Hardware Manual

xNAV650

20 Years Navigation Experience in one small INS

Measure with confidence OXTS

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Introduction

Thank you for choosing the xNAV650 inertial navigation system (INS). The xNAV650 combines dual GNSS receivers and a multi-core tactical-grade IMU into one self-contained package. This document covers the technical information and hardware design instructions for the xNAV650 module to enable you to successfully integrate it into your system.

The xNAV650 is OxTS' newest Inertial Navigation System using the latest technology we have developed in our smallest form factor yet. The intended use of the product is to deliver high quality navigation data and diagnostics to the specification detailed within this manual and on the xNAV650 datasheet for a wide range of applications and vehicles. The unit can be used in land vehicles or on drones, for example for LiDAR or camera surveying.

Related documents

This manual covers the installation and operation of the xNAV650, but it is beyond its scope to provide details on service or repair. Please contact OxTS support or your local representative for customer service-related enquiries.

Additional manuals provide further information on some of the software and communication types mentioned in this manual. Table 1 lists related manuals and where to find them.

The xNAV650 Quick Start Guide is another useful tool for using your INS system.

Table 1: Supplementary manuals

Manual	Description
OxTS Georeferencer	Use OxTS Georeferencer to calibrate your setup and create pointclouds. https://support.oxts.com/hc/en-us/articles/360016436060
NAVconfig	Use NAVconfig to configure the settings on your INS and to tell it what the physical and hardware setup is that you are using. https://support.oxts.com/hc/en-us/articles/360018688799
NAVsolve	Use NAVsolve to process your raw data into NCOM navigation data. https://support.oxts.com/hc/en-us/articles/360000225449-NAVsolve-manual
NAVgraph	Use NAVgraph to display your navigation data and diagnostics after processing. https://support.oxts.com/hc/en-us/articles/115002433465-NAVgraph-Online-manual
NAVdisplay	Use NAVdisplay to view your navigation data in real time. https://support.oxts.com/hc/en-us/articles/115002433285-NAVdisplay-Online-manual
NCOM Manual	Use this manual for decoding and using the NCOM format. https://support.oxts.com/hc/en-us/articles/360011890040-NCOM-Manual
NCOM C Code Drivers	A collection of C functions that can be used to decode the binary protocols from the INS. https://github.com/OxfordTechnicalSolutions/NCOMdecoder
NMEA 0183 Description	NMEA description manual for the NMEA outputs. https://support.oxts.com/hc/en-us/articles/360011890180-NMEA-Manual

Scope of delivery

The xNAV650 is supplied with the items listed below in the basic kit. Other items such as antennas and antenna cables are provided separately.

Table 2: xNAV650 scope of delivery

Item	xNAV650 basic kit
xNAV650 inertial navigation system	✔
Software USB	✔
Quick start guide	✔
Ethernet cable (2 m)	✔
Ethernet cross-coupler	✔
Declaration of conformity	✔

Conformance notices

The xNAV650 complies with the radiated emission limits for 47 CFR 15.109:2010 class A of part 15 subpart B of the FCC rules, and with the emission and immunity limits for class A of EN 55022. These limits are designed to provide reasonable protection against harmful interference in business, commercial and industrial uses. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or both of the following methods:

- Re-orient or relocate the receiving antenna.
- Increase the separation between the equipment and the receiver.

The xNAV650 incorporates GNSS receivers. No GNSS receiver will be able to track satellites in the presence of strong RF radiations within 70 MHz of either the L1 GPS frequency (1575 MHz) or L2 (1228 MHz).

The xNAV650 conforms to the requirements for CE.

The xNAV650 is certified for use with GNSS antennae with a gain of less than or equal to 35 dB.

Regulator testing standards

EMC

- BS EN 61326-2-1:2013 - Electrical equipment for measurement, control and laboratory use.
- BS EN 301 489-19 v2.1.1 (2019-04) – Electro Magnetic Compatibility (EMC) standard for radio equipment and services; Part 19: Specific conditions for Receive Only Mobile Earth Stations (ROMES) operating in the 1,5 GHz band providing data communications and GNSS receivers operating in the RNSS band (ROGNSS) providing positioning, navigation, and timing data.

LVD

- BS EN 61010-1:2010 - Safety requirements for electrical equipment for measurement, control, and laboratory use.

RED

- BS EN 303 413 V1.1.1 (2017-06) - Global Navigation Satellite System (GNSS) receivers. Radio equipment operating in the 1 164 MHz to 1 300 MHz and 1 559 MHz to 1 610 MHz frequency bands.

RoHS

- BS EN 50581:2012 – Technical documentation for the assessment of electrical and electronics products with respect to the restriction of hazardous substances.

FCC

- 47 CFR 15.109 – Code of Federal Regulations – Title 47 (Telecommunication): Part 15 (Radio Frequency Devices) – Subpart B (Unintentional Radiators) – Section 15.109.
- ICES-003 Issue 6 January 2016 – Information Technology Equipment (Including Digital Apparatus) – Limits and Methods of Measurement.

Hardware description

Overview

The xNAV650 is a miniature GNSS-aided inertial navigation system. It combines dual multi-constellation, multi-frequency xNAV GNSS receivers with a tactical-grade quad IMU array to provide a compact centimetre-level navigation solution. Additionally, the system includes 32 GB data storage and an on-board processor running the real-time strapdown navigator and Kalman filter.

The dual receiver integration allows greater heading accuracy with wider antenna baselines and ensures stable heading performance even when stationary and during low dynamics. The custom built quad IMU array consists of four individual IMU sensors that each combine 6-axis MEMS gyros and accelerometers, providing improved performance, noise reduction and redundancy. The sensor fusion between the GNSS receivers and inertial sensors is done seamlessly in real time for a continuous 100 Hz navigation output. Data is automatically logged to the 32 GB eMMC for added data protection.

The user must perform visual inspection of equipment before use to ensure there is no damage.

Figure 1 and Figure 2 show the key points of note on the xNAV650. The numbered labels are described in Table 3.

Figure 1: xNAV650 front view

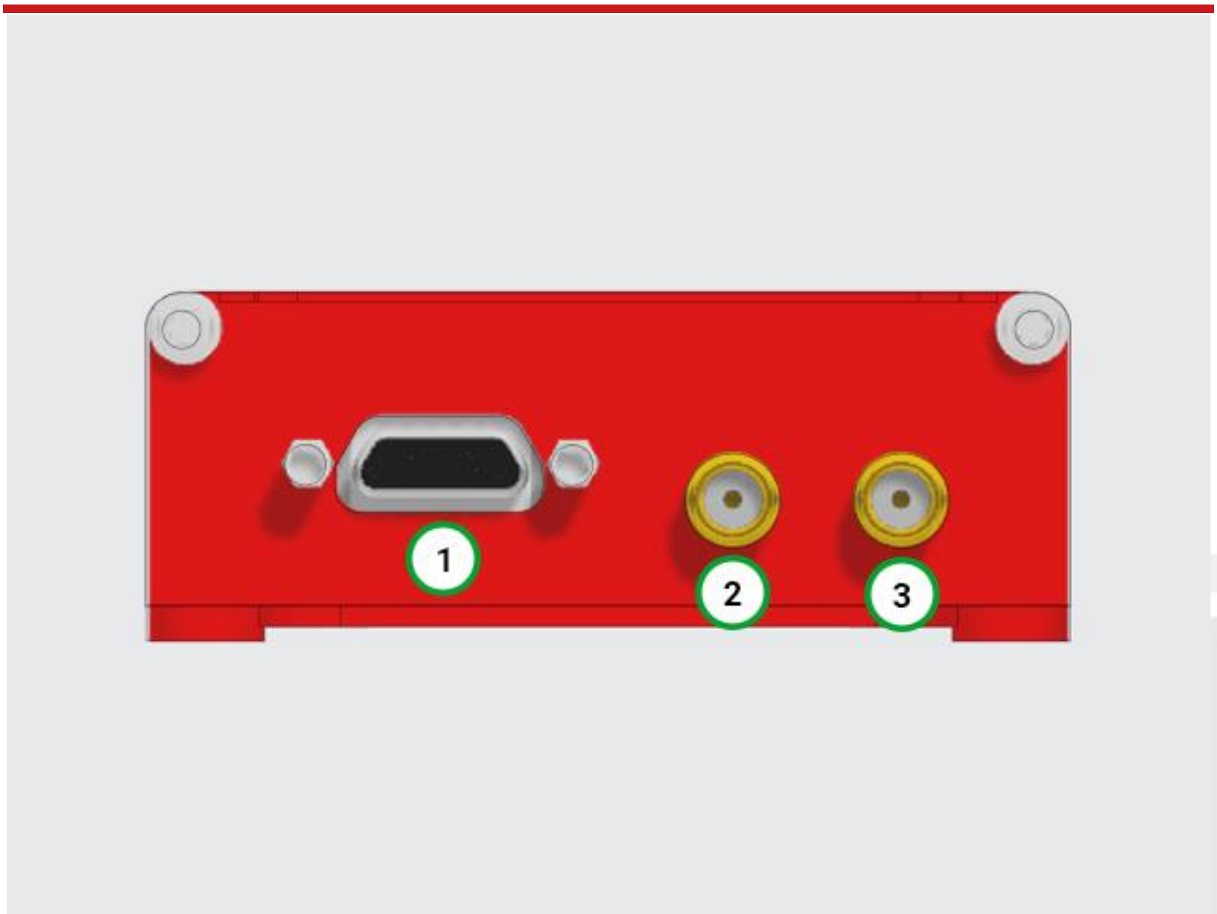


Figure 2: xNAV650 top view

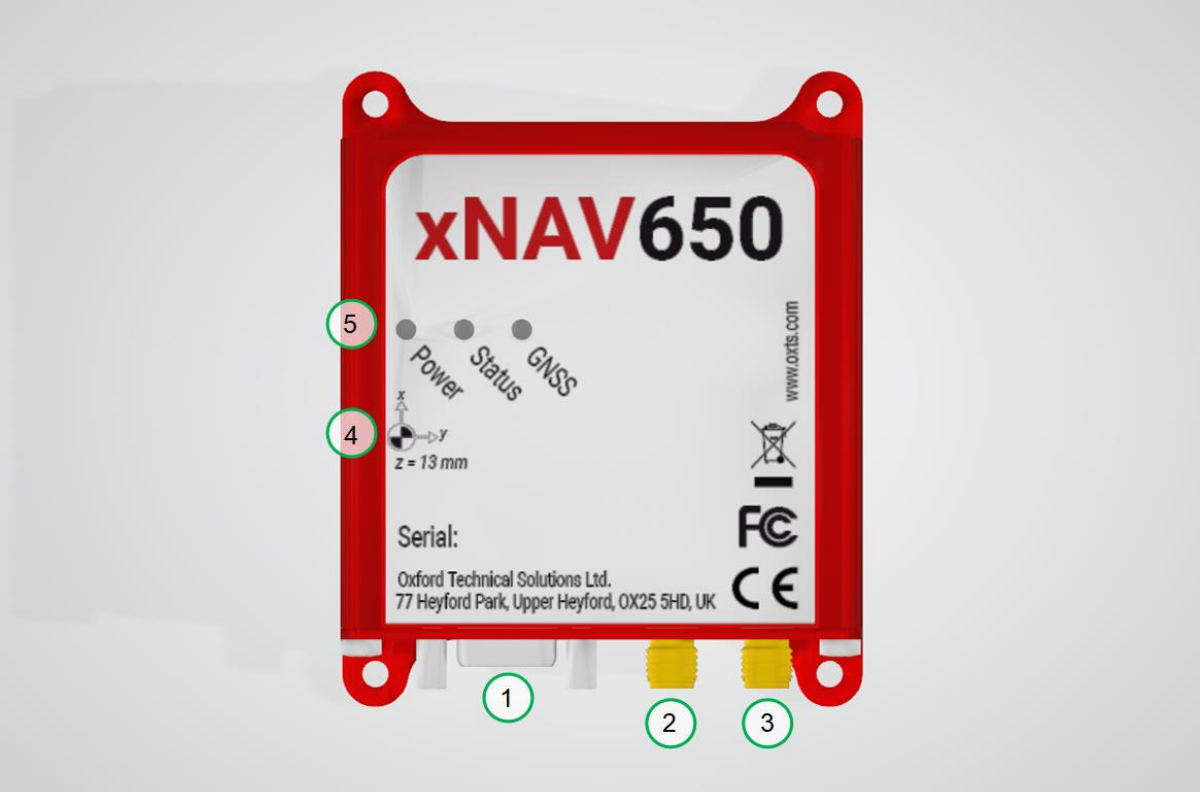


Table 3: xNAV650 points of interest

Label number	Description
1	Main I/O connector (15-way Micro-D) ○ Power ○ Ethernet ○ PPS ○ Serial TX/RX ○ Digital I/O signal 1/2 (configurable)
2	Primary GNSS connector (SMA)
3	Secondary GNSS connector (SMA)
4	Measurement origin point
5	LEDs

LED definitions

Tables 4, 5 and 6 show the descriptions for each of the LED functions.

Table 4: Power LED

Colour	Description
Off	There is no power to the system or the power supply has failed.
Green	Power is applied to the system.
Orange	The system is powered and an ethernet link is present.

Table 5: Status LED

Colour	Description
Off	The operating system has not yet booted (this occurs at start-up).
Red-green flash	The system is asleep. Contact OxTS support for further information.
Red flash	The operating system has booted but the GNSS receiver has not yet output a valid time, position, or velocity.
Red	The GNSS receiver has locked-on to satellites and has adjusted its clock to valid time (1PPS output now valid). The INS is ready to initialise.
Orange	The INS has initialised and data is being output, but the system is not yet real time (the Kalman filter delay is a few seconds). It takes ~10 seconds for the system to become real time.
Green	The INS is running and the system is real-time.

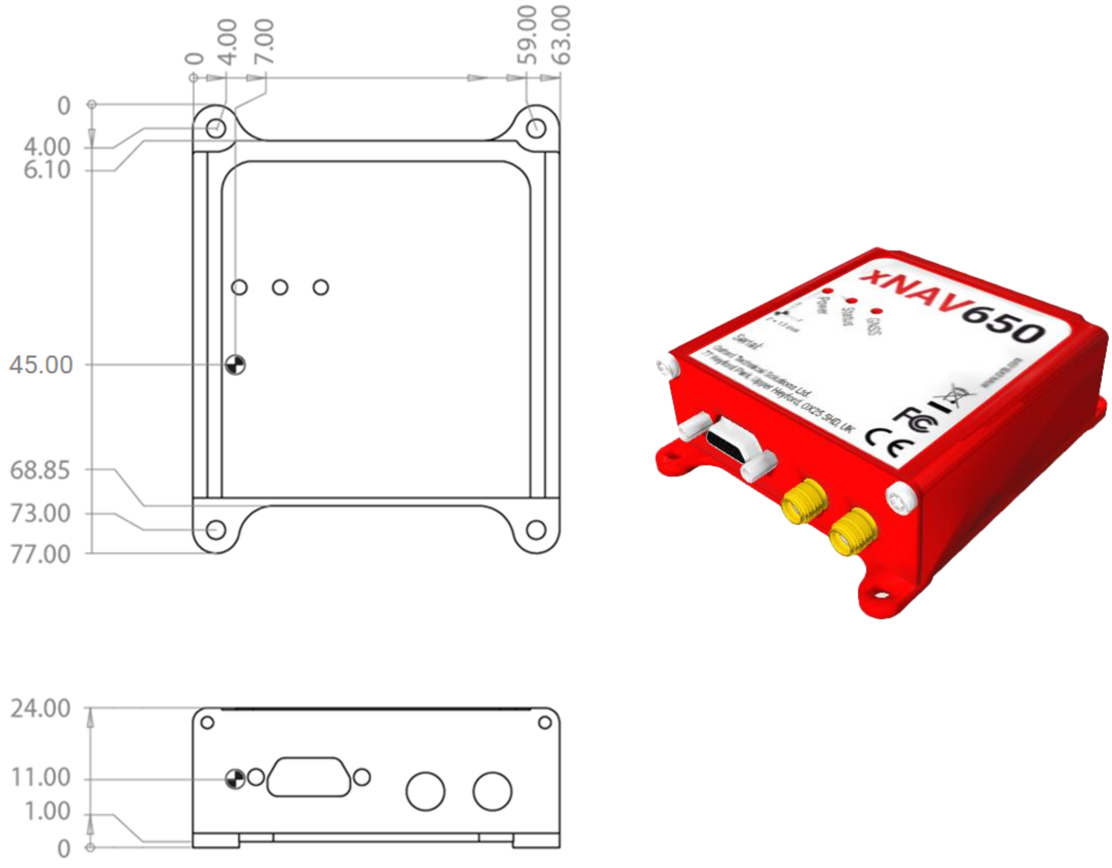
Table 6: GNSS LED

Colour	Description
Off	The GNSS receiver has a fault (valid only after start-up).
Red flash	The GNSS receiver is active but has not yet determined heading.
Red	The GNSS receiver has a differential heading lock.
Orange	The GNSS receiver has a floating (poor) calibrated heading lock.
Green	The GNSS receiver has an integer (good) calibrated heading lock.

Dimensions

Figure 3 shows the outer dimensions of the xNAV650, the mounting points, and the measurement origin point. When making measurements required in the configuration files, measurements should be made from the origin point.

Figure 3: xNAV650 dimensions and measurement origin point (mm)



Coordinate frame

The IMU reference frame shown in Figure 4 is popular with navigation systems – where the positive X-axis points forwards, the positive Y-axis points right and the positive Z-axis points down. The xNAV650 can be mounted in any orientation, it is not necessary for its axes to match those of the host vehicle. The configuration file will specify the transformation from the IMU frame to the vehicle frame.

Figure 4: xNAV650 coordinate frame axes

Interfaces

Main connector

The main I/O connector on the xNAV650 is a 15-way Micro D-sub. Figure 5 shows the pin layout.

Figure 5: xNAV650 main connector pin layout

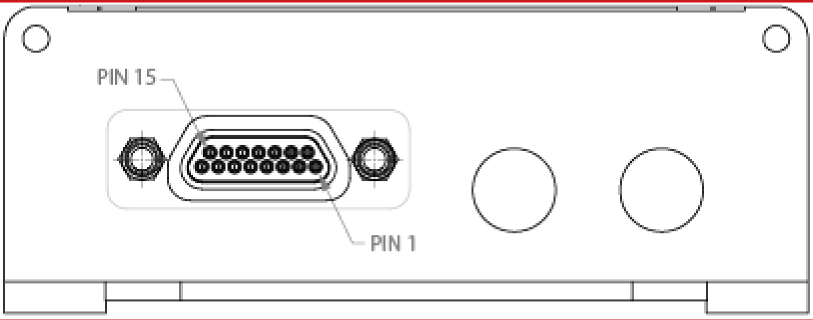


Table 7 shows the pin descriptions.

Table 7: Main connector pin description

Pin #	Name (function)	I/O type	Description
1	Supply+	P	Power supply +
2	Supply+	P	Power supply +
3	Serial	I/O	Serial RS232 RX
4	Serial	I/O	Serial RS232 TX
5	ERX-	I	Ethernet receive -
6	ERX+	I	Ethernet receive +
7	ETX-	O	Ethernet transmit -
8	ETX+	O	Ethernet transmit +
9	I/O signal 2	I/O	Configurable I/O. Contact OxTS for options
10	I/O signal 1	I/O	Configurable I/O. Contact OxTS for options
11	Signal ground (isolated)	P	Isolated signal ground
12	PPS (isolated)	O	Pulse per second synchronisation output, referenced to isolated signal ground (#11)
13	Signal ground	P	Signal ground
14	Supply-	P	Power supply -
15	Supply-	P	Power supply -

PPS

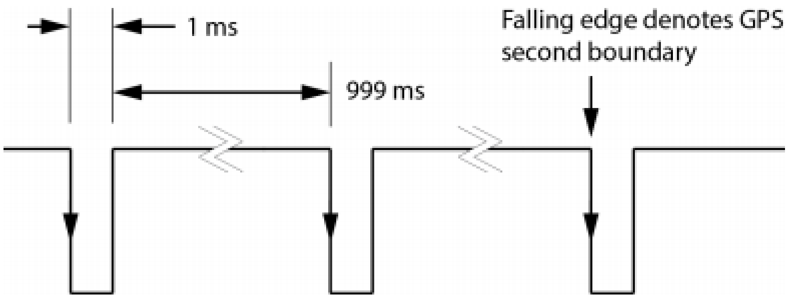
The PPS output is a pulse generated by the GNSS receiver. The output is active even when the GNSS receiver has no valid position measurement. The falling edge of the pulse is the exact transition from one second to the next in GPS time. The pulse is low for 1 ms, then high for 999 ms and repeats every second. The output is a low-voltage CMOS output, with 0.8 V or less representing a low and 2.4 V or more representing a high. No more than 10 mA should be drawn from this output.

Table 8: PPS electrical specifications

PPS	Typical	Min	Max
Output Voltage High (V)	3.3	2	3.3
Output Voltage Low (V)	0	-	0.8
Output Current (mA)	-	-	2

The signal is configurable to the rising or falling edge. For details, please refer to the support article for NAVconfig or check the hardware section of this manual.

Figure 6: PPS waveform



Serial

The serial interface uses a standard 5V logic RS232. The exact transceiver used is the SN65C3221EPWR. For full details you can read the datasheet from Texas Instruments https://www.ti.com/lit/ds/symlink/sn65c3221e.pdf?ts=1612353780873&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FSN65C3221E

Digital I/O

Table 9: Digital I/O electrical specifications

I/O	Typical	Min	Max
Input Low Voltage (V)	-	-20	0.5
Input High Voltage (V)	-	2	20
Output Voltage high (V)	3.3	2	3.3
Output Voltage Low (V)	0	-	0.8
Output Current (mA)	-	-	4

Note that triggers are pulled up internally to allow a switch to be used to short them to GND.

User cable

The standard xNAV650 user cable is designed for quick access to the main interfaces. Figure 7 shows the cable diagram and Table 11 shows the pin descriptions for the interface connectors. At the end of this manual there is a full page drawing of the user cable provided.

Power lines should be correctly terminated and insulated and wired up with a fuse somewhere between the unit and power source before being connected to a power source. The user must again perform a visual inspection of the cable equipment before use to ensure there is no damage.

Figure 7: xNAV650 user cable

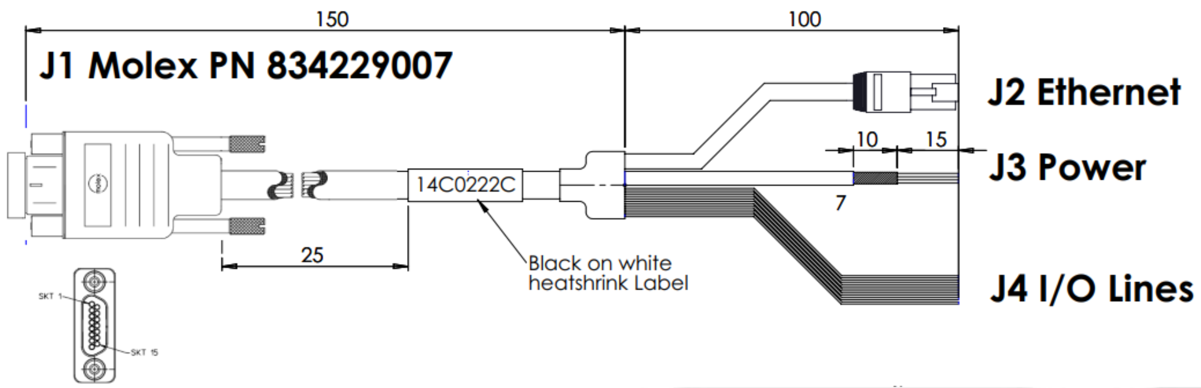


Table 10: xNAV650 user cable pin description

J1 Pin	Wire colour from J1	Description	Terminate to
1	Black	Supply+	J3-1, Red
2	Brown		
3	Red	Serial RX	J4
4	Orange	Serial TX	
5	Yellow	ERX-	J2-6, Green
6	Green	ERX+	J2-3, White/Green
7	Blue	ETX-	J2-2, Orange
8	Violet	ETX+	J2-1, White/Orange
9	Grey	I/O signal 2	J4
10	White	I/O signal 1	
11	White/Black	Signal ground (isolated)	
12	White/Brown	PPS (isolated)	
13	White/Red	Signal ground	
14	White/Orange	Supply-	J3-2, Black
15	White/Yellow		
Shield	Braid	Earth	

Antennas

The xNAV650 has SMA connectors for the primary and secondary GNSS antennas. Antennas used with the xNAV650 must at least be capable of tracking the GPS L1 signal for operation and additionally the GPS L2 signal for RTK performance. Antennas capable of tracking L1 and L2 GLONASS signals, E1 and E5b Galileo signals, and B1 and B2 Beidou signals should be used for optimal performance and improved reliability.

The xNAV650 is certified for use with GNSS antennae with a gain of less than or equal to 35 dB.

When using the xNAV650 in a dual antenna configuration, it is recommended to use the same type of antenna with the same cable lengths for both the primary and secondary receivers.

A suitable ground plane is required for the antennas to achieve good performance.

Internal storage

The xNAV650 uses a 32 GB eMMC for storage of hardware information, configuration files, and navigation data. Files can be sent to, or retrieved from, the card via FTP or with the software utilities provided (NAVconfig for configuration files and NAVsolve for data files).

The xNAV650 starts logging data automatically on power-up. Each individual raw data file (*.rd) can be a maximum of 2 GB, equivalent to around one full day of logging at 100 Hz data rate with four GNSS constellations. Once the 2 GB file limit is reached, a new file is started automatically to continue logging.

If the 32 GB storage limit is reached, the system will start overwriting existing RD files, starting from the oldest first.

Data from other devices can be logged directly onto the xNAV650 with the Generic Ethernet Logging feature code. LiDAR units with data rates similar to the VLP-16 LiDAR or less are able to log directly onto the INS. When data is recorded in this way the LiDAR data is recorded as a .lcom file. The data is stored without ethernet headers so is not identical to a traditional PCAP file. The limit for recording data can be as high as 5MB/s but 3MB/s is the specification given for reliable operation. This is more than enough for a VLP16 LiDAR for example but not for a VLP32.

Ethernet configuration

To configure the xNAV650 for unrestricted data transmission it is necessary to use the ethernet connection. The operating system at the heart of the xNAV650 allows connection to the unit via FTP. The use of FTP allows the user to manage the data logged to the unit; files can be downloaded for reprocessing. Configuration files for alternative configurations require FTP to put the configuration files on to the xNAV650. The default username and password are both “user”.

The xNAV650 outputs its data over ethernet using a UDP broadcast. The use of a UDP broadcast allows everyone on the network to receive the data sent by the xNAV650. The data rate of the UDP broadcast is 100 Hz.

Each xNAV650 is configured with a static IP address, to enable communication by ethernet. The default IP address will have the following format:

192.168.196.1*xx*

Where *xx* is the last two digits of the unit’s serial number.

The IP address of the computer being used to communicate with the xNAV650 may need to be changed so it matches the subnet. For example, 192.168.196.32 should be available since this IP address is never used by the xNAV650 by default.

Connection details for ethernet configuration

The RJ-45 connector on the 14C0222x user cable is designed to be connected directly to a network hub. To extend the cable it is necessary to use an in-line coupler. This is two RJ-45 sockets wired together in a straight-through configuration. Following the in-line coupler, a normal, straight UDP Cat 5e cable can be used to connect the coupler to the hub.

The xNAV can be connected directly to an ethernet card in a computer. To do this a crossed in-line coupler must be used.

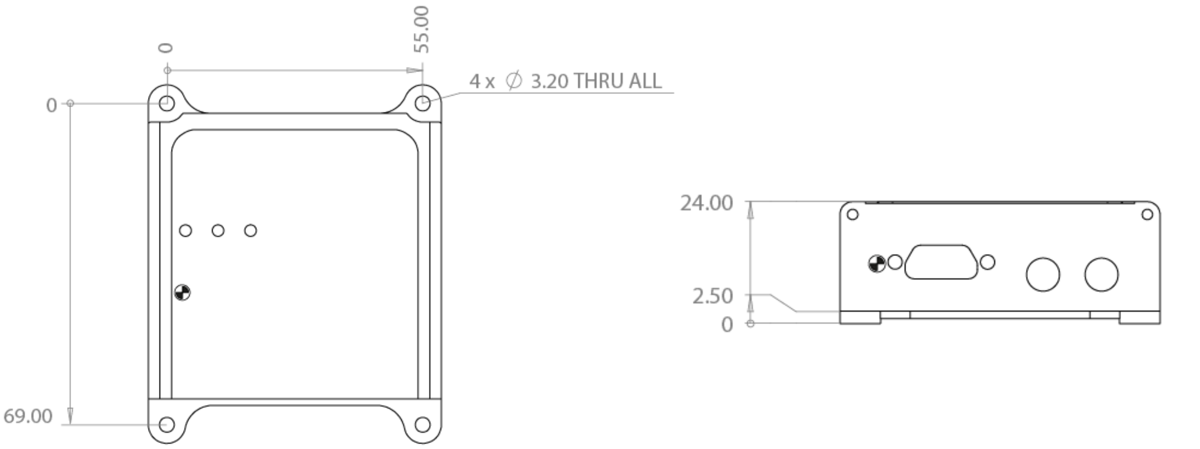
Best practices

Mounting

It is essential to mount the xNAV650 rigidly in the vehicle. The xNAV650 should not be able to move or rotate compared to the GNSS antennas, otherwise the performance will be reduced. In most circumstances the xNAV650 should be mounted directly to the chassis of the vehicle. If the vehicle experiences high shocks, then vibration mounts may be required.

Figure 8 shows the mounting points for the XNAV650. The mounting holes are suitable for M3 threaded screws.

Figure 8: xNAV650 mounting points (mm)



Do not install the xNAV650 where it is in direct sunlight as this may cause the case to exceed the maximum temperature specification.

Orientation and alignment

The orientation of the xNAV650 in the vehicle is normally specified using three consecutive rotations that transform the system to the vehicle's co-ordinate frame. Refer to Figure 4 for directions of axes. The order of the rotations is:

- Heading (z-axis rotation);
- then pitch (y-axis rotation);
- then roll (x-axis rotation).

It is important to get the order of the rotations correct or the transformation may not apply correctly.

The xNAV650 can be mounted at any angle in the vehicle as long as the orientation is described in the configuration. This allows the outputs to be rotated based on the settings entered to transform the measurements to the vehicle frame.

Dual antenna systems

It is often useful to have an understanding of how the xNAV650 uses the measurements from the dual antenna system. This can lead to improvements in the results obtained. A warmup needs to be completed for using the INS but if you have completed one the result of it can be saved and following warmups only need to be around 3 minutes, see the last step for this. For example in step 1 where a warm-up process is mentioned, only a short warmup is needed if a warmup has been saved with the same configuration.

1. To use the measurements properly the xNAV needs to know the angle of the GNSS antennas compared to the angle of the xNAV. This is very difficult to measure accurately without specialised equipment, therefore the xNAV needs to measure this itself as part of the warm-up process.
2. The xNAV will lock on to satellites, but it cannot estimate heading so it cannot start. Either motion or static initialisation can be used to initialise the xNAV.
3. When the vehicle drives forward and reaches the initialisation speed, the xNAV assumes that the heading and track are similar and initialises heading to track angle.
4. If the xNAV is mounted in the vehicle with a large heading offset then the initial value of heading will be incorrect. This can also happen if the xNAV is initialised in a turn. This can lead to problems later.
5. When the combined accuracy of heading plus the orientation accuracy figure for the secondary antenna is sufficiently accurate then the xNAV will solve the RTK Integer problem using the inertial heading. There is no need for the xNAV to solve the RTK Integer problem by searching.
6. If the antenna angle is offset from the xNAV by too much then the RTK Integer solution that is solved will be incorrect. For a 2 m antenna separation the xNAV orientation and the secondary antenna orientation should be known to within 5°. For wider separations, the secondary antenna orientation angle needs to be more accurate.
7. Once the RTK Integer solution is available, the xNAV can start to use the dual antenna solution to improve heading. The level of correction that can be applied depends on how accurately the angle of the secondary antenna is known compared to the inertial sensors.
8. The Kalman filter tries to estimate the angle between the inertial sensors and the secondary antenna. The default value used in the configuration software (5°) is not accurate enough so that the xNAV can improve the heading using this value. The accuracy in this angle will start to improve as conditions become dynamic.
9. Driving a normal warm-up, with stops, starts and turns, helps the Kalman filter improve the accuracy of the secondary antenna angle. The accuracy of this angle can be viewed in NAVdisplay. This is less essential if a warm-up has been saved (see step 11).
10. In the unlikely event that the RTK Integer solution is incorrect at the start then the Kalman filter can update the secondary antenna orientation incorrectly. If this happens then things start to go wrong. The Kalman filter becomes more convinced that it is correct, so it resolves faster, but it always solves incorrectly. Solving incorrectly makes the situation worse.
11. To avoid the Kalman filter from getting things wrong it is possible to drive a calibration run, then use the Improve Configuration wizard within NAVconfig. This tells the Kalman filter it has already estimated the angle of the secondary antenna in the past and it will be much less likely to get it wrong or change it. This step should only be done if the xNAV is permanently mounted in a vehicle and the antennas are bolted on. Any movement of either the xNAV or the antennas will upset the algorithms.
12. One way to improve the dual-antenna (in all cases) is to measure the dual-antenna separation to 1 cm and to set it in the Accuracies part of NAVconfig to 1 cm. This will save a lot of incorrect static initialisations. Can be done even to 5 mm.

Multipath effects on dual antenna systems

Dual antenna systems are very susceptible to the errors caused by multipath. Multipath is where the signal from the satellite has a direct path and one or more reflected paths. Because the reflected paths are not the same length as the direct path, the GNSS receiver cannot track the satellite signal as accurately. This can be from buildings, trees, roof-bars, etc.

The dual antenna system in the xNAV works by comparing the carrier-phase measurements at the two antennas. This tells the system the relative distance between the two antennas and which way they are pointing (the heading). For the heading to be accurate the GNSS receivers must measure the relative position to about 3 mm. The level of accuracy can only be achieved if there is little or no multipath.

In an ideal environment, with no surrounding buildings, trees, road signs or other reflective surfaces, the only multipath received is from the vehicle's roof. The antennas supplied with the xNAV are designed to minimise multipath from the vehicle's roof when the roof is made of metal. For use on non-metallic roofs a different type of antenna is required.

If you are using the INS in GNSS conditions where multipath effects are prevalent (lots of objects, particularly buildings around) then it is worth using higher-end antennas that have a greater signal filtering capability.

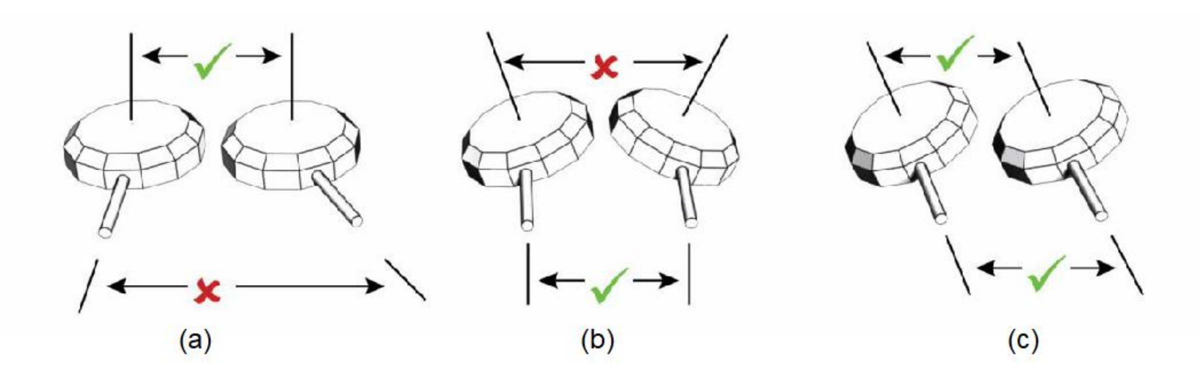
Antenna placement and orientation

For optimal performance it is essential for the GNSS antenna(s) to be mounted where they have a clear, uninterrupted view of the sky and on a suitable ground plane, such as the roof of a vehicle. For good multipath rejection the antennas must be mounted on a metal surface using the magnetic mounts provided; no additional gap may be used.

The antennas cannot be mounted on non-conducting materials or near the edges of conducting materials. If the antennas are to be mounted with no conductor below them then different antennas must be used. It is recommended to mount the antennas at least 30 cm from any edge where possible.

For dual antenna systems, the secondary antenna should be mounted in the same orientation as the primary antenna, as shown in Figure 9. The antenna baseline should also be aligned with one of the vehicle axes where possible, either inline or perpendicular to the vehicle's forward axis. In the default configuration the primary antenna should be at the front of the vehicle and the secondary antenna should be at the rear and they should be as far apart as possible.

Figure 9: Dual antenna orientations



a) The bases of the antennas are parallel, but the cables exit in different directions.

b) The cables exit in the same direction but the bases of the antennas are not parallel.

c) The bases of the antennas are parallel and the cables exit in the same direction. This configuration will achieve the best results.

It is best to mount the two antennas on the top of the vehicle. Although it is possible to mount one on the roof and one on the bonnet (hood), the multipath reflections from the windscreen will degrade the performance of the system.

Multipath affects dual antenna systems on stationary vehicles more than moving vehicles and it can lead to heading errors of more than 0.5° RMS if the antennas are mounted poorly.

It is critical to have the xNAV mounted securely in the vehicle. If the angle of the xNAV can change relative to the vehicle, then the dual antenna system will not work correctly. This is far more critical for dual antenna systems than for single antenna systems. The user should aim to have no more than 0.05° of mounting angle change throughout the testing. (If the xNAV is shock mounted then the xNAV mounting will change by more than 0.05°; this is acceptable, but the hysteresis of the mounting may not exceed 0.05°).

For both single and dual antenna systems it is essential that the supplied GNSS antenna cables are used and not extended, shortened or replaced. This is even more critical for dual antenna systems and the two antenna cables must be of the same specification. Do not, for example, use a 5 m antenna cable for one antenna and a 15 m antenna cable for the other. Do not extend the cable, even using special GNSS signal repeaters that are designed to accurately repeat the GNSS signal. Cable length options are available in 1 m, 5 m and 15 m lengths. This is important because the signal can deteriorate over longer cables and the signals are expected to match.

xNAV650 orientation and alignment

The orientation of the xNAV in the vehicle is normally specified using three consecutive rotations that rotate the xNAV to the vehicle’s co-ordinate frame. The order of the rotations is heading (z-axis rotation), then pitch (y-axis rotation), then roll (x-axis rotation). It is important to get the order of the rotations correct or the transformation may not apply correctly.

In the default configuration the xNAV expects its y-axis to be pointing right and its z-axis pointing down relative to the host vehicle. Please refer to Figure 4 in this manual or see on the top panel of the INS itself for the correct directions of axes. There are times however when installing an xNAV in the default configuration is not possible. The xNAV can be mounted at any angle in the vehicle as long as the configuration is described to the xNAV using NAVconfig. This allows the outputs to be rotated based on the settings entered to transform the measurements to the vehicle frame.

For ease of use, it is best to try and mount the xNAV so its axes are aligned with the vehicle axes. This saves the offsets having to be measured by the user. If the system must be mounted misaligned with the vehicle and the user cannot accurately measure the angle offsets, the xNAV has some functions to measure these offsets itself. The heading offset can be measured if the vehicle has a non-steered axle. The Improve Configuration wizard in NAVconfig should be used for this. Roll and pitch offsets can be measured using the Surface tilt utility in NAVdisplay.

Specifications

Specifications for xNAV650 can be found in Tables 11, 12 and 13. These specifications are listed for operation of the system under the following conditions:

- After a warm-up period of three minutes' continuous operation.
- Using combined post-processing the highest specification can be achieved effectively instantly for the entire duration of the dataset but the warm-up manoeuvres should always be performed.
- Open-sky environment, free from cover by trees, bridges, buildings or other obstructions. The vehicle must have remained in open sky for at least five minutes for full accuracy.
- The vehicle must exhibit some motion behaviour which should be achieved during the warmup. Acceleration of the unit in different directions is required so the Kalman filter can estimate any errors in the sensors. Without this estimation, some of the specifications degrade.
- The distance from the xNAV measurement point to the primary GNSS antenna must be known by the system to a precision of five millimetres or better. The vibration of the system relative to the vehicle cannot allow this to change by more than five millimetres. The system will estimate this value itself in dynamic conditions.
- For dual antenna systems, the system must know the relative orientation of the two antennas to 0.05° or better (the system will estimate this value itself under dynamic conditions).
- For single antenna systems, the heading accuracy is only achieved under dynamic conditions. Under benign conditions, such as motorway driving, the performance will degrade. The performance is undefined when stationary for prolonged periods of time.

Table 11: xNAV650 performance specifications

Parameter	Value
GNSS tracking	GPS L1, L2 GLONASS L1, L2 BeiDou B1, B2 Galileo E1, E5b
Position accuracy[a]	1.5 m CEP SPS 0.4 m DGPS 0.02 m RTK
Roll/pitch accuracy	0.05° 1σ
Heading accuracy	0.1° 1σ[b]

Table 12: xNAV650 inertial sensor specifications

Accelerometers	Value
Full range	±8 *g*
In-run bias stability	0.08 m*g*
Scale factor	0.08%
VRW	0.06 m/s/√hr

Gyros	Value
Full range	±480°/s
In-run bias stability	5°/hr
Scale factor	0.3%
ARW	0.48°/√hr

Table 13: xNAV650 physical characteristics

Parameter	Value
Input voltage[c]	5-30 V dc
Power consumption	4 W
Dimensions	77 × 63 × 24 mm
Mass	0.13 kg
Operating temperature	-40 to 70°C
Calibration temperature	-20 to 70°C
Vibration	10-500 Hz 1.42 *g* RMS
Shock	15 *g* 11 ms half sine
Internal storage	32 GB
Data logging rate	3 MB/s
Data output rate	100 Hz with 200 and 250 Hz options

a) To achieve specification, relevant differential corrections from a base station or NTRIP are required.
b) With two-meter antenna separation. Wider separation will improve accuracy (up to around five-meter separation).
c) Voltage range of connected devices such as radio modems must be considered.

Notes on specifications

To achieve full accuracy in real time, the xNAV650 will require appropriate differential corrections where applicable, for example from a base station. Alternatively, a RINEX file can be downloaded post-mission and used to post-process the data to full accuracy.

The "1σ" specification has been used for parameters where offset cannot be measured by the xNAV, for example position (the offset of the base station cannot be found by the xNAV alone). The "RMS" specification was used where the offset is known, for example velocity. For angles and measurements derived from the angles, the "1σ" specification is used because the mounting of the xNAV compared to the vehicle gives an offset the xNAV cannot measure.

- Full specification accuracy will be achieved after a short warm-up period during which motion inputs will be used by the navigation system to estimate sensor error characteristics.
- The heading accuracy that can be achieved by the dual antenna system in the xNAV650 is 0.2° 1σ per metre of separation in ideal, open sky conditions. The system can provide these accuracies in static and dynamic conditions.
- For single antenna systems, the heading is calculated from the inertial measurements and requires dynamic conditions to achieve the best performance.
- Non-ideal mounting of the GNSS antennas will reduce the heading accuracy, particularly for dual antenna systems.

Heading accuracy

The heading accuracy that can be achieved by the dual antenna system in the xNAV650 is about 0.2° 1σ per metre of separation in ideal, open sky conditions. The system can provide these accuracies in static and dynamic conditions. A two-metre separation is required to reach the accuracy listed in Table 11. The maximum recommended separation is five metres, at which it may be possible to achieve better accuracy than that listed if the structure is rigid, including temperature variation.

For single antenna systems, the heading is calculated from the GNSS velocity vector and the inertial measurements. The accuracies listed in Table 11 are achievable under dynamic conditions. Under static conditions the heading accuracy of single antenna systems will degrade. A feature called 'heading lock' is available and can be used to improve single antenna performance in stationary periods, this prevents drifting in static conditions.

Non-ideal mounting of the GNSS antennas will reduce the heading accuracy, particularly for dual antenna systems.

When stationary, the heading from the xNAV will show some error; the size of the error depends on the multipath in the environment.

With obstructions, the dual antenna might not be working in which case the performance will degrade indefinitely. If it does not work, the antenna separation is relevant and the greater the separation the greater the performance.

Export control classification number

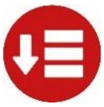
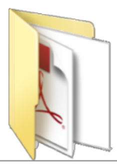
Export control regulations are subject to change, and so the classification number of the xNAV650 may also change. The information presented here is correct at the time of publishing.

The accelerometer and gyro sensors used in the xNAV650, as well as the xNAV650 navigation system as a whole, does not fall under the requirements for controlled items on the Commerce Control List (CCL). As such the xNAV650 is designated ECCN 7A994 meaning no licence is required for export or reexport.

Software installation

Included with every xNAV is a USB stick containing the software package NAVsuite. This package contains several programs required to take full advantage of the xNAV's capabilities. Table 15 lists the contents of NAVsuite.

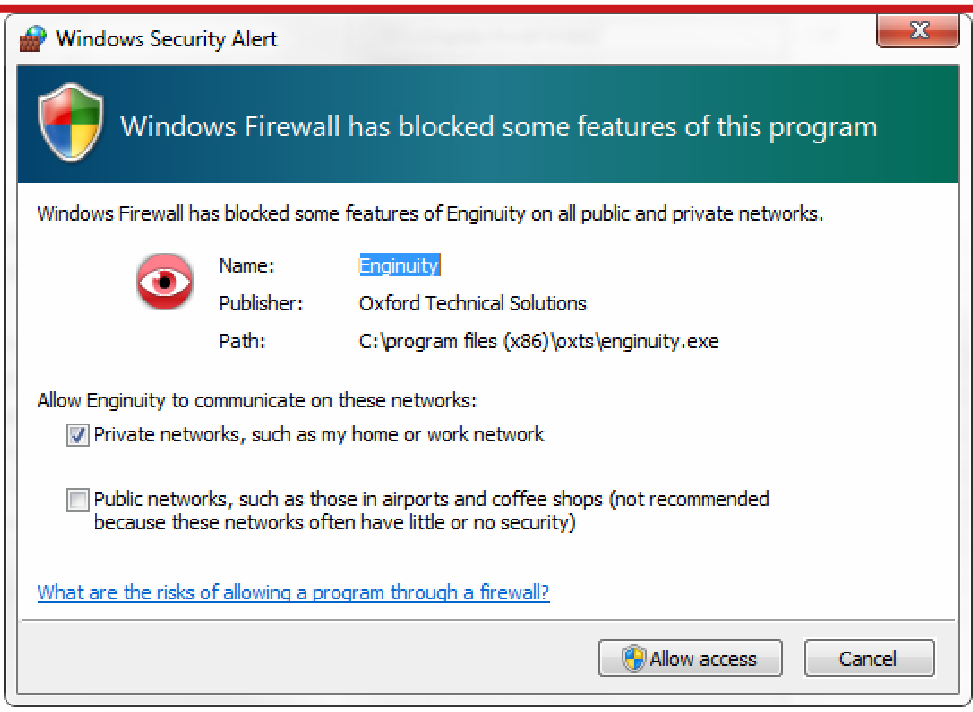
Table 14: NAVsuite components

Icon	Software	Description
	NAVdisplay	Used to view real-time data from OxTS products via ethernet or a serial port. It can also be used to transmit special commands and replay logged data.
	NAVstart	A menu from which you can navigate between OxTS applications. This opens automatically when you are connected to a unit.
	NAVconfig	Used to create, send, and receive configurations from OxTS products. As configurations vary between products there is no manual for NAVconfig.
	NAVsolve	Used to download raw data files from the xNAV and post-process the data. The configuration can be changed and differential corrections can be applied before the data is reprocessed. It can export NCOM, XCOM and CSV file formats.
	NAVgraph	Used to graph NCOM, XCOM and RCOM files created in post-process. It can display graphs, cursor tables and map plots and data can be exported in CSV or KML (Google Earth) format.
	NAVbase	Used to configure and manage xNAV-Base S and GPS-Base base stations, which can be used to achieve RTK integer level position accuracy.
	Manuals	This folder contains PDF versions of relevant OxTS manuals. Other manuals can be downloaded from the OxTS website. http://www.oxts.com/support/manuals/

To install NAVsuite, insert the USB stick into your PC and run **NAVsetup.exe**. Follow the onscreen instructions to install the software. By default, the installer creates the program files in C:\Program Files (x86)\OxTS on 64 bit operating systems or C:\Program Files\OxTS on 32 bit operating systems.

The first time some OxTS applications are run, a firewall warning message similar to that shown in Figure 10 may be triggered. This is because the program is attempting to listen for, and communicate with, OxTS devices on the network. The firewall must be configured to allow each program to communicate on the network, or programs will not work as intended.

Figure 10: Windows Firewall warning message



Ensure both Private and Public networks are selected to ensure the software can continue functioning when moving from one type to another.

Operating principles

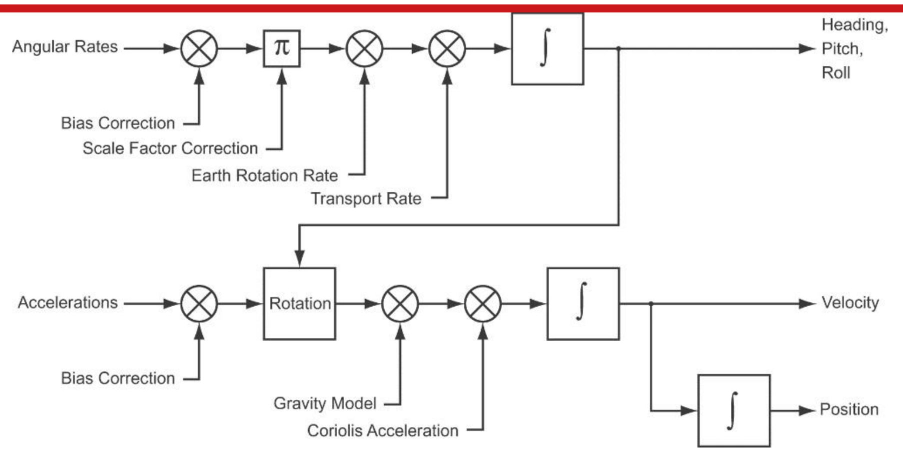
This section gives some background information on the components in the xNAV650 and how they work together to give the outputs. A short overview of the algorithm is given and some explanation of how the software works. This section is provided as "interesting information" and is not required for normal operation.

Strapdown navigator

The outputs of the system are derived directly from the strapdown navigator. The role of the strapdown navigator is to convert the measurements from the accelerometers and angular rate sensors to position. Velocity and orientation are also tracked and output by the strapdown navigator.

Figure 11 shows a basic overview of the strapdown navigator. Much of the detail has been left out and only the key elements are shown here.

Figure 11: Schematic of the strapdown navigator



The angular rates have their bias and scale factor corrections (from the Kalman filter) applied. Earth rotation rate is also subtracted to avoid the 0.25° per minute rotation of the Earth. The transport rate is also corrected; this is the rate that gravity rotates by due to the vehicle moving across the earth's surface and it is proportional to horizontal speed. Finally, the angular rates are integrated to give heading, pitch and roll angles.

The accelerations have their bias corrections (from the Kalman filter) applied. Then they are rotated to give accelerations in the earth's co-ordinate frame (north, east, down). Gravity is subtracted and Coriolis acceleration effects removed. The accelerations are integrated to give velocity. This is integrated to give position.

The strapdown navigator uses a WGS 84 model of the earth, the same as GPS uses. This is an elliptical model of the earth rather than a spherical one. The position outputs are in degrees latitude, degrees longitude and altitude. The altitude is the distance from the model's earth sea level.

Extended Kalman filter

Kalman filters can be used to merge several measurements of a quantity and therefore give a better overall measurement. This is the case with position and velocity in the xNAV; the Kalman filter is used to improve the position measurement made from two sources, inertial sensors and GNSS.

The Kalman filter used in the xNAV is able to apply corrections to several places in the strapdown navigator, including position, velocity, heading, pitch, roll, angular rate bias and scale factor and acceleration bias.

Using a model of how one measurement affects another, the Kalman filter is able to estimate states where it has no direct measurement.

Position and velocity are compensated directly, but other measurements like accelerometer bias, have no direct measurements. The Kalman filter tunes these so the GNSS measurements and the inertial measurements match each other as closely as possible.

Use with survey hardware

For using your xNAV650 INS device with a range of different surveying devices we have online support manuals. This is by no means exhaustive, the xNAV650 is compatible with almost any LiDAR or camera when it is configured correctly, and the correct interfaces are created between the devices.

Table 15: Hardware integration manuals for surveying devices

Manual	Description
Hesai LiDAR	Hesai hardware integration guide https://support.oxts.com/hc/en-us/articles/360017030840
Ouster LiDAR	Ouster hardware integration guide https://support.oxts.com/hc/en-us/articles/360017072719
Phase One Camera	Phase One Camera User Guide https://support.oxts.com/hc/en-us/articles/360000099345-Phase-One-Camera-User-Guide
Velodyne LiDAR	Hardware integration with Velodyne LiDAR https://support.oxts.com/hc/en-us/articles/360017123620
Z&F Profiler	Hardware integration with Z&F 9012 Profiler https://support.oxts.com/hc/en-us/articles/360002379180-Hardware-integration-with-Z-F-9012-Profiler
PTP	Procedure for configuring PTP for a time synchronisation method over ethernet https://support.oxts.com/hc/en-us/articles/360016515759-PTP-Quick-Start-Guide-Beta-

For information on setting up a configuration for your INS to work with survey devices you can follow the guides above and the NAVconfig support guide.

Many devices will require to receive NMEA messages and a time synchronisation. For the xNAV650, time synchronisation can be done using PPS or using PTP. See the manual at the hyperlink above to configure your INS to use PTP. PTP messages are sent over ethernet whereas PPS will require a suitable cable connection to be made. NMEA messages can be configured to be sent over serial or over ethernet using NAVconfig. For the serial connection, there must again be a suitable cable connection made.

Using NAVconfig you can also configure input and output triggers and a displaced output if you want the navigation data to be representative of the survey device instead of the INS.

Data logging

A Feature Code can be purchased to allow your xNAV650 device to log ethernet traffic directly onto the unit. This allows you to bypass the need to monitor and record your files in real time. Files can be retrieved from the device in the same way as RD files via FTP interfacing.

When LiDAR data is logged in this way it is recorded as .lcom which is identical to a .pcap except without ethernet headers. LCOM and PCAP files work identically in OxTS Georeferencer.

Please note that data logging does not work for all LiDAR. Data rates from LiDAR devices can be very large which can be overbearing for the CPU of the xNAV650. For Velodyne LiDAR usage, a 16 laser LiDAR will log comfortably onto the xNAV but a 32 laser LiDAR will not log correctly onto the xNAV. 3MB/s is the given specification for data recording reliably.

This setting can be enabled or disabled in the LiDAR Scanner tab of the Hardware Setup in NAVconfig. Select the Velodyne VLP-16 as your scanner type (regardless of your device) and then select 'Log data' and 'Log telemetry'.

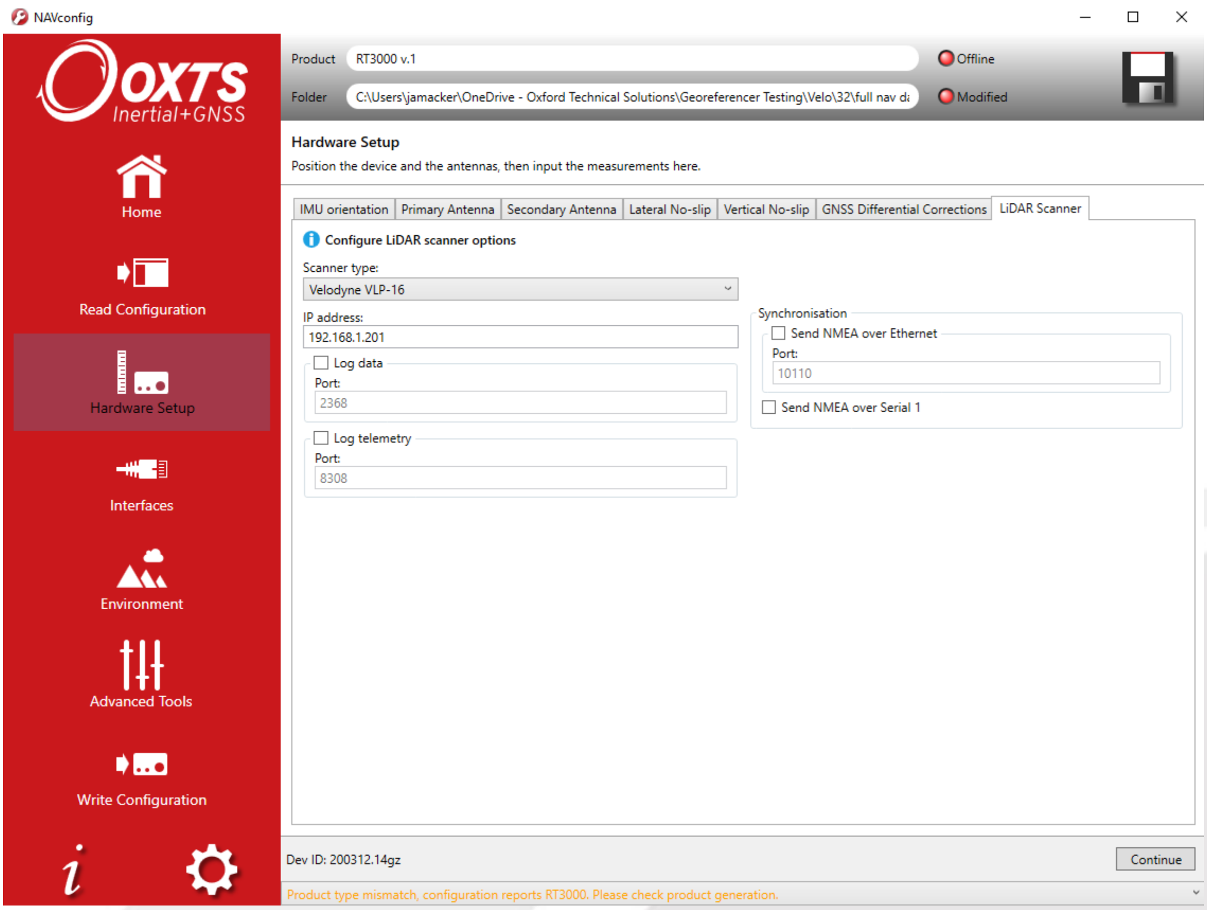
PPS and NMEA

Many survey devices require to receive PPS synchronisation and NMEA data. This can be easily configured using NAVconfig. The hardware setup will also have to be made to support this via a suitable cable. Furthermore, ensure that the PPS requirements for the device are the same as the INS output. If you require TTL input, for example, you will need an adapter between the two devices.

In NAVconfig PPS and NMEA can be set in the LiDAR Scanner tab of the Hardware Setup section. Choosing Velodyne VLP-16 (regardless of your device) will allow you to choose NMEA settings. Depending on the cabling setup you have used you are able to send NMEA messages over either ethernet or serial. For example, when using a PTP setup you will want NMEA and PTP messages to both be sent over ethernet to the device.

There are further PPS options in the PPS/Triggers section.

Figure 12: NAVconfig LiDAR Scanner tab



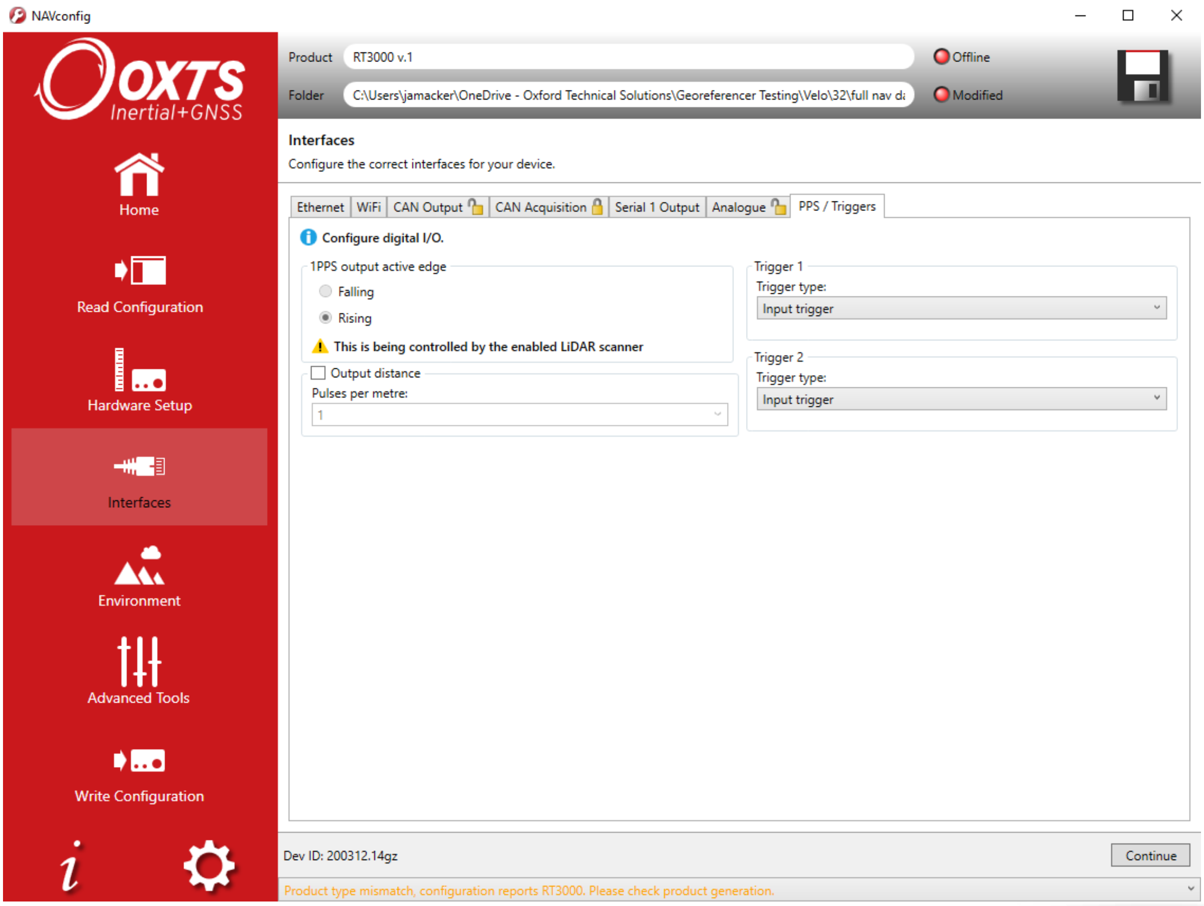
PPS/Triggers

NAVconfig allows users to easily configure trigger inputs for cameras within the PPS/Triggers tab of the Interfaces section. These are set on the right-hand side and can be input, output triggers or IMU sync triggers.

PPS signals can be set to have the active edge in the falling or rising edge in this tab also. Check your device's manual to determine which is required.

NCOM (navigation data) packets can be set to output on triggers in the ethernet tab.

Figure 13: The PPS/Triggers tab in NAVconfig.



PTP

Currently (March 2021), there is no GUI way of configuring PTP settings but this will be implemented in a future release of NAVsuite.

Use the link above to access the PTP Quick Start Guide on our support site that has more details.

To use PTP on your xNAV650 device ensure that you have the PTP feature code purchased and enabled and do the following:

1. Upgrade the firmware of the OxTS INS.
2. Upload a ptpd.conf file and the leap-seconds.list file to the unit.
3. Ensure the PTP feature code is enabled.
4. Append -enable_ptp to mobile.cfg.
5. Reboot the unit.

For the PTP functionality to work, the unit must have the primary GNSS antenna connected and be tracking satellites. For optimum performance, the unit must also be initialised.

All of the other PTP settings are configured with the “ptpd.conf” file. All the options are documented (for example, https://manpages.debian.org/testing/ptpd/ptpd.conf.5.en.html), though some are not supported. See the support article for an example of this. To edit the configuration, edit the ptpd.conf file and then upload it again to the unit and reboot it.

PTP packets will be viewable in software such as Wireshark as PTPv2 protocol packets.

OxTS devices get their time solution from GNSS satellites which use very accurate atomic clocks. The time that OxTS devices receive from the satellites is the number of seconds since midnight January 5th - January 6th 1980. This is known as the GPS epoch and from this the device can calculate the current date and time. By default, when an OxTS device is used with PTP, it will be using the GPS epoch.

Not all devices expect timestamps to be in the GPS epoch. Here is a list of commonly used time modes:

Table 16: Epoch time configurations

GPS	Time in seconds since the GPS epoch (1980-01-01 00:00:00 UTC), same as NCOM.
Unix	Time in seconds since the Unix epoch (1970-01-01 00:00:00 UTC).
UTC	Time in seconds since the Unix epoch (1970-01-01 00:00:00 UTC), including leap seconds.
PTP	Time in seconds since the PTP epoch (1969-12-31 23:59:51 TAI), including leap seconds.

To get the correct date and time from a timestamp, it is important to know which epoch is being used.

If the PTP device being synchronised to the OxTS device does not use the GPS epoch, it is possible to configure the OxTS device to output PTP timestamps from a different epoch (this will not change the timestamps in the NCOM stream). This is done by adding the relevant advanced command in NAVconfig (Modify Configuration>Advanced>Commands):

Table 17: Time epoch advanced commands

GPS	-ptp_time_mode_gps
Unix	-ptp_time_mode_unix or -ptp_custom_offset_315964800
UTC	-ptp_time_mode_utc or -ptp_custom_offset_315964782
PTP	-ptp_time_mode_ptp or -ptp_custom_offset_315964819

Here you can see that the different time modes can be reached by adding different offsets to the GPS timestamps. Similarly, the -ptp_custom_offset_%d command can also be used to access time modes not listed above by finding the correct offset (which will be the number of seconds between the different epochs).

During internal testing of the PTP feature, a data was collected with a Hesai Pandar40P and an RT3000 v3. Time synchronisation was achieved using PTP. The RT3000 v3 was in GPS mode but the Hesai Pandar40P was expecting timestamps in UTC. The following command was required to generate an accurate pointcloud:

lidar_time_offset=315964785000000000

If the RT3000 v3 was instead in Unix time mode, the following command would be required:

lidar_time_offset=-18000000000

Finally, ensure that your survey device is correctly configured to anticipate PTP time synchronisation.

Cable modification

The standard user cable for the xNAV650 is shown in Figure 7. This has been made to be ideal for modification to the user's selected purpose. Using the cable wiring diagram and the wiring guide shown at the end of this document you will be able to wire up a cable with a suitable connector to interface with whichever requirements you have. If you are creating your own cable you will need to ensure that the same micro-d connector is used and the pinouts are correctly configured.

OxTS does not guarantee the functionality of any modifications made to the user cable and is not responsible for any damage caused to the INS or other devices.

Appendix

Wiring guide for standard interfaces

Serial from selectable IO

Micro-d pin	Colour	Signal	Male d-type pin
13	W/RED	Signal Ground	5
9	GRY	I/O Signal 2/Rx	2
10	WHT	I/O Signal 1/Tx	3

Digital IO

Only connect Wheelspeed or Triggers at any one time, connects isolated and non-isolated system grounds.

Micro-d pin	Colour	Signal	Female d-type pin
12	W/BRN	PPS (ISO)	1
9	GRY	I/O Signal 2/Rx	2, 3
10	WHT	I/O Signal 1/Tx	4, 5
13	W/RED	Signal Ground	6-5
11	W/BLK	Signal Ground (ISO)	6-5

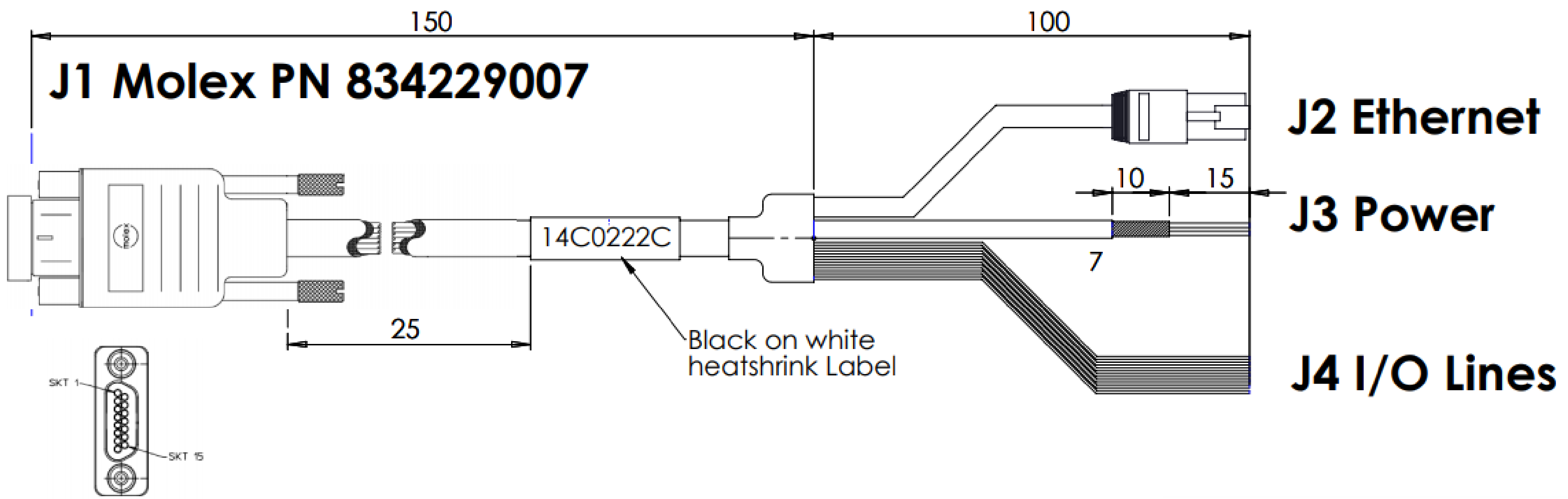
Serial

For xNAV650, no isolation in this product

Micro-d pin	Colour	Signal	Male d-type pin
3	RED	CAN+ (ISO)/RS232 Rx	2
4	ORG	CAN- (ISO)/RS232 Tx	3
11	W/BLK	Signal Ground (ISO)	5

Appendix 2

Drawings

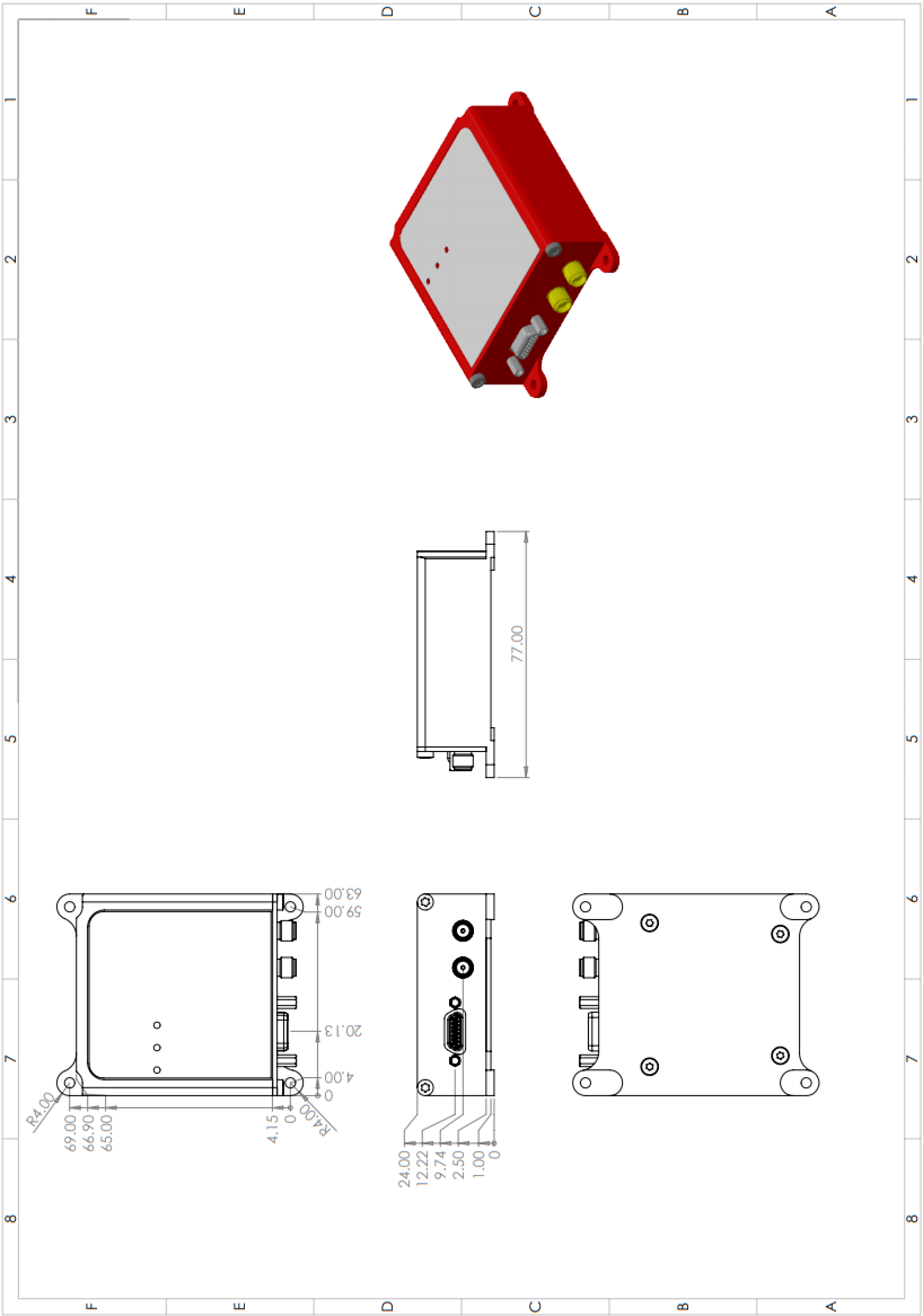


J1 Pin No	Wire Color from J1	Signal Description	Terminate To	Assembly Notes
5	YEL	ERX-	J2-6, GRN	Pre-moulded shielded FTP Ethernet cable to be used for J2 and joined to wired from J1 in centre joint. Part should be selected with similar look to that of cable from J1.
6	GRN	ERX+	J2-3, W/GRN	
7	BLU	ETX-	J2-2, ORG	
8	VIO	ETX+	J2-1, W/ORG	
1	BLK	Supply +	J3-1, RED	2 core 7/32 shielded cable to be terminated to J1 wires at centre join. Must have red and block insulation on inner cores (Red for Supply +) and outer insulation to have simlar look to the cable from J1. Outer insulation to be stripped back 25 mm from end and shield to be stripped back 15 mm.
2	BRN			
14	W/ORG	Supply -	J3-2, BLK	
15	W/YEL			
3	RED	CAN+ (ISO)/RS232 Rx	J4	Signal wires from J1 should be left intact at the centre point and cut at the length specified from the centre point.
4	ORG	CAN- (ISO)/RS232 Tx		
11	W/BLK	Signal Ground (ISO)		
12	W/BRN	PPS (ISO)		
13	W/RED	Signal Ground		
9	GRY	I/O Signal 2		
10	WHT	I/O Signal 1		
Shield	Braid	Earth	Shields from J 2&3's moulded cables to be joined to that of J1 at the centre join, join should also be shielded	

Notes:

- This cable is suitable for both the AV200 and xUAV530 products
  - In the AV200 J1-5&6 will be isolated CAN referenced to the isolated signal ground on J1-13, the PPS signal on J1-12 will also be referenced to the isolated signal ground.
  - In the xUAV530 J1 5&6 will be a serial port and there will be no isolation of any signals or grounds.

DATE: 01/07/20		OXTS Inertial+GNSS Oxford Technical Solutions Ltd Park Farm Barns, Middleton Stoney Oxfordshire, OX25 4AL
DRAWN BY: Sean Bedford		
CHECKED BY: Tom Bailey		
APPROVED BY: Sam Whelan		
TITLE: AV200/xUAV530 Minimal User Cable		DRAWING No : 14M0222
DIMENSIONS: mm DRAWING NOT TO SCALE	SHEET 1 OF 1	DRAWING REVISION: C


77.00
63.00
59.00
20.13
4.00
0
R4.00
R4.00
69.00
66.90
65.00
4.15
0
24.00
12.22
9.74
2.50
1.00
0

Revision history

Revision	Comments
201117	Draft version last updated
210204	Draft version for website release
210311	Final release for product launch

OXTS