R	Wind Estimation Packet
58	16	R	Heave Packet
Configuration Packets			
180	4	R/W	Packet Timer Period Packet
181	-	R/W	Packets Period Packet

Packet ID	Length	R/W	Name
182	17	R/W	Baud Rates Packet
184	4	R/W	Sensor Ranges Packet
185	73	R/W	Installation Alignment Packet
186	17	R/W	Filter Options Packet
187	-	R/W	Advanced Filter Parameters Packet
188	13	R/W	GPIO Configuration Packet
189	49	R/W	Magnetic Calibration Values Packet
190	1	W	Magnetic Calibration Configuration Packet
191	3	R	Magnetic Calibration Status Packet
192	8	R/W	Odometer Configuration Packet
193	1	W	Set Zero Orientation Alignment Packet
194	49	R/W	Heave Offset Packet

9.7 System Packets

9.7.1 Acknowledge Packet

Acknowledgement Packet				
Packet ID				0
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Packet ID being acknowledged
2	1	u16	2	CRC of packet being acknowledged
3	3	u8	1	Acknowledge Result, see section 9.7.1.1

Table 15: Acknowledge packet

9.7.1.1 Acknowledge Result

Value	Description
0	Acknowledge Success
1	Acknowledge failure, CRC error
2	Acknowledge failure, packet size incorrect
3	Acknowledge failure, values outside of valid ranges
4	Acknowledge failure, system flash memory failure
5	Acknowledge failure, system not ready
6	Acknowledge failure, unknown packet

Table 16: Acknowledge result

9.7.2 Request Packet

Request Packet				
Packet ID				1
Length				1 x (number of packets requested)
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Packet ID requested
+				Field 1 repeats for additional packet requests

Table 17: Request packet

9.7.3 Boot Mode Packet

Boot Mode Packet				
Packet ID				2
Length				1
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Boot mode, see section 9.7.3.1

Table 18: Boot mode packet

9.7.3.1 Boot Mode Types

Value	Description
0	Bootloader
1	Main Program

Table 19: Boot mode types

9.7.4 Device Information Packet

Device Information Packet				
Packet ID				3
Length				24
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Software version
2	4	u32	4	Device ID
3	8	u32	4	Hardware revision
4	12	u32	4	Serial number part 1
5	16	u32	4	Serial number part 2
6	20	u32	4	Serial number part 3

Table 20: Device information packet

9.7.5 Restore Factory Settings Packet

Restore Factory Settings Packet				
Packet ID				4
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Verification Sequence (set to 0x85429E1C)

Table 21: Restore factory settings packet

9.7.6 Reset Packet

Reset Packet				
Packet ID				5
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Verification Sequence (set to 0x21057A7E)

Table 22: Reset packet

9.8 State Packets

Spatial supports a large number of packets providing extensive functionality. However for the majority of users the easiest approach is to configure Spatial using the Spatial Manager software and then support only the single system state packet shown below in section 9.8.1. Advanced functionality can be added through the other packets.

9.8.1 System State Packet

System State Packet				
Packet ID				20
Length				100
Field #	Bytes Offset	Data Type	Size	Description
1	0	u16	2	System status, see section 9.8.1.1
2	2	u16	2	Filter status, see section 9.8.1.2
3	4	u32	4	Unix time seconds, see section 9.8.1.3
4	8	u32	4	Microseconds, see section 9.8.1.4
5	12	fp64	8	Latitude (rad)
6	20	fp64	8	Longitude (rad)
7	28	fp64	8	Height (m)
8	36	fp32	4	Velocity north (m/s)
9	40	fp32	4	Velocity east (m/s)
10	44	fp32	4	Velocity down (m/s)
11	48	fp32	4	Body acceleration X (m/s/s)
12	52	fp32	4	Body acceleration Y (m/s/s)
13	56	fp32	4	Body acceleration Z (m/s/s)
14	60	fp32	4	G force (g)
15	64	fp32	4	Roll (radians)
16	68	fp32	4	Pitch (radians)
17	72	fp32	4	Heading (radians)
18	76	fp32	4	Angular velocity X (rad/s)
19	80	fp32	4	Angular velocity Y (rad/s)
20	84	fp32	4	Angular velocity Z (rad/s)
21	88	fp32	4	Latitude standard deviation (m)
22	92	fp32	4	Longitude standard deviation (m)
23	96	fp32	4	Height standard deviation (m)

Table 23: System state packet

9.8.1.1 System Status

This field contains 16 bits that indicate problems with the system. These are boolean fields with a zero indicating false and one indicating true.

Bit	Description
0	System Failure
1	Accelerometer Sensor Failure
2	Gyroscope Sensor Failure
3	Magnetometer Sensor Failure
4	Pressure Sensor Failure
5	GNSS Failure
6	Accelerometer Over Range
7	Gyroscope Over Range
8	Magnetometer Over Range
9	Pressure Over Range
10	Minimum Temperature Alarm
11	Maximum Temperature Alarm
12	Low Voltage Alarm
13	High Voltage Alarm
14	GNSS Antenna Disconnected
15	Data Output Overflow Alarm

Table 24: System status

9.8.1.2 Filter Status

This field contains 16 bits that indicate the status of the filters. These are boolean fields with a zero indicating false and one indicating true.

Bit	Description
0	Orientation Filter Initialised
1	Navigation Filter Initialised
2	Heading Initialised
3	UTC Time Initialised
4	GNSS 2D Fix
5	GNSS 3D Fix
6	GNSS SBAS Fix
7	GNSS Differential Fix
8	GNSS RTK Fix
9	Internal GNSS Enabled
10	Magnetometers Enabled
11	Velocity Heading Enabled
12	Atmospheric Altitude Enabled
13	External Position Active
14	External Velocity Active
15	External Heading Active

Table 25: Filter Status

9.8.1.3 Unix Time Seconds

This field provides UTC time in seconds since January 1, 1970, not counting leap seconds.

9.8.1.4 Microseconds

This field provides the sub-second component of time. It is represented as microseconds since the last second. Minimum value is 0 and maximum value is 999999.

9.8.2 Unix Time Packet

Unix Time Packet				
Packet ID				21
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Unix time seconds, see section 9.8.1.3
2	4	u32	4	Microseconds, see section 9.8.1.4

Table 26: Unix time packet

9.8.3 Formatted Time Packet

Formatted Time Packet				
Packet ID				22
Length				14
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Microseconds
2	4	u16	2	Year
3	6	u16	2	Year day, 0 - 365
4	8	u8	1	Month, 0 - 11
5	9	u8	1	Month Day, 1 - 31
6	10	u8	1	Week Day, 0 - 6
7	11	u8	1	Hour, 0 - 23
8	12	u8	1	Minute, 0 - 59
9	13	u8	1	Second, 0 - 59

Table 27: Formatted time packet

9.8.4 Status Packet

Status Packet				
Packet ID				23
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u16	2	System status, see section 9.8.1.1
2	2	u16	2	Filter status, see section 9.8.1.2

Table 28: Status packet

9.8.5 Position Standard Deviation Packet

Position Standard Deviation Packet				
Packet ID				24
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Latitude standard deviation (m)
2	4	fp32	4	Longitude standard deviation (m)
3	8	fp32	4	Height standard deviation (m)

Table 29: Position standard deviation packet

9.8.6 Velocity Standard Deviation Packet

Velocity Standard Deviation Packet				
Packet ID				25
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Velocity north standard deviation (m/s)
2	4	fp32	4	Velocity east standard deviation (m/s)
3	8	fp32	4	Velocity down standard deviation (m/s)

Table 30: Velocity standard deviation packet

9.8.7 Euler Orientation Standard Deviation Packet

Euler Orientation Standard Deviation Packet				
Packet ID				26
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Roll standard deviation (rad)
2	4	fp32	4	Pitch standard deviation(rad)
3	8	fp32	4	Heading standard deviation(rad)

Table 31: Euler orientation standard deviation packet

9.8.8 Quaternion Orientation Standard Deviation Packet

Quaternion Orientation Standard Deviation Packet				
Packet ID				27
Length				16
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Q0 standard deviation
2	4	fp32	4	Q1 standard deviation
3	8	fp32	4	Q2 standard deviation
4	12	fp32	4	Q3 standard deviation

Table 32: Quaternion orientation standard deviation packet

9.8.9 Raw Sensors Packet

Raw Sensors Packet				
Packet ID				28
Length				48
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Accelerometer X (m/s/s)
2	4	fp32	4	Accelerometer Y (m/s/s)
3	8	fp32	4	Accelerometer Z (m/s/s)
4	12	fp32	4	Gyroscope X (rad/s)
5	16	fp32	4	Gyroscope Y (rad/s)
6	20	fp32	4	Gyroscope Z (rad/s)
7	24	fp32	4	Magnetometer X (mG)
8	28	fp32	4	Magnetometer Y (mG)
9	32	fp32	4	Magnetometer Z (mG)
10	36	fp32	4	IMU Temperature (deg C)
11	40	fp32	4	Pressure (Pascals)
12	44	fp32	4	Pressure Temperature (deg C)

Table 33: Raw sensors packet

9.8.10 Raw GNSS Packet

Raw GNSS Packet				
Packet ID				29
Length				36
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	Latitude (rad)
2	8	fp64	8	Longitude (rad)
3	16	fp64	8	Height (m)
4	24	fp32	4	Velocity north (m)
5	28	fp32	4	Velocity east (m)
6	32	fp32	4	Velocity down (m)

Table 34: Raw GNSS packet

9.8.11 Satellites Packet

Satellites Packet				
Packet ID				30
Length				13
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	HDOP
2	4	fp32	4	VDOP
3	8	u8	1	GPS satellites
4	9	u8	1	GLONASS satellites
5	10	u8	1	COMPASS satellites
6	11	u8	1	GALILEO satellites
7	12	u8	1	SBAS satellites

Table 35: Satellites packet

9.8.12 Detailed Satellites Packet

Detailed Satellites Packet				
Packet ID				31
Length				7 x number of satellites
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Navigation system, see section 9.8.12.1
2	1	u8	1	Satellite number
3	2	s8	1	Satellite frequencies, see section 9.8.12.2
4	3	u8	1	Elevation (deg)
5	4	u16	2	Azimuth (deg)
6	6	u8	1	SNR
+				Fields 1-6 repeat for additional satellites

Table 36: Detailed satellites packet

9.8.12.1 Navigation System

Value	System
1	GPS
2	GLONASS
5	GALILEO
6	COMPASS
4	SBAS

Table 37: Navigation systems

9.8.12.2 Satellite Frequencies

Bit	Description
1	L1 C/A
2	L1 C
3	L1 P
4	L1 M
5	L2 C
6	L2 P
7	L2 M
8	L5

Table 38: Satellite frequencies

9.8.13 Geodetic Position Packet

Geodetic Position Packet				
Packet ID				32
Length				24
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	Latitude (rad)
2	8	fp64	8	Longitude (rad)
3	16	fp64	8	Height (m)

Table 39: Geodetic position packet

9.8.14 ECEF Position Packet

ECEF Position Packet				
Packet ID				33
Length				24
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	ECEF X (m)
2	8	fp64	8	ECEF Y (m)
3	16	fp64	8	ECEF Z (m)

Table 40: ECEF position packet

9.8.15 UTM Position Packet

UTM Position Packet				
Packet ID				34
Length				25
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	Northing (m)
2	8	fp64	8	Easting (m)
3	16	fp64	8	Height (m)
4	24	s8	1	Zone character

Table 41: UTM position packet

9.8.16 NED Velocity Packet

NED Velocity Packet				
Packet ID				35
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Velocity north (m/s)
2	4	fp32	4	Velocity east (m/s)
3	8	fp32	4	Velocity down (m/s)

Table 42: NED velocity packet

9.8.17 Body Velocity Packet

Body Velocity Packet				
Packet ID				36
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Velocity X (m/s)
2	4	fp32	4	Velocity Y (m/s)
3	8	fp32	4	Velocity Z (m/s)

Table 43: Body velocity packet

9.8.18 Acceleration Packet

Acceleration Packet				
Packet ID				37
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Acceleration X (m/s/s)
2	4	fp32	4	Acceleration Y (m/s/s)
3	8	fp32	4	Acceleration Z (m/s/s)

Table 44: Acceleration packet

9.8.19 Body Acceleration Packet

Body Acceleration Packet				
Packet ID				38
Length				16
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Body acceleration X (m/s/s)
2	4	fp32	4	Body acceleration Y (m/s/s)
3	8	fp32	4	Body acceleration Z (m/s/s)
4	12	fp32	4	G force (g)

Table 45: Body acceleration packet

9.8.20 Euler Orientation Packet

Euler Orientation Packet				
Packet ID				39
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Roll (rad)
2	4	fp32	4	Pitch (rad)
3	8	fp32	4	Heading (rad)

Table 46: Euler orientation packet

9.8.21 Quaternion Orientation Packet

Quaternion Orientation Packet				
Packet ID				40
Length				16
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Q0
2	4	fp32	4	Q1
3	8	fp32	4	Q2
4	12	fp32	4	Q3

Table 47: Quaternion orientation packet

9.8.22 DCM Orientation Packet

DCM Orientation Packet				
Packet ID				41
Length				36
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	DCM[0][0]
2	4	fp32	4	DCM[0][1]
3	8	fp32	4	DCM[0][2]
4	12	fp32	4	DCM[1][0]
5	16	fp32	4	DCM[1][1]
6	20	fp32	4	DCM[1][2]
7	24	fp32	4	DCM[2][0]
8	28	fp32	4	DCM[2][1]
9	32	fp32	4	DCM[2][2]

Table 48: DCM orientation packet

9.8.23 Angular Velocity Packet

Angular Velocity Packet				
Packet ID				42
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Angular velocity X (rad/s)
2	4	fp32	4	Angular velocity Y (rad/s)
3	8	fp32	4	Angular velocity Z (rad/s)

Table 49: Angular velocity packet

9.8.24 Angular Acceleration Packet

Angular Acceleration Packet				
Packet ID				43
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Angular acceleration X (rad/s/s)
2	4	fp32	4	Angular acceleration Y (rad/s/s)
3	8	fp32	4	Angular acceleration Z (rad/s/s)

Table 50: Angular acceleration packet

9.8.25 External Position & Velocity Packet

External Position & Velocity Packet				
Packet ID				44
Length				60
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	Latitude (rad)
2	8	fp64	8	Longitude (rad)
3	16	fp64	8	Height (m)
4	24	fp32	4	Velocity north (m/s)
5	28	fp32	4	Velocity east (m/s)
6	32	fp32	4	Velocity down (m/s)
7	36	fp32	4	Latitude standard deviation (m)
8	40	fp32	4	Longitude standard deviation (m)
9	44	fp32	4	Height standard deviation (m)
10	48	fp32	4	Velocity north standard deviation (m/s)
11	52	fp32	4	Velocity east standard deviation (m/s)
12	56	fp32	4	Velocity down standard deviation (m/s)

Table 51: External position & velocity packet

9.8.26 External Position Packet

External Position Packet				
Packet ID				45
Length				36
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp64	8	Latitude (rad)
2	8	fp64	8	Longitude (rad)
3	16	fp64	8	Height (m)
4	24	fp32	4	Latitude standard deviation (m)
5	28	fp32	4	Longitude standard deviation (m)
6	32	fp32	4	Height standard deviation (m)

Table 52: External position packet

9.8.27 External Velocity Packet

External Velocity Packet				
Packet ID				46
Length				24
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Velocity north (m/s)
2	4	fp32	4	Velocity east (m/s)
3	8	fp32	4	Velocity down (m/s)
4	12	fp32	4	Velocity north standard deviation (m/s)
5	16	fp32	4	Velocity east standard deviation (m/s)
6	20	fp32	4	Velocity down standard deviation (m/s)

Table 53: External velocity packet

9.8.28 External Body Velocity Packet

External Body Velocity Packet				
Packet ID				47
Length				16
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Velocity X (m/s)
2	4	fp32	4	Velocity Y (m/s)
3	8	fp32	4	Velocity Z (m/s)
4	12	fp32	4	Velocity standard deviation (m/s)

Table 54: External body velocity packet

9.8.29 External Heading Packet

External Heading Packet				
Packet ID				48
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Heading (rad)
2	4	fp32	4	Heading standard deviation (rad)

Table 55: External heading packet

9.8.30 Running Time Packet

Running Time Packet				
Packet ID				49
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Running time seconds
2	4	u32	4	Microseconds

Table 56: Running time packet

9.8.31 Local Magnetic Field Packet

Local Magnetic Field Packet				
Packet ID				50
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Local magnetic field X (mG)
2	4	fp32	4	Local magnetic field Y (mG)
3	4	fp32	4	Local magnetic field Z (mG)

Table 57: Local magnetic field packet

9.8.32 Odometer State Packet

Odometer State Packet				
Packet ID				51
Length				20
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Odometer pulse count
2	4	fp32	4	Odometer distance (m)
3	8	fp32	4	Odometer speed (m/s)
4	12	fp32	4	Odometer slip (m)
5	16	u8	1	Odometer active
6	17		3	Reserved

Table 58: Odometer state packet

9.8.33 External Time Packet

External Time Packet				
Packet ID				52
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	u32	4	Unix time seconds, see section 9.8.1.3
2	4	u32	4	Microseconds, see section 9.8.1.4

Table 59: External time packet

9.8.34 External Depth Packet

External Depth Packet				
Packet ID				53
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Depth (m)
2	4	fp32	4	Depth standard deviation (m)

Table 60: External depth packet

9.8.35 Geoid Height Packet

This packet provides the offset between the WGS84 ellipsoid and the EGM96 geoid model at the current location. This can be used to determine mean sea level height and also depth through the following equations:

Mean Sea Level Height = Height – Geoid Height

Depth = Geoid Height – Height

Geoid Height Packet				
Packet ID				54
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Geoid Height (m)

Table 61: Geoid height packet

9.8.36 RTCM Corrections Packet

This packet is used to encapsulate RTCM SC-104 differential correction data to be sent to Spatial's internal GNSS receiver for differential GNSS functionality.

RTCM Corrections Packet				
Packet ID				55
Length				Variable, up to 255 bytes
Field #	Bytes Offset	Data Type	Size	Description
1	0			RTCM corrections data

Table 62: RTCM corrections packet

9.8.37 External Pitot Pressure Packet

This packet is used to interface a pitot tube to Spatial for enhanced navigation using aircraft airspeed. The packet should contain differential pressure in pascals. If outside air temperature is available it should be set in the message for increased accuracy, otherwise this field should be set to 15 degrees.

External Pitot Pressure Packet				
Packet ID				56
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Differential pressure (pascals)
2	4	fp32	4	Outside air temperature (deg C)

Table 63: External pitot pressure packet

9.8.38 Wind Estimation Packet

This packet provides Spatial's current estimate of 3D wind velocity. These values are only valid when a pitot tube is interfaced to Spatial.

Wind Estimation Packet				
Packet ID				57
Length				12
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Wind velocity north
2	4	fp32	4	Wind velocity east
3	8	fp32	4	Wind velocity down

Table 64: Wind estimation packet

9.8.39 Heave Packet

Heave Packet				
Packet ID				58
Length				16
Field #	Bytes Offset	Data Type	Size	Description
1	0	fp32	4	Heave point 1 (m)
2	4	fp32	4	Heave point 2 (m)
3	8	fp32	4	Heave point 3 (m)
4	12	fp32	4	Heave point 4 (m)

Table 65: Heave packet

9.9 Configuration Packets

Configuration packets can be both read from and written to the device. On many of the configuration packets the first byte is a permanent flag. A zero in this field indicates that the settings will be lost on reset, a one indicates that they will be permanent.

9.9.1 Packet Timer Period Packet

Packet Timer Period Packet				
Packet ID				180
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	UTC synchronisation, see section 9.9.1.1
3	2	u16	2	Packet timer period, see section 9.9.1.2

Table 66: Packet timer period packet

9.9.1.1 UTC Synchronisation

This is a boolean value that determines whether or not the packet timer is synchronised with UTC time, with zero for disabled and one for enabled. For UTC Synchronisation to be enabled the packet timer period must multiply into 1000000 evenly. For example if the packet timer period is 10000 (10 ms), 1000000/10000 = 100 which is valid for UTC synchronisation. If the packet timer period is 15000 (15 ms), 1000000/15000 = 66.6666 which is not valid for UTC synchronisation. To get the rate use the following.

Packet Timer Rate = 1000000/(Packet Timer Period) Hz

9.9.1.2 Packet timer period

This is a value in microseconds that sets the master packet timer period. The minimum value is 1000 (1 ms) or 1000 Hz and the maximum value is 65535 (65.535 ms) or 15.30 Hz.

9.9.2 Packets Period Packet

Packets Period Packet				
Packet ID				181
Length				2 + (5 x number of packet periods)
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	Clear existing packet periods, see section 9.9.2.1
3	2	u8	1	Packet ID
4	3	u32	4	Packet period, see section 9.9.2.2
+				Fields 3-4 repeat for additional packet periods

Table 67: Packets period packet

9.9.2.1 Clear Existing Packets

This is a boolean field, when set to one it deletes any existing packet rates. When set to zero existing packet rates remain. Only one packet rate can exist per packet ID, so new packet rates will overwrite existing packet rates for the same packet ID.

9.9.2.2 Packet Period

This indicates the period in units of the packet timer period. The packet rate can be calculated as follows.

Packet Rate = 1000000/(Packet Period x Packet Timer Period) Hz

For example if the packet timer period is set to 1000 (1 ms). Setting packet ID 20 with a packet period of 50 will give the following.

Packet 20 Rate = 1000000/(50 x 1000)

Packet 20 Rate = 20 Hz

9.9.3 Baud Rates Packet

Baud Rates Packet				
Packet ID				182
Length				17
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u32	4	Primary serial port baud rate (1200 to 1000000)
3	5	u32	4	GPIO 1 & 2 baud rate (1200 to 1000000)
4	9	u32	4	GPIO 3 & 4 baud rate (1200 to 1000000)
5	13	u32	4	Reserved (set to zero)

Table 68: Baud rates packet

9.9.4 Sensor Ranges Packet

Sensor Ranges Packet				
Packet ID				184
Length				4
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	Accelerometers range, see section 9.9.4.1
3	2	u8	1	Gyroscopes range, see section 9.9.4.2
4	3	u8	1	Magnetometers range, see section 9.9.4.3

Table 69: Sensor ranges packet

9.9.4.1 Accelerometers Range

Value	Description
0	2 g (19.62 m/s/s)
1	4 g (39.24 m/s/s)
2	16 g (156.96 m/s/s)

Table 70: Accelerometers range

9.9.4.2 Gyroscopes Range

Value	Description
0	250 degrees/second
1	500 degrees/second
2	2000 degrees/second

Table 71: Gyroscopes range

9.9.4.3 Magnetometers Range

Value	Description
0	2 Gauss
1	4 Gauss
2	8 Gauss

Table 72: Magnetometers range

9.9.5 Installation Alignment Packet

Installation Alignment Packet				
Packet ID				185
Length				73
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	fp32	4	Alignment DCM[0][0]
3	5	fp32	4	Alignment DCM[0][1]
4	9	fp32	4	Alignment DCM[0][2]
5	13	fp32	4	Alignment DCM[1][0]
6	17	fp32	4	Alignment DCM[1][1]
7	21	fp32	4	Alignment DCM[1][2]
8	25	fp32	4	Alignment DCM[2][0]
9	29	fp32	4	Alignment DCM[2][1]
10	33	fp32	4	Alignment DCM[2][2]
11	37	fp32	4	GNSS antenna offset X (m)
12	41	fp32	4	GNSS antenna offset Y (m)
13	45	fp32	4	GNSS antenna offset Z (m)
14	49	fp32	4	Odometer offset X (m)
15	53	fp32	4	Odometer offset Y (m)
16	57	fp32	4	Odometer offset Z (m)
17	61	fp32	4	External data offset X (m)
18	65	fp32	4	External data offset Y (m)
19	69	fp32	4	External data offset Z (m)

Table 73: Installation alignment packet

9.9.5.1 Alignment DCM

The alignment DCM (direction cosine matrix) is used to represent an alignment offset of Spatial from it's standard alignment. A DCM is used rather than euler angles for accuracy reasons. To convert euler angles to DCM please use the formula below with angles in radians.

DCM[0][0] = cos(heading) * cos(pitch)

DCM[0][1] = sin(heading) * cos(pitch)

DCM[0][2] = -sin(pitch)

DCM[1][0] = -sin(heading) * cos(roll) + cos(heading) * sin(pitch) * sin(roll)

DCM[1][1] = cos(heading) * cos(roll) + sin(heading) * sin(pitch) * sin(roll)

DCM[1][2] = cos(pitch) * sin(roll)

DCM[2][0] = sin(heading) * sin(roll) + cos(heading) * sin(pitch) * cos(roll)

DCM[2][1] = -cos(heading) * sin(roll) + sin(heading) * sin(pitch) * cos(roll)

DCM[2][2] = cos(pitch) * cos(roll)

9.9.6 Filter Options Packet

Filter Options Packet				
Packet ID				186
Length				17
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	Vehicle type, see section 9.9.6.1
3	2	u8	1	Internal GNSS enabled (boolean)
4	3	u8	1	Magnetometers enabled (boolean)
5	4	u8	1	Atmospheric altitude enabled (boolean)
6	5	u8	1	Velocity heading enabled (boolean)
7	6	u8	1	Reserved (set to zero)
8	7	u8	1	Reserved (set to zero)
9	8	u8	1	Reserved (set to zero)
10	9	u8	1	Reserved (set to zero)
11	10	u8	1	Reserved (set to zero)
12	11	u8	1	Reserved (set to zero)
13	12	u8	1	Reserved (set to zero)
14	13	u8	1	Reserved (set to zero)
15	14	u8	1	Reserved (set to zero)
16	15	u8	1	Reserved (set to zero)
17	16	u8	1	Reserved (set to zero)

Table 74: Filter options packet

9.9.6.1 Vehicle Types

Value	Description
0	Unconstrained
1	Bicycle or Motorcycle
2	Car
3	Hovercraft
4	Submarine
5	3D Underwater Vehicle
6	Fixed Wing Plane
7	3D Aircraft
8	Human

Table 75: Vehicle types

9.9.7 Advanced Filter Parameters Packet

Please contact Advanced Navigation support.

9.9.8 GPIO Configuration Packet

GPIO Configuration Packet				
Packet ID				188
Length				13
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	GPIO1 Function, see section 9.9.8.1
3	2	u8	1	GPIO2 Function, see section 9.9.8.2
4	3	u8	1	GPIO3 Function, see section 9.9.8.3
5	4	u8	1	GPIO4 Function, see section 9.9.8.4
6	5		8	Reserved

Table 76: GPIO configuration packet

9.9.8.1 GPIO1 Functions

Value	Description
0	Inactive
1	1PPS Output
2	GNSS Fix Output
3	Odometer Input
4	Stationary Input
5	Pitot Tube Input
7	NMEA Output
10	Motec Output
12	ANPP Output
13	Disable Magnetometers
14	Disable GNSS
15	Disable Pressure
16	Set Zero Orientation Alignment
17	System State Packet Trigger
18	Raw Sensors Packet Trigger
26	Pressure Depth Transducer Input
27	Left Wheel Speed Sensor
28	Right Wheel Speed Sensor
29	1PPS Input

Table 77: GPIO1 functions

9.9.8.2 GPIO2 Functions

Value	Description
0	Inactive
1	1PPS Output
2	GNSS Fix Output
3	Odometer Input
4	Stationary Input
5	Pitot Tube Input
6	NMEA Input
8	Novatel GNSS Input
9	Topcon GNSS Input
11	ANPP Input
13	Disable Magnetometers
14	Disable GNSS
15	Disable Pressure
16	Set Zero Orientation Alignment
17	System State Packet Trigger
18	Raw Sensors Packet Trigger
19	RTCM Differential GNSS Corrections Input
20	Trimble GNSS Input
21	u-blox GNSS Input
22	Hemisphere GNSS Input
23	Teledyne DVL Input
24	Tritech USBL Input
25	Linkquest DVL Input
26	Pressure Depth Transducer Input
27	Left Wheel Speed Sensor
28	Right Wheel Speed Sensor
29	1PPS Input

Table 78: GPIO2 functions

9.9.8.3 GPIO3 Functions

Value	Description
0	Inactive
1	1PPS Output
2	GNSS Fix Output
3	Odometer Input
4	Stationary Input
5	Pitot Tube Input
7	NMEA Output
10	Motec Output
12	ANPP Output
13	Disable Magnetometers
14	Disable GNSS
15	Disable Pressure
16	Set Zero Orientation Alignment
17	System State Packet Trigger
18	Raw Sensors Packet Trigger
26	Pressure Depth Transducer Input
27	Left Wheel Speed Sensor
28	Right Wheel Speed Sensor
29	1PPS Input

Table 79: GPIO3 functions

9.9.8.4 GPIO4 Functions

Value	Description
0	Inactive
1	1PPS Output
2	GNSS Fix Output
3	Odometer Input
4	Stationary Input
5	Pitot Tube Input
6	NMEA Input
8	Novatel GNSS Input
9	Topcon GNSS Input
11	ANPP Input
13	Disable Magnetometers
14	Disable GNSS
15	Disable Pressure
16	Set Zero Orientation Alignment
17	System State Packet Trigger
18	Raw Sensors Packet Trigger
19	RTCM Differential GNSS Corrections Input
20	Trimble GNSS Input
21	u-blox GNSS Input
22	Hemisphere GNSS Input
23	Teledyne DVL Input
24	Tritech USBL Input
25	Linkquest DVL Input
26	Pressure Depth Transducer Input
27	Left Wheel Speed Sensor
28	Right Wheel Speed Sensor
29	1PPS Input

Table 80: GPIO4 functions

9.9.9 Magnetic Calibration Values Packet

Magnetic Calibration Values Packet				
Packet ID				189
Length				49
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	fp32	4	Hard iron bias X
3	5	fp32	4	Hard iron bias Y
4	9	fp32	4	Hard iron bias Z
5	13	fp32	4	Soft iron transformation XX
6	17	fp32	4	Soft iron transformation XY
7	21	fp32	4	Soft iron transformation XZ
8	25	fp32	4	Soft iron transformation YX
9	29	fp32	4	Soft iron transformation YY
10	33	fp32	4	Soft iron transformation YZ
11	37	fp32	4	Soft iron transformation ZX
12	41	fp32	4	Soft iron transformation ZY
13	45	fp32	4	Soft iron transformation ZZ

Table 81: Magnetic calibration values packet

9.9.10 Magnetic Calibration Configuration Packet

Magnetic Calibration Configuration Packet				
Packet ID				190
Length				1
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Magnetic calibration action, see section 9.9.10.1

Table 82: Magnetic calibration configuration packet

9.9.10.1 Magnetic calibration Actions

Value	Description
0	Cancel magnetic calibration
1	Stabilise heading
2	Start 2D magnetic calibration
3	Start 3D magnetic calibration

Table 83: Magnetic calibration action

9.9.11 Magnetic Calibration Status Packet

Magnetic Calibration Status Packet				
Packet ID				191
Length				3
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Magnetic calibration status, see section 9.9.11.1
2	1	u8	1	Magnetic calibration progress (%)
3	2	u8	1	Local magnetic error (%)

Table 84: Magnetic calibration status packet

9.9.11.1 Magnetic Calibration Status

Value	Description
0	Magnetic calibration not completed
1	2D magnetic calibration completed
2	3D magnetic calibration completed
3	Custom values magnetic calibration completed
4	Stabilising in progress
5	2D calibration in progress
6	3D calibration in progress
7	2D calibration error: excessive roll
8	2D calibration error: excessive pitch
9	Calibration error: sensor over range event
10	Calibration error: time-out
11	3D calibration error: not enough points

Table 85: Magnetic calibration status

9.9.12 Odometer Configuration Packet

Odometer Configuration Packet				
Packet ID				192
Length				8
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	u8	1	Automatic pulse measurement active
3	2	u8	1	Reserved (set to zero)
4	3	u8	1	Reserved (set to zero)
5	4	fp32	4	Pulse length (m)

Table 86: Odometer configuration packet

9.9.13 Set Zero Orientation Alignment Packet

Set Zero Orientation Alignment Packet				
Packet ID				193
Length				1
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent

Table 87: Set zero orientation alignment packet

9.9.14 Heave Offset Packet

Heave Offset Packet				
Packet ID				194
Length				49
Field #	Bytes Offset	Data Type	Size	Description
1	0	u8	1	Permanent
2	1	fp32	4	Heave point 1 offset X (m)
3	5	fp32	4	Heave point 1 offset Y (m)
4	9	fp32	4	Heave point 1 offset Z (m)
5	13	fp32	4	Heave point 2 offset X (m)
6	17	fp32	4	Heave point 2 offset Y (m)
7	21	fp32	4	Heave point 2 offset Z (m)
8	25	fp32	4	Heave point 3 offset X (m)
9	29	fp32	4	Heave point 3 offset Y (m)
10	33	fp32	4	Heave point 3 offset Z (m)
11	37	fp32	4	Heave point 4 offset X (m)
12	41	fp32	4	Heave point 4 offset Y (m)
13	45	fp32	4	Heave point 4 offset Z (m)

Table 88: Heave offset packet