RT
GNSS-aided inertial measurement systems

User Manual

Covers RT3000 v3 and RT500 v1 models

The inertial experts.

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Any use of misuse of the RT in a manner not intended may impar the protection provided. Please contact OxTS if you believe any service of repair is required on your RT.

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Introduction

The RT family of inertial navigation system (INS) devices are instruments for making precision measurements of motion in real time.

There are three divisions within the RT family – RT500s (v1) RT3000s (v3) and RT1003s (v1) – and each division has performance options. The RT500 and RT3000 products are covered in this manual. The RT1003 product has its own manual, which can be downloaded from the OxTS Support Site here.

From September 2019 the RT3000 became v3 with new functionality. v2 devices are now end of life and include: RT2000s, RT3000s (v2), and RT4000s. The RT1003 is unchanged.

The "RT-Range Hunter" is a variant of the RT3000 v3 that runs the OxTS RT-Range processing engine for vehicle-to-vehicle and vehicle-to-lane testing inside the RT itself. This functionality used to be available from the RT-Range S Hunter accessory but now runs on board the RT3000 v3 as an optional feature. If you are configuring an RT-Range S Hunter for ADAS testing then you will need to refer to the RT-Range user manual – available to download at support.oxts.com.

To obtain high-precision measurements, the RT uses mathematical algorithms developed for use in fighter aircraft navigation systems. An inertial sensor block with three accelerometers and three gyros (angular rate sensors) is used to compute all the outputs. A WGS 84 modelled strapdown navigator algorithm compensates for earth curvature, rotation and Coriolis accelerations, while measurements from high-grade kinematic GNSS receivers update the position and velocity navigated by the inertial sensors. This innovative approach gives the RT several distinct advantages over systems that only use GNSS:

- The RT has a high (100 Hz, 200 Hz or 250 Hz) update rate and a wide bandwidth.

- The outputs are available with low, 1 ms latency.

- All outputs remain available continuously during GNSS blackouts when, for example, the vehicle drives under a bridge.

- The RT recognises jumps in GNSS position and ignores them.

- The position and velocity measurements the GNSS makes are smoothed to reduce the high-frequency noise.

- The RT makes many measurements GNSS cannot, for example acceleration, angular rate, pitch and roll.

An RT system processes data in real time. The real-time results are output via an RS232 serial port, over 10/100 Base-T Ethernet using a UDP broadcast and on CAN bus. Outputs are time-stamped and refer to GPS time; a 1PPS timing sync can be used to give accurate timing synchronisation between systems. The inertial measurements are synchronised to the GPS clock.

Internal data logging enables the data to be reprocessed post-mission. Data can be collected in the unit, downloaded using "ftp", processed on a PC and viewed using the NAVdisplay.

Easy operation

There is minimal configuration required to use the system. The configuration can be saved to the RT so it can operate autonomously without user intervention. A lot of work has been put into the initialisation of the inertial algorithms so the RT can reliably start to navigate in the vast majority of situations.

The single unit contains inertial sensors, GNSS receiver, data storage and CPU. One or two antennas need to be mounted outside the vehicle where they have a clear view of the sky. A 10–50 V dc power supply can be obtained from most vehicles. A laptop computer allows real-time viewing of the results.

Self-correcting

Unlike conventional inertial navigation systems, the RT uses GNSS to correct all its measurements. GNSS makes measurements of position, velocity and (for dual antenna systems) heading. Using these measurements, the RT is able to keep other measurements, such as roll and pitch, accurate. Tight coupling of the GNSS and inertial measurements means the raw GNSS data can also be used. There is no drift from the RT in any of the measurements while GNSS is present.

Interchangeable

The RT500 (v1) and RT3000 (v3) products have identical output capabilities. The serial port, Ethernet, Wi-Fi and CAN bus are the same on RT500 and RT3000 devices including the data formats. Each device comes with two user cables which house the connections needed for data transfer from the RT to other devices e.g. laptop, Data Acquisition system, LiDAR etc.

Advanced processing

In poor GNSS environments, drift times can be halved by using the combined results of processing forwards and backwards in time. Our proprietary gx/ix™ processing engine can further improve performance with single satellite aiding algorithms and tight coupling of the inertial and GNSS measurements, meaning position updates even with fewer than four satellites in view.

Related documents

This manual covers the installation and operation of RT systems, but it is beyond its scope to provide details on service or repair. Contact OxTS support or your local representative for customer service related inquiries.

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.

Table 1. Supplementary manuals

Manual	Description
NAVdisplay Manual	For viewing real-time information from an RT. https://support.oxts.com/hc/en-us/articles/115002433285-NAVdisplay-Online-manual
NAVgraph Manual	For plotting and exporting captured data. https://support.oxts.com/hc/en-us/articles/115002433465-NAVgraph-Online-manual
NCOM Manual	For decoding and using the NCOM format. www.oxts.com/Downloads/Support/NCOM Manual and Code Drivers/ncomman.pdf
NCOM C Code Drivers	A collection of C functions that can be used to decode the binary protocols from the RT. www.oxts.com/Downloads/Support/NCOM Manual and Code Drivers/ncomrx.zip
NMEA 0183 Description	NMEA description manual for the NMEA outputs. www.oxts.com/Downloads/Support/NMEA/nmeaman.pdf
NAVsolve Manual	Explains how to use our post-processing application. https://support.oxts.com/hc/en-us/articles/360000225449-NAVsolve-manual

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RT product family

The RT product family is split into three device types (one of which is the RT1003 which has its own manual, available to download at support.oxts.com). The other two product device types are:

- **RT500s (v1)**
  Fitted with lower-cost GNSS receivers. The RT500 is a dual antenna model and is GLONASS enabled. 100 Hz and 250 Hz versions are available. An optional BeiDou upgrade is available.

- **RT3000s (v3)**
  Survey-grade GNSS receivers provide high-precision position and velocity measurements even in high multipath environments. Can be GLONASS and BeiDou enabled. The RT3000 L1 only mode is single antenna only and does not provide RTK position accuracy. The RT3000 with RTK support is dual antenna. 100 Hz and 250 Hz versions are available. The RT3000 is also able to run the OxTS RT-Range Hunter feature codes for ADAS testing.

The options contained within each device type are listed in the "Specification" section on page 16.

Single antenna

An advanced algorithm in the RT software means most road vehicle customers are able to use a single antenna system. The Heading lock and Advanced slip features allow RT devices to maintain an accurate heading while stationary and while driving with low vehicle dynamics.

Single antenna systems can experience reduced heading accuracy on aircraft, boats or in low-speed land vehicles.

Dual antenna

Dual antenna systems provide high accuracy heading information and almost constant heading performance under all conditions.

For aircraft or marine applications, or road vehicle applications on low-friction surfaces (e.g. ice), a dual antenna system is recommended to maintain high accuracy heading.

Advanced processing in the RT allows relock to occur after five seconds of a sky-obstruction – unlike GNSS-only systems which can take several minutes; in this time the RT's heading will not have significantly degraded. The fast relock time is made possible because the RT's own heading is used to resolve the ambiguities in the GNSS measurements. Resolution of these ambiguities is what normally takes several minutes.

The heading software in the RT enables significantly better performance and coverage compared to GNSS-only solutions.

GLONASS

GLONASS capability adds the ability to utilise the Russian satellite constellation GLONASS as well as the American constellation GPS. This means an extra 24 satellites are available for the RT to lock on to and obtain position and velocity updates from.

In open sky conditions, the addition of GLONASS capability is of little benefit as the GPS signals are unlikely to be interrupted and full accuracy can be achieved almost 100% of the time. However, in open-road testing situations there are likely to be bridges, trees, and tall buildings that can block the view of satellites or cause multipath effect errors. In these situations, GPS and GLONASS receivers are able to maintain 1 cm accurate RTK positioning mode at times when GPS-only receivers are not. They are also able to re-establish RTK lock and resolve its ambiguities after an obstruction faster.

BeiDou

BeiDou capability adds the ability to utilise the Chinese satellite constellation BeiDou as well as the American constellation GPS and Russian constellation GLONASS. This means an extra 34 satellites are available for the RT to lock on to and obtain position and velocity updates from.

250 Hz

1. All products (including the RT1003) have the option of coming with a 250 Hz version of the inertial measurement unit (IMU).

Satellite differential corrections

To improve the positioning accuracy of standard GNSS, two satellite-based differential correction services are available. These are SBAS and TerraStar.

Services such as WAAS and EGNOS, are wide-area differential corrections provided for free. They can provide an accuracy of better than 1 m CEP. WAAS is available in North America; EGNOS is available in Europe; MSAS is available in Japan; GAGAN is available in India; SDCM is available in Russia. Other parts of the world are not covered and cannot use this service.

TerraStar is a subscription service. RT systems that have TerraStar capability include the necessary hardware to receive corrections. It is necessary to pay a licence fee to activate these corrections. Capable RT systems will use the TERRASTAR-D service which can provide better than 10 cm position accuracy. TerraStar is available on all continents. Marine versions also exist.

For more information, see TerraStar's website: http://www.terrastar.net.

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Scope of delivery

RT products are supplied complete with users cables, an Ethernet cable and crossover, a Wi-Fi antenna, software, a calibration certificate, a tape measure, and a quick start guide.

RT500 and RT3000 system components

Table 2 lists all items that are delivered with each standard RT500 and RT3000 model.

Table 2. Summary of RT500 and RT3000 system components

Description	RT500 and RT3000
RT500 or RT3000 unit	✔
Power cable 77C0002B	✔
14P0038 user cable	✔
Aux user cable	✔
Ethernet cable (cross-over)	✔
USB stick with manual and software	✔
Tape measure	✔
Calibration certificate	✔
Quick start guide	✔

The RT3000 product that is RTK capable requires the correct differential corrections in order to work to full specification. Differential corrections can be supplied by an RT-Base S, GPS-Base, NTRIP or other suitable differential correction source.

In addition to the components supplied, the user will require a laptop computer or other logging system

Specification

Specifications for RT products can be found in Table 3 and Table 4. These specifications are listed for operation of the system under the following conditions:

- After a warm-up period of 15 minutes' continuous operation.

- 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. 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 RT 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.

  Optionally, extended measurement ranges covering 30 g acceleration and 300°/s angular rate may be requested. The specification using the extended measurement range sensors can be marginally worse than those listed here.

Table 3. RT500 and RT3000 specifications

Parameter	RT500 v1 (Dual antenna)	RT3000 v3 L1 only (single antenna)	RT3000 v3 (Dual antenna)
Positioning	GPS L1 GLONASS L1	GPS L1 GLONASS L1 BeiDou L1[1]	GPS L1, L2 GLONASS L1, L2 BeiDou L1, L2[1]
Position accuracy[2]	2.0 m CEP SPS 1.0 m CEP SBAS 0.5 m CEP DGPS	2.0 m CEP SPS 1.0 m CEP SBAS 0.4 m CEP DGPS	1.5 m CEP SPS 0.6 m CEP SBAS 0.4 m CEP DGPS 0.1 m CEP PPP 0.2 m 1σ L1 0.01 m 1σ L1/L2
Velocity accuracy	0.1 km/h RMS	0.1 km/h RMS	0.05 km/h RMS
Roll/pitch	0.05° 1σ	0.05° 1σ	0.03° 1σ
Heading	0.15° 1σ[3]	0.15° 1σ[3]	0.1° 1σ[3]
Acceleration – Bias stability – Linearity – Scale factor – Range	5 µg 1σ 0.01% 1σ 0.1% 1σ 100 m/s^2	5 µg 1σ 0.01% 1σ 0.1% 1σ 100 m/s^2	5 µg 1σ 0.01% 0.1% 1σ 100 m/s^2
Angular rate – Bias – Scale factor – Range	0.01°/s 1σ 0.1% 1σ 100°/s	0.01°/s 1σ 0.1% 1σ 100°/s	0.01°/s 1σ 0.1% 1σ 100°/s
Track (at 50 km/h)	0.15° 1σ	0.15° 1σ	0.07° 1σ
Slip angle (at 50 km/h)	0.25° 1σ	0.2° 1σ	0.15° 1σ
Lateral velocity	0.5% 1σ	0.4% 1σ	0.2% 1σ
Update rate	100 Hz / 250 Hz	100 Hz / 250 Hz	100 Hz / 250 Hz
Input voltage[4]	10–48 V dc	10–48 V dc	10–48 V dc
Power consumption	12 W	14 W	14 W
Dimensions	$184 \times 120 \times 71$ mm	$184 \times 120 \times 71$ mm	$184 \times 120 \times 71$ mm
Mass	1.5 kg	1.5 kg	1.5 kg

[1] Optional upgrade.

[2] To achieve specification, relevant differential corrections from a base station, NTRIP or TerraStar subscription are required.

[3] With two-meter antenna separation. Wider separation will improve accuracy (supports up to five-meter separation).

[4] Voltage range of connected devices such as radio modems must be considered.

Common specifications

Table 4. RT common specifications

Parameter	Specification
Calculation latency	1 ms
Operating temperature[1]	-40° to 70 °C
Vibration	0.1 g^2/Hz 5–500 Hz
Shock survival	100 g, 11 ms
Internal storage	32 GB

Notes on specifications

To achieve full accuracy in real time, the RT products will require appropriate differential corrections where applicable, either from a base station or with a TerraStar licence. Alternatively, a RINEX file can be downloaded post-mission and used to post-process the data to full accuracy.

For the TerraStar service, at least 30 minutes of open-sky condition may be required before full accuracy is achieved. This service can easily achieve this accuracy in airborne applications.

The "1σ" specification has been used for parameters where offset cannot be measured by the RT, for example position (the offset of the base station cannot be found by the RT 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 RT compared to the vehicle gives an offset the RT cannot measure.

The accuracy of the product will depend on the operating mode of the GNSS. For example, an RT3000 operating without differential corrections enabled will have the specifications of the RT3000 L1 only.

Heading accuracy

The heading accuracy that can be achieved by the dual antenna system in the RTs in Table 5 is 0.2° 1σ per metre of separation in ideal, open sky conditions. The system can provide these accuracies in static and dynamic conditions. A four-metre separation is required to reach the accuracy listed in Table 5. 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.

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For single antenna systems, the heading is calculated from the inertial measurements. The accuracies listed in Table 3 are achievable under dynamic conditions. Under static conditions the heading accuracy of single antenna systems will degrade.

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

Environmental protection

The RT500 and RT3000 products are rated to IP65. To achieve IP65 it is necessary to have connectors fitted to both TNC antenna connectors and to use self-amalgamating tape over the TNC connectors.

Export control classification number

Export control regulations change, and so the classification number of the RT may also change. The information presented here was correct when the manual was published. RT products can fall under two different export control categories depending on the type of accelerometer fitted internally. The type of accelerometer does not affect the specification of the product, only the export control classification number (ECCN). Table 5 lists the ECCN for the products.

Table 5. ECCN for RT products

Product	Serial number	ECCN
RT500		7A003d
RT3000 v3 L1 Only		Either 7A003d or 7A103a1, see invoice or delivery note or contact support at OxTS. Some products will have codes that relate to export control on their labels. EXCT-1—7A003d EXCT-2—7A103a1
RT3000 v3		7A003d

Conformance notices

The RT 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 more of the following:

o Re-orient or relocate the receiving antenna.

o Increase the separation between the equipment and the receiver.

The RT incorporates a GNSS receiver. 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 RT conforms to the requirements for CE.

Regulator testing standards

RT500 and RT3000 products

o 47 CFR 15.109:2010 class A (radiated emissions).

o EN 61000-4 criterion A according to standard EN 301 489-1:2008 (-2:2009 electrostatic discharge), (-3:2006+A2:2010 radiated immunity), (-4:2012 electrical fast transients), (-5:2006 voltage surge) and (-6:2009 conducted radio frequency immunity).

o EN 55022:2010 class A according to standard EN 301 489-1:2008 (Radiated electromagnetic emissions) and (conducted emissions).

o EN 55011:2009+A1:2010 class A according to standard EN 301 489- 1:2008 (Radiated electromagnetic emissions).

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Software installation

Included with every RT is a USB stick containing the software package NAVsuite. This package contains several programs required to take full advantage of the RT's capabilities. Table 6 lists the contents of NAVsuite.

Table 6. 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 RT 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 RT-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.

To install NAVsuite, insert the USB stick 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 1 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 talk on the network, or programs will not work as intended.

Figure 1. Windows Firewall warning message
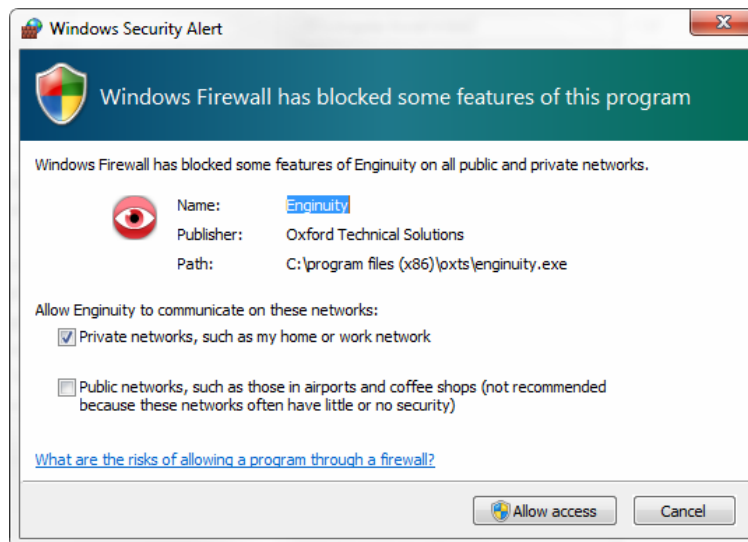
Ensure both Private and Public networks are selected to ensure the software can continue functioning when moving from one type to another.

Hardware installation

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

The RT is compatible with the RT-Strut product from OxTS to provide a quick and secure vehicle mounting solution.

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

RT orientation and alignment

The orientation of the RT in the vehicle is normally specified using three consecutive rotations that rotate the RT 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.

In the default configuration the RT expects its y-axis to be pointing right and its z-axis pointing down relative to the host vehicle. There are times however when installing an RT in the default configuration is not possible, for example when using the RT-Strut. The RT can be mounted at any angle in the vehicle as long as the configuration is described to the RT 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 RT 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 RT 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.

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 2. 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.

Figure 2. Dual antenna orientations
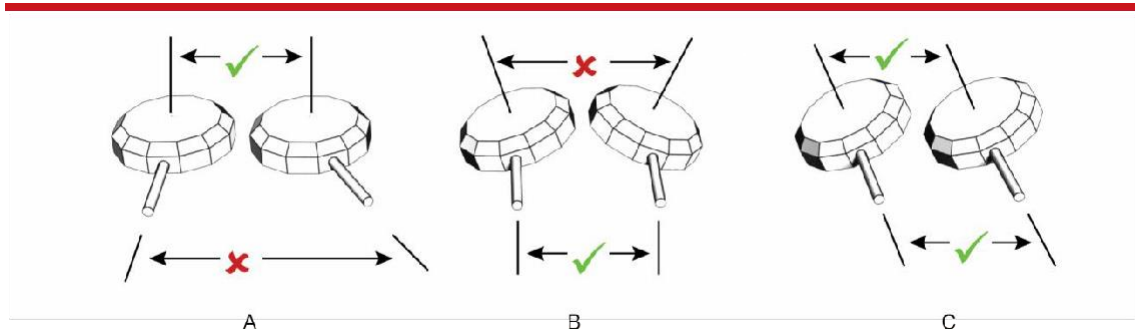
A) The bases of the antennas are parallel, but the cables exit in different directions. **B)** The cables exit in the same direction but the bases of the antennas are not parallel. **C)** The bases of the antennas are parallel and the cables exit in the same direction. This configuration will achieve 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 RT mounted securely in the vehicle. If the angle of the RT 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 RT is shock mounted then the RT 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 5 m and 15 m lengths.

Operation

The top label and LEDs convey some basic information that aids configuration and troubleshooting. Once power is applied, the RT requires no further input from the user to start logging and outputting data.

This section covers some basic information required for operation of the RT.

Front panel layout

Figure 3 shows the layout of the RT500 and RT3000 front panel. Table 7 lists the parts of the front panel labelled in Figure 3. For single antenna models, the secondary antenna connector is not connected internally.

Figure 3. RT500/RT3000 front panel layout

Table 7. RT3000 v3 RT500 v1 front panel descriptions

Label no.	Description
1	Power LED
2	Status LED
3	GNSS LED
4	User cable main connector
5	Second user cable connector
6	Primary GNSS antenna connector
7	Secondary GNSS antenna connector
8	WI-Fi antenna connector

LED definitions

The LEDs on the connector panel provide information about the current system state, but it is not possible for the LEDs to communicate everything the product is capable of measuring.

Instead, they provide a snapshot of the current status and are useful for at-a-glance checks without the need for a portable PC. The tables below describe the behaviour of each LED.

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Table 8. GNSS LED states

Colour	Description
Off	GNSS receiver fault (valid only after start-up)
Red flash	GNSS receiver is active, but has been unable to determine heading
Red	The GNSS 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

Table 9. Status LED states

Colour	Description
Off	The operating system has not yet booted and the program is not yet running. This occurs at start-up
Red-green flash	The RT1003 is asleep. Contact OxTS support for further information
Red flash	The operating system has booted and the program is running. 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 (the 1PPS output will now be valid). The strapdown navigator is ready to initialise. If the vehicle is travelling faster than the value set for "Initialisation speed" during configuration then the strapdown navigator will initialise and the system will become active. On dual antenna systems the system will initialise once the GNSS receiver has determined heading, even if the vehicle is stationary or moving slowly
Orange	The strapdown navigator has initialised and data is being output, but the system is not real-time yet. It takes 10 seconds for the system to become real-time after start up
Green	The strapdown navigator is running and the system is real-time[a]

a. In the current versions of the software the strapdown navigator will not leave green and return to any other state. This may change in future releases.

Table 10. Power (PWR) states

Colour	Description
Off	There is no power to the system or the system power supply has failed
Green	Power is applied to the system
Orange	The system is powered and Ethernet traffic is present

Co-ordinate frame conventions

Measurements made by the INS are available in a number of different reference frames for use in different applications.

IMU frame

The IMU reference frame used by the RT (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.

When making measurements required in the configuration files, measurements should be made between the point of interest and the measurement origin shown in Figure 4. The axes and measurement origin point are the same for all RT models.

Figure 4. IMU co-ordinate frame and measurement origin
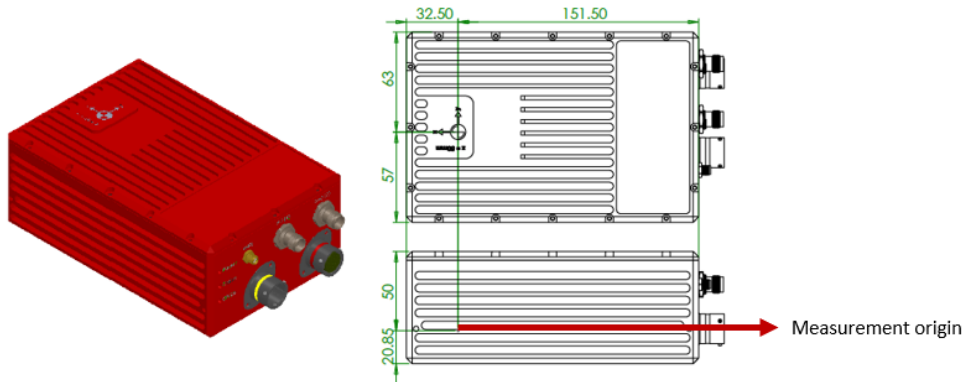
Table 11 lists the directions that the axes should point for zero heading, pitch and roll outputs when the default mounting orientation is used.

Table 11. Direction of axes for zero heading, pitch and roll outputs

Axis	Direction	Vehicle axis
X	North	Forward
Y	East	Right
Z	Down	Down

Once installed, if the RT axes and the vehicle axes are not the same as those listed in Table 12, they can be aligned by reconfiguring the RT for a different mounting orientation using the NAVconfig software.

If the RT-Strut is being used to mount the RT in the vehicle then NAVconfig will have to be used to configure the orientation or the RT will not work correctly.

OxTS NED navigation frame

Table 12. OxTS NED navigation frame definition

Axis	Description
North	The north axis (N) is perpendicular to the gravity vector and in the direction of the North Pole along the earth's surface.
East	The east axis (E) is perpendicular to gravity, perpendicular to the north axis and is in the east direction.
Down	The down axis (D) is along the gravity vector.

Figure 5. OxTS NED navigation frame definition

The OxTS navigation frame is attached to the vehicle but does not rotate with it. The down axis is always aligned to the gravity vector and north always points north.

ISO 8855 ENU earth-fixed system

Table 13. ISO 8855 ENU earth-fixed system

Axis	Description
East	The east axis (E) is perpendicular to gravity, perpendicular to the north axis and is in the east direction.
North	The north axis (N) is perpendicular to the gravity vector and in the direction of the north pole along the earth's surface.
Up	The up axis (U) is co-axial with the gravity vector, and positive in the up direction.

Figure 6. ISO 8855 ENU earth-fixed system

The ISO earth-fixed system is attached to the vehicle but does not rotate with it. The north and east axes are perpendicular to the gravity vector and north always points north.

OxTS horizontal frame

The OxTS horizontal frame (sometimes called the level frame) is attached to the vehicle but does not rotate with the roll and pitch of the vehicle. It rotates by the heading of the vehicle. The definition of the OxTS Horizontal frame is listed in Table 14 and shown in Figure 7.

Table 14. OxTS Horizontal frame definition

Axis	Description
Forward	This is the longitudinal (forward) direction of the vehicle, projected in to the horizontal plane.
Lateral	This is the lateral direction of the vehicle, pointing to the right, projected in to the horizontal plane.
Down	This is the vertical (down) direction of the vehicle, along the gravity vector.

Figure 7. OxTS horizontal frame definition
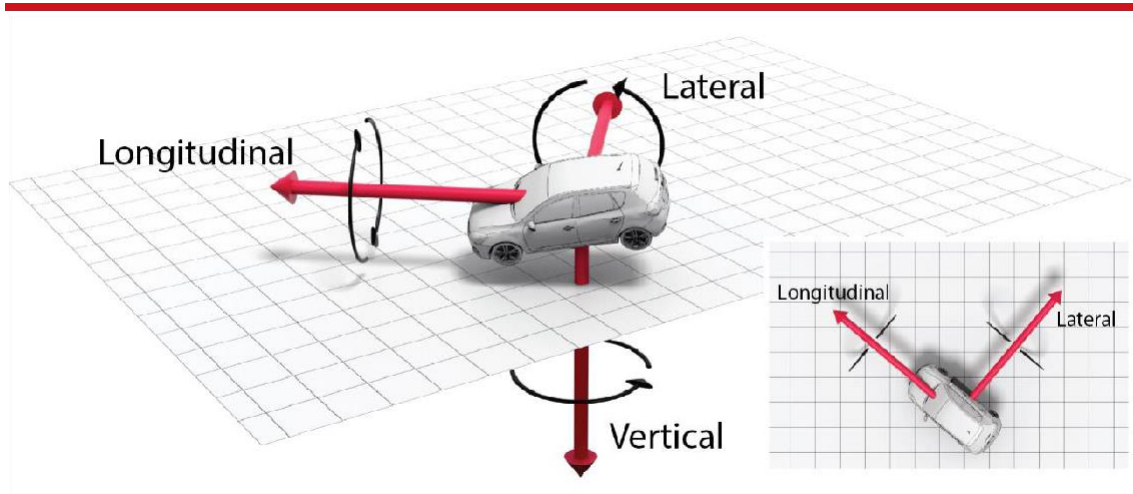
The OxTS horizontal frame is attached to the vehicle. The longitudinal and lateral axes remain parallel to a horizontal plane. The longitudinal axis is also parallel to the vehicle's heading when viewed from above.

ISO 8855 intermediate system

The ISO 8855 intermediate system is attached to the vehicle but the *X*- and *Y*-axis both remain parallel to the ground plane. The *X*-axis is also aligned with the vertical projection of the vehicle heading. The definition of the ISO 8855 intermediate system is listed in Table 15. ISO 8855 intermediate system and shown in Figure 8.

Figure 8. ISO 8855 intermediate system
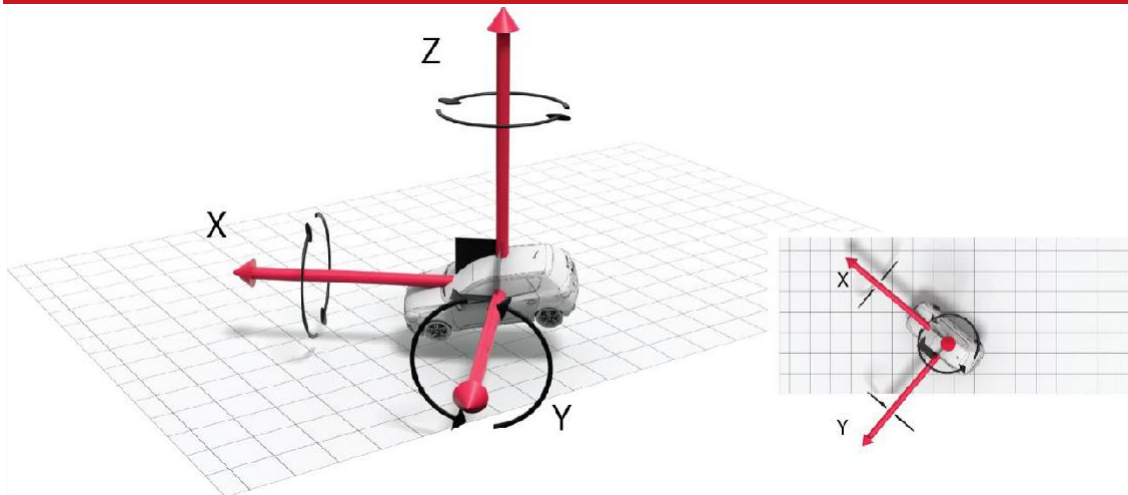
The ISO intermediate system is attached to the vehicle. The X- and Y-axes remain parallel to a horizontal plane. The X-axis is also parallel to the vehicle's heading when viewed from above.

Table 15. ISO 8855 intermediate system

Axis	Description
X	This is the forward direction of the vehicle, projected into the horizontal plane.
Y	This is the lateral direction of the vehicle, pointing to the left, projected in to the horizontal plane.
Z	This is the vertical direction of the vehicle, pointing up.

OxTS vehicle frame

The OxTS vehicle frame is attached to the body of the vehicle. It is related to the INS through the rotations in the Orientation page of NAVconfig. It can be changed while the INS is running using the Quick Config tool of NAVdisplay. The definitions of the vehicle frame are listed in Table 16 and shown in Figure 9.

Table 16. Vehicle frame definition

Axis	Description
X	This is the forward direction of the car.
Y	This is the right direction of the car.
Z	This is the down direction of the car.

Figure 9. Vehicle frame definition
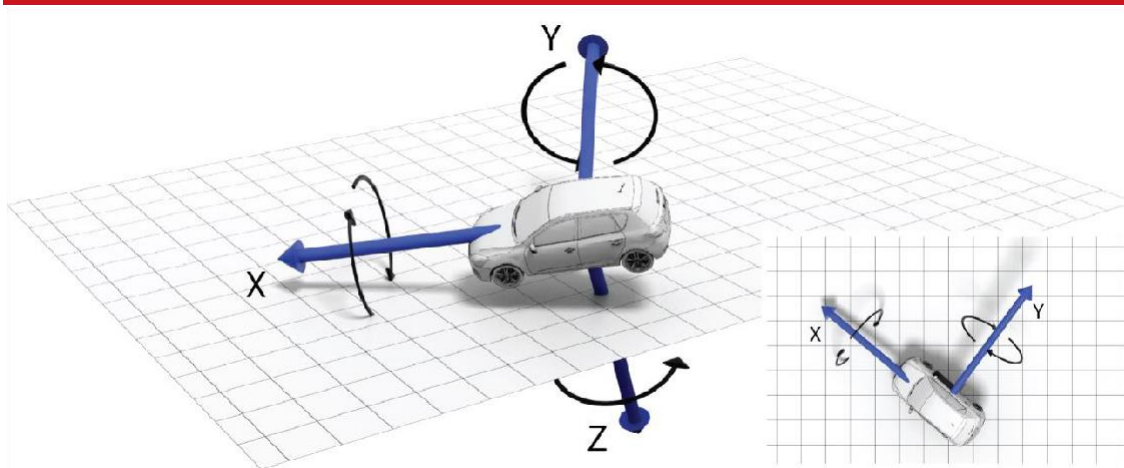
The OxTS vehicle frame is attached to the vehicle and rotates with it in all three axes. The X-axis remains parallel to the vehicle's heading, while the Y-axis points to the right and is perpendicular to the vehicle's vertical plane of symmetry

ISO 8855 vehicle system

The ISO 8855 vehicle system is attached to the body of the vehicle. At rest, the *X*-axis points forwards horizontally and is parallel to the vehicle's longitudinal axis. The *Y*-axis is perpendicular to the longitudinal axis and points left. The *Z*-axis is orthogonal to the *X*- and *Y*-axes. Definitions are listed in Table 17 and shown in Figure 10.

Table 17. ISO 8855 vehicle system

Axis	Description
X	This is the forward direction of the car.
Y	This is the left direction of the car.
Z	This is the up direction of the car.

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Figure 10. ISO 8855 vehicle system

The ISO vehicle frame is attached to the vehicle and rotates with it in all three axes. The X-axis remains parallel to the vehicle's heading, while the Y-axis points to the left and is perpendicular to the vehicle's vertical plane of symmetry.

Ethernet configuration

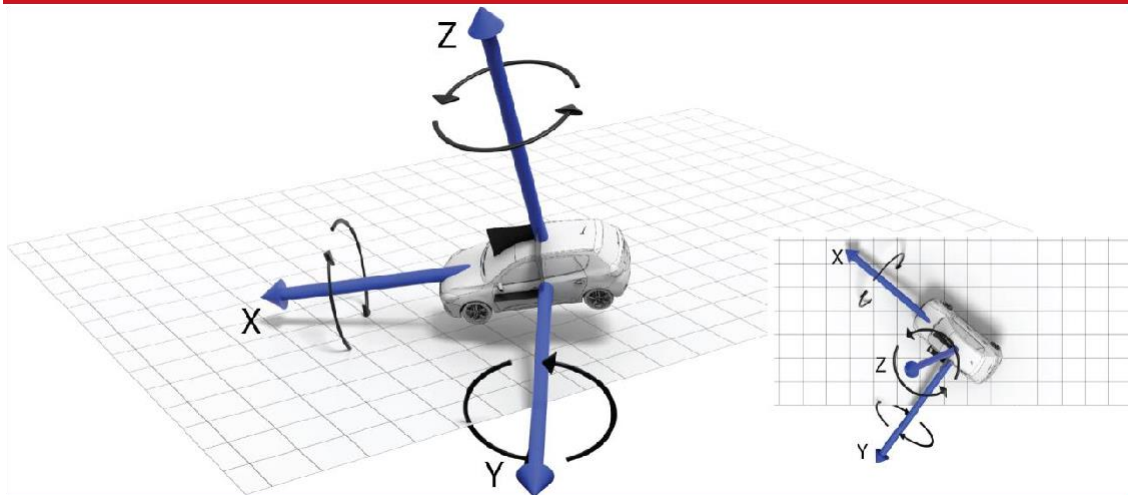To configure the RT for unrestricted data transmission it is necessary to use the Ethernet connection. The RT 500 and RT3000 v3 also support Wi-Fi data transmission and the setup of WiFi is covered later in this manual. The operating system at the heart of the RT products allows connection to the unit via FTP. The use of FTP allows the user to manage the data logged to the unit; files can be downloaded for reprocessing and deleted to make space for future files. Configuration files for alternative configurations require FTP to put the configuration files on to the RT. The default username and password are both "user".

The RT 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 RT. The data rate of the UDP broadcast is 100 Hz or 250 Hz.

In order to communicate via Ethernet each RT is configured with a static IP address that is shown on the delivery note. If the delivery note is unavailable, the default IP address normally takes the form 195.0.0.sn, where sn is the last two digits of the RT's serial number. The serial number can be found on the top of the RT or on the delivery note.

The IP address of the computer being used to communicate with the RT may need to be changed so it matches the subnet. For example, 195.0.0.200 should be available since this IP address is never used by the RT by default.

To change the IP address of the computer, follow these steps (applies to Windows Vista/7/8/10):

1. Open the 'Control Panel' from the Start menu.

2. In category view, select 'Network and Internet' and then 'Network and Sharing Centre'.

3. Select 'Change adapter settings' in the side panel.

4. Right-click the Ethernet option and select 'Properties'.

5. In the window that opens, navigate the list to find **Internet Protocol Version 4 (TCP/IPv4)**. Select it and click 'Properties'.

6. In the TCP/IPv4 Properties window (Figure 11), select 'Use the following IP address' and enter the IP address and subnet mask to use.

7. Click 'OK' when finished.

Figure 11. Configuring the computer's IP address for Ethernet data transmission
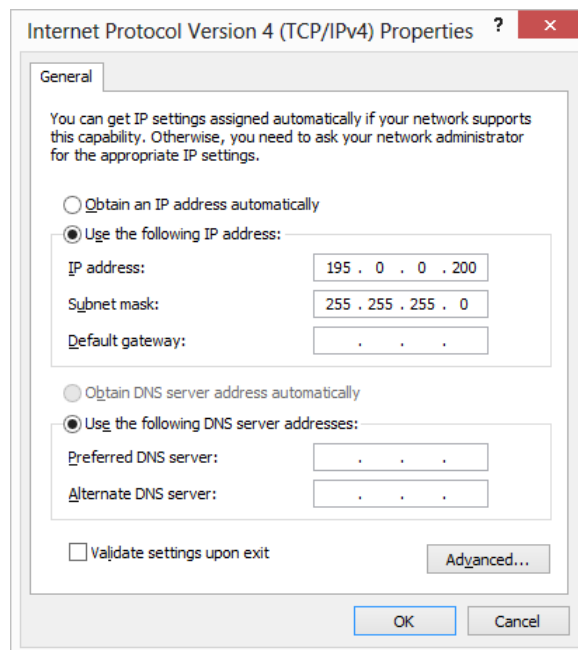
Once the computer is configured the IP address of an RT can be found by running NAVdisplay software; this will display the IP address of any RT connected.

Note that it is possible to change the IP address of RT systems. If the IP address has been changed then NAVdisplay should still be able to identify the address that the RT is using, as long as the PC has a valid IP address and this is not the same as the RT's.

Connection details for Ethernet configuration

The RJ-45 connector on the 14C0038*x* 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 RT can be connected directly to an Ethernet card in a computer. To do this a crossed in-line coupler must be used. The connections in the crossed coupler are given in Table 18. Note that this is not the normal configuration sold and it may be necessary to modify an existing coupler to suit.

Table 18. In-line coupler connections

Socket 1	Straight socket 2	Crossed socket 2
Pin 1	Pin 1	Pin 6
Pin 2	Pin 2	Pin 3
Pin 3	Pin 3	Pin 2
Pin 4	Pin 4	–
Pin 5	Pin 5	–
Pin 6	Pin 6	Pin 1
Pin 7	Pin 7	–
Pin 8	Pin 8	–

A typical in-line coupler is shown in Figure 12.

Figure 12. In-line RJ-45 coupler

Wi-Fi configuration

The RT can be configured via a Wi-Fi connection using the Wi-Fi access point inside the RT itself. Like Ethernet, the use of FTP via a Wi-Fi connection allows the user to manage the data logged to the unit; files can be downloaded for reprocessing and deleted to make space for future files. Configuration files for alternative configurations require FTP to put the configuration files on to the RT.

The RT outputs its data over Wi-Fi to each device connected to its access point as a UDP unicast message.

In order to communicate via Wi-Fi, each RT is configured with a static IP address that is shown on the delivery note. If the delivery note is unavailable, the default IP address normally takes the form 195.0.0.sn, where sn is the last two digits of the RT's serial number. The serial number can be found on the front panel of the RT or on the delivery note.

Once you are on the same IP range as the RT you can connect to the RT via Wi-Fi. Via your PC's network settings you should be able to select the 'RT as a Wi-Fi network'. The RT that you wish to connect to can be identified by its serial number. See Fig 14 below.

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Figure 13. Connect to the Wi-Fi module in the RT
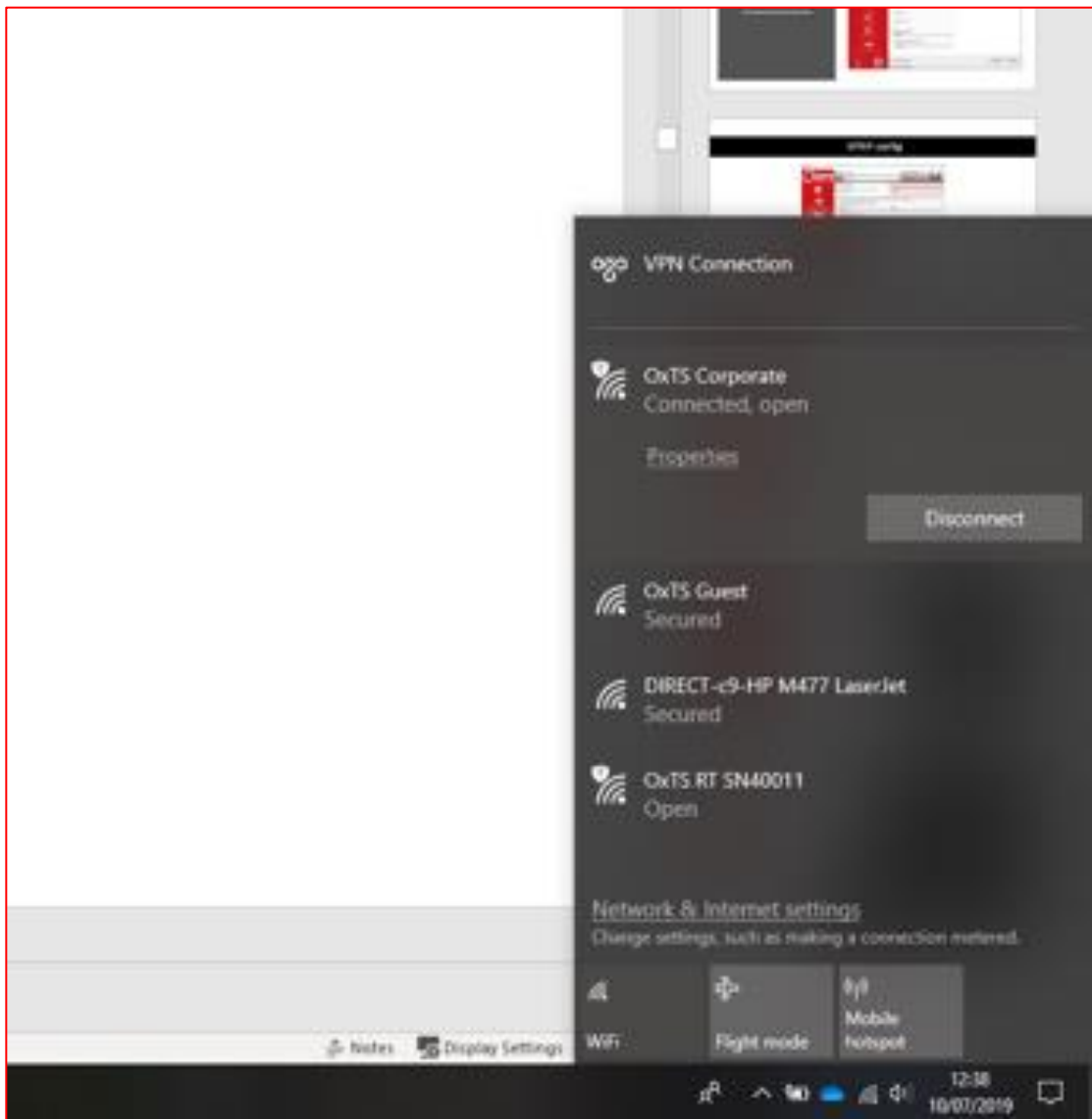
Wi-Fi settings are configured using NAVconfig and this process is explained later in this manual.

Dual antenna systems

It is often useful to have an understanding of how the RT uses the measurements from the dual antenna system. This can lead to improvements in the results obtained.

1. To use the measurements properly the RT needs to know the angle of the GNSS antennas compared to the angle of the RT. This is very difficult to measure accurately without specialised equipment, therefore the RT needs to measure this itself as part of the warm-up process.

2. The RT 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 RT.

3. When the vehicle drives forward and reaches the initialisation speed, the RT assumes that the heading and track are similar and initialises heading to track angle.

    If the RT 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 RT is initialised in a turn. This can lead to problems later.

4. When the combined accuracy of heading plus the orientation accuracy figure for the secondary antenna is sufficiently accurate then the RT will solve the RTK Integer problem using the inertial heading. There is no need for the RT to solve the RTK Integer problem by searching.

    If the antenna angle is offset from the RT by a lot then the RTK Integer solution that is solved will be incorrect. For a 2 m antenna separation the RT 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.

5. Once the RTK Integer solution is available, the RT 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.

6. 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 RT can improve the heading using this value. If you want the vehicle heading to 0.1°, but the angle of the two GNSS antennas is only known to 5°, then the measurements from the antenna are not going to be able to improve the heading of the vehicle.

    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 is available in the verified in NAVdisplay.

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7.   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.

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 RT is permanently mounted in a vehicle and the antennas are bolted on. Any movement of either the RT or the antennas will upset the algorithms.

Multipath effects on dual antenna systems

Dual antenna systems are very susceptible to the errors caused by multipath. This can be from buildings, trees, roof-bars, etc. 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.

The dual antenna system in the RT 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 RT 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.

When stationary the heading from the RT will show some error; the size of the error depends on the multipath in the environment. Table 19 lists the errors to be expected when stationary with a 1 m base-line.

Table 19. Typical heading error for when stationary in different environments

Environment	Typical error (3σ)
Complete open-sky	0.6° (0.2° 1σ)
Near trees, buildings	1°
Next to trees, buildings	2°

Typical figures using a 1 m base-line. For accuracy specification of 0.1° RMS a 2 m separation is required. Using a 2 m base-line can halve the figures shown here.

Inputs and outputs

RTs have two connectors for their inputs and outputs. The J1 connector of the 14C0038 user cable connects to the primary user cable and connectors J2–J7 provide connections for the inputs and outputs. The J1 connector on the Aux user cable (secondary) provides three additional inputs and outputs. See the user cable drawings located at the back of this manual for more details on the connectors and pin assignments. The main connectors are keyed so the user cable must be correctly aligned for it to connect.

The system can output data on the serial port, over Ethernet and over CAN bus. The standard serial output of the RT is a proprietary binary format, referred to as NCOM. OxTS offers C and C++ code that will interpret the packet. This can be used freely in users' programs to interpret the output of the RT. More information about NCOM can be found in the NCOM description manual.

It is also possible to output a standard NMEA string from the RT to mimic the output of standard GNSS receivers.

OxTS offers a service to tailor the serial output format to the customer's specification. Contact Oxford Technical Solutions for details of this service

Digital inputs and outputs

Table 20 describes each of the signals on the digital I/O connector J5 of the 14C0038X user cable. A more detailed explanation of each signal can be found below.

Table 20. Digital I/O signals

Pin#	Name (function)	Description
J5-1	Digital 1 (1PPS output)	Pulsed output from primary GNSS receiver, synchronised with the transition of GPS seconds
J5-2	Digital 2 (Trigger 1)	User-selectable I/O (input/distance output/IMU sync output)
J5-3	Digital 3 (Wheel speed 1A)	Input for Hall-effect wheel speed sensor. When connecting a quadrature sensor, this input is the A-channel
J5-4	Digital 4 (Trigger 2)	User-selectable I/O (input/distance output/IMU sync output)
J5-5	Digital 5 (Wheel speed 1B)	When connecting a quadrature wheel speed sensor, this input is for the B-channel
J5-6	Digital ground	
J5-7	Digital ground	
J5-8	Digital ground	
J5-9	Digital ground	

1PPS output

The 1PPS (J5-1) 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.

Figure 14. 1PPS waveform

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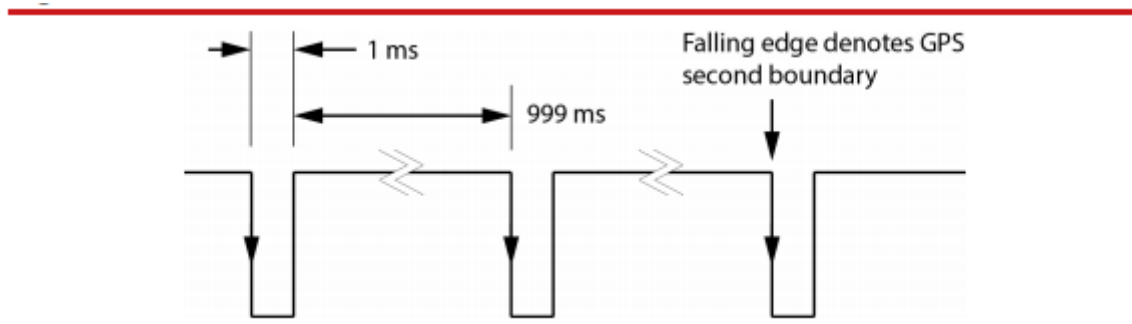
Trigger 1 and 2

Trigger 1 (J5-2) and Trigger 2 (J5-4) can be used to generate events within the RT for purposes of identifying external events, or to output a time/distance-based signal for the purpose of driving external events. Both Triggers are independently configurable in the Options page of NAVconfig.

In input mode, the trigger waits for a signal from an external device such as a camera or switch. When a signal is detected, a time-stamped measurement is generated by the INS in addition to the normal measurements being generated. The trigger inputs have a pull-up resistor so they can be used with a switch or as a CMOS input.

Input signal characteristics:

• 0 V and 5 V input
• low < 0.6 V
• high > 2.6 V

In output mode, the trigger generates pulses based on distance or in synchronisation with the IMU clock rate. The pulse width of the distance-based signal is 1 ms, whereas the IMU sync signal has a duty cycle of approximately 50%.

Output signal characteristics:

• 0 V and 5 V output
• low <= 0.8 V
• high >= 2.4 V

Camera mode is a software condition that is automatically entered when the PPM distance output is configured as less than 1 PPM. It exists in order to generate time-stamped INS measurements synchronised with distance-based output triggers. The output is called camera mode as it's often used to trigger image recording equipment, which can then be matched to the position measurements at the precise moment of the trigger. Camera mode provides a method of achieving this.

To enter camera mode, configure a trigger as an output, and set the distance to less than one pulse per metre. A signal will be generated according to the specifications above at the distance interval defined by the PPM settings. At the same moment the trigger signal is output, a position measurement will be internally generated and logged alongside the regular measurement data. To generate a real-time message in relation to the camera trigger, it is necessary to select the 'Output on camera trigger option' on the Ethernet configuration window.

Wheel speed input

The wheel speed 1A input (J5-3) accepts TTL pulses from an encoder on a single wheel. An encoder from a gearbox should not be used, and simulated TTL pulses (e.g. converted from the CAN bus) should not be used either. The timing of the wheel speed input pulses is critical and nothing should cause any delay to them.

The RT also accepts signals from quadrature wheel speed sensors. When using quadrature sensors, connect one channel from the quadrature sensor to wheel speed 1A, and the other to wheel speed 1B input (J5-5). The odometer input should be configured as per a normal wheel speed sensor – the RT will automatically detect the use of the quadrature sensor.

The wheel speed input requires less than 0.8 V for a low pulse and more than 2.4 V for a high pulse. Limited protection is provided on this port, however the input voltage should not exceed 12 V.

Wheel speed input signal characteristics:

• 0 V to 12 V
• low < 0.8 V
• high > 2.4 V

The wheel that is used should not steer the vehicle. The RT will assume the wheel travels straight.

IMU sync output pulse

The synchronising edge of the PPS is configurable in NAVconfig.

Configuring the RT

To obtain the best results from your RT it will be necessary to configure the RT to suit the installation and application before using it. The program NAVconfig can be used to do this. This section describes how to use NAVconfig and gives additional explanations on the meanings of some of the terms used.

It is only possible to change the RT configuration using Ethernet or WiFi. It is necessary to have the Ethernet and Wi-Fi adaptor settings on your computer configured correctly in order to communicate with the RT and change the settings. See the sections "Ethernet configuration" and "WiFi configuration" on pages 36 and 37 for
 more information.

Overview

In order to give the best possible performance, the RT needs to know the following things:

- The orientation of the RT as it is mounted in the vehicle.

- The position of the primary GNSS antenna compared to the RT.

- The orientation of dual antennas (if applicable) compared to the RT.

- The position of the rear wheels (or non-steering wheels) compared to the RT.

- Some environment parameters.

The RT can work out many of these parameters by itself, but this takes time. Measuring the parameters yourself and configuring the RT reduces the time taken to achieve full specification.

RT products can calculate the position of the GNSS antenna. This works well when using a base station to achieve 1 cm accuracy, but can take hours with less accurate positioning modes. It is best to measure the position of the GNSS antenna to an accuracy of 10 cm or better.

If the RT has been running for some time, it will have improved the measurements. It is possible to read these improved measurements into NAVconfig, commit them to the RT, then use them next time you start the system. If you move the RT from one vehicle to another it is essential you create a new configuration rather than using parameters that have been tuned for a different vehicle.

Working through NAVconfig

NAVconfig is split into seven sections. Each section contains several tabs with settings that can be applied to the device. The sections are: Home, Ready Configuration, Hardware Setup, Interfaces, Environment, Advanced Tools and Write Configuration.

When a device is connected via WiFi or Ethernet, the product name (including serial number) will be displayed at the top of the application. By clicking on the 'Save' icon at the top right of the application you can save your configuration process to a destination on your computer. This can be done at any stage.

NAVconfig supports English and Chinese (simplified) languages.. You can switch language in NAVconfig by clicking on the 'Settings' button at the bottom left of the window and choosing your preferred language from the options.

If you are connected to a device or editing a configuration file from an RD file then it is possible to view information related to the device in NAVconfig. Click the '*i*' icon in the bottom left of the window to see a list of features related to your device.

NAVconfig Home section in NAVconfig

NAVconfig is a universal tool that is used to configure many different devices. The first step is to choose whether you are starting a new configuration, modifying an existing configuration or improving a configuration after a device warm-up.

When you select 'New configuration' you must then go through each step of the configuration wizard in order before committing a new configuration to the device.

When you select 'Modify configuration' you can jump in and edit the configuration, navigating through all the options in any order before committing the changes.

Selecting "Improve configuration" sets up a different workflow within NAVconfig for users who have completed a device warm-up and want to apply improved settings to the device and recommit these settings.

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Figure 15. NAVconfig Home section
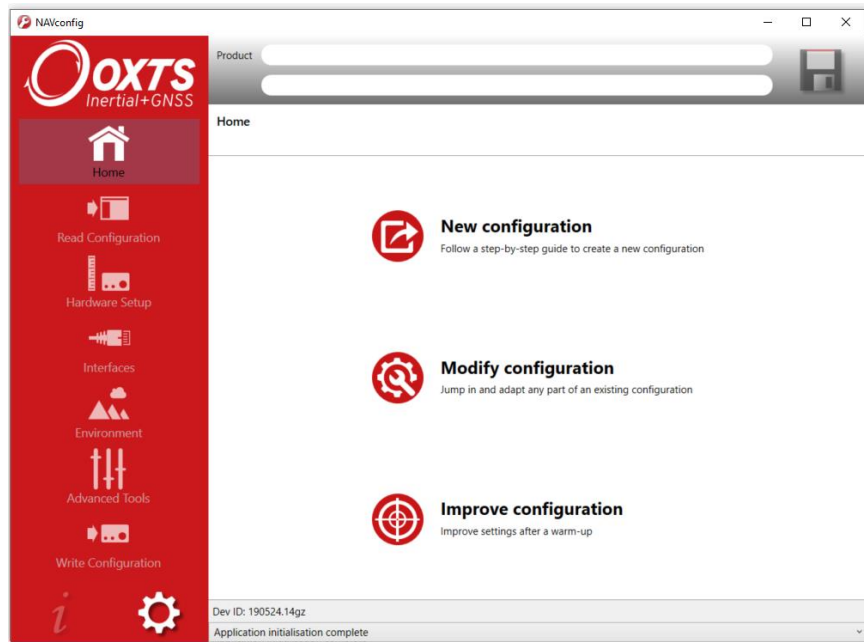
Start/Read Configuration section in NAVconfig

Figure 16. NAVconfig Start/Read Configuration section

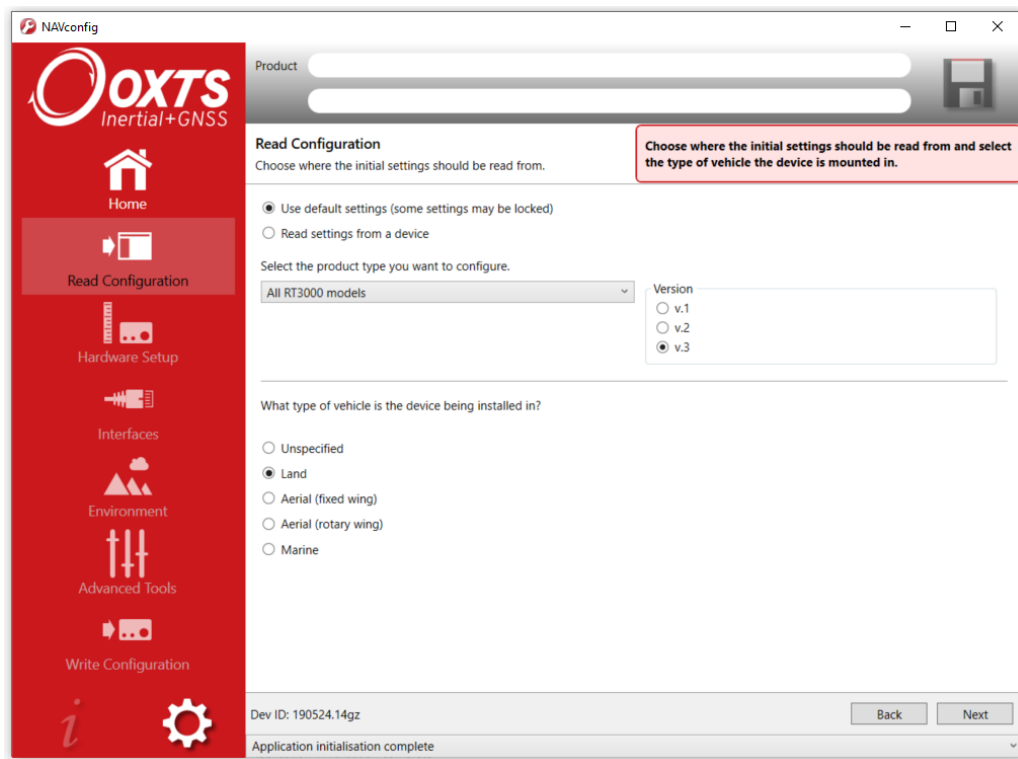This section becomes available when you choose "New configuration" or "Modify configuration" from the Home section. It is important to ensure the correct Product type and version is selected. The settings available in NAVconfig vary depending on the product type and version chosen.

The product model and generation (version) can be found on the label on your product.

Read Configuration section

The Read Configuration choice tells NAVconfig where to read the initial configuration from (see Figure 18).

Figure 17. NAVconfig Read Configuration section

Read settings from a folder: It is possible to store a configuration in a folder. The configuration comprises several files, so it is tidier to keep it in a folder by itself. To read the configuration from a folder, select this option and then specify a folder by clicking the 'Browse…' button.

'Read settings from a raw data (RD) file:' The RT writes the configuration it is using to the internally stored RD file. This option extracts the configuration used and loads it into the configuration wizard. Specify an RD file by clicking the 'Browse'**…** button.

Read initial settings from device: If the RT is connected to the computer via Ethernet or WiFi it is possible to read the initial settings directly from the RT. The settings loaded are the settings that were last committed to the RT using NAVconfig or the factory default settings applied at manufacture stage. Select this option and enter the correct IP address of your RT or select it from the dropdown list.

You must also specify the type of vehicle that the device is being installed in. This will tailor the settings available to edit in NAVconfig.

Hardware Setup section in NAVconfig

This section contains settings related to the position and orientation of the RT in the vehicle and the GNSS antennas as well as the profile of the vehicle in which the RT is being installed (position of axles). It is broken up into tabs and it is recommended that you work through each tab in order.

IMU orientation tab

The IMU orientation tab is used to define the vehicle co-ordinate frame relative to the RT's co-ordinate frame. It is important to get the orientation correct as although settings entered on this page do not affect the accuracy of the RT, if the outputs are not properly rotated to the vehicle frame then the measurements will appear incorrect.

When using an RT-Strut, the orientation will need to be changed. Figure 19 shows an RT mounted on an RT-Strut in a vehicle. In this configuration, the *y*-axis points left and the *z*-axis points forwards. Other configurations are possible with the RT-Strut.

Figure 18. An RT device mounted on our RT-Strut

Use the **Y axis points** and the **Z axis points** box to specify which way the RT's axes point in the vehicle. Figure 4 shows the RT axes' directions. The IMU orientation tab of the configuration wizard, also has illustrations to visualise the orientation of the RT in a vehicle based on the settings input. The advanced settings will change to show the three rotations associated with orientation input, even when unavailable.

Figure 19. NAVconfig IMU orientation tab in the Hardware Setup section
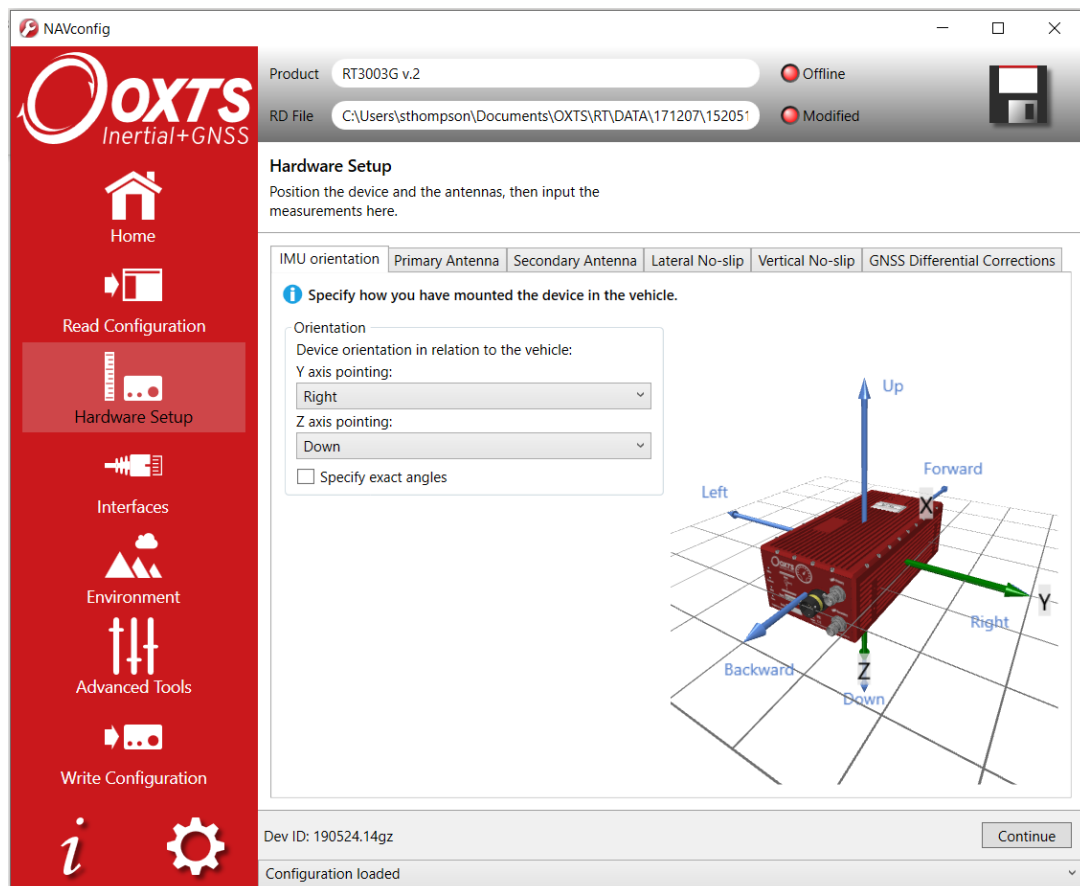
For correct initialisation, it is necessary to get the heading orientation correct. The RT gets its initial heading by assuming the vehicle is travelling forwards in a straight line. If the definition of the vehicle's x-axis (forward direction) is incorrect in the RT then it will not initialise correctly when the vehicle drives forwards.

If the vehicle level option is used, then the pitch and roll orientations must also be correct.

To make small adjustments, select the 'Specify exact angles' checkbox to enable the rotations for editing. This allows any slip angle, pitch or roll offsets to be zeroed.

Primary antenna tab

The RT can calculate the position of the primary antenna itself. However, this takes time and better results can be achieved sooner if the user measures the distance accurately. Getting these measurements wrong is one of the main reasons for poor results from the RT, so it is important to be careful. It is recommended to measure the GNSS antenna position to an accuracy of 10 cm or better. Figure 21 shows the Primary Antenna page.

Figure 20. NAVconfig Primary Antenna tab
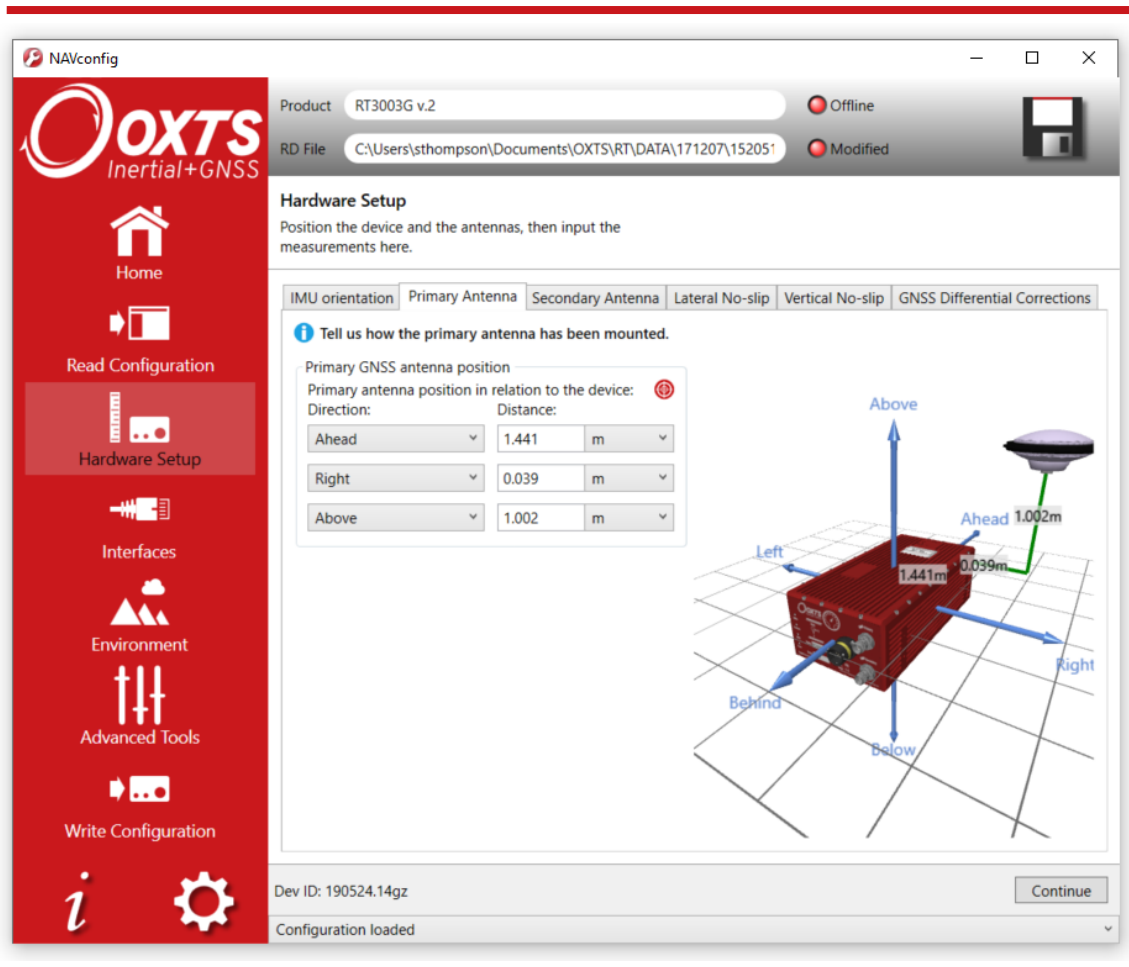
It is necessary to tell the RT the distance between its measurement origin (shown in Figure 4) and the GNSS antenna's measurement point. This should be entered in the vehicle's co-ordinate frame.

The RT will try to improve the position of the primary GNSS antenna during use. To use the values the RT has estimated use the "Improve configuration" wizard after your warm-up on the Orientation utility page.

Secondary Antenna tab

If your system has two antennas, click the 'Secondary GNSS antenna' checkbox on the Secondary Antenna page (Figure 22) to allow the configuration to be entered. If it is not enabled, the RT will ignore the secondary antenna and will not use it to compute a heading solution.

Enter the antenna separation and select to position of the secondary antenna relative to the primary antenna from the dropdown list. The illustrations will change according to the settings you choose to help visualise the configuration of the antennas.

Figure 21. NAVconfig Secondary Antenna tab in the Hardware Setup section
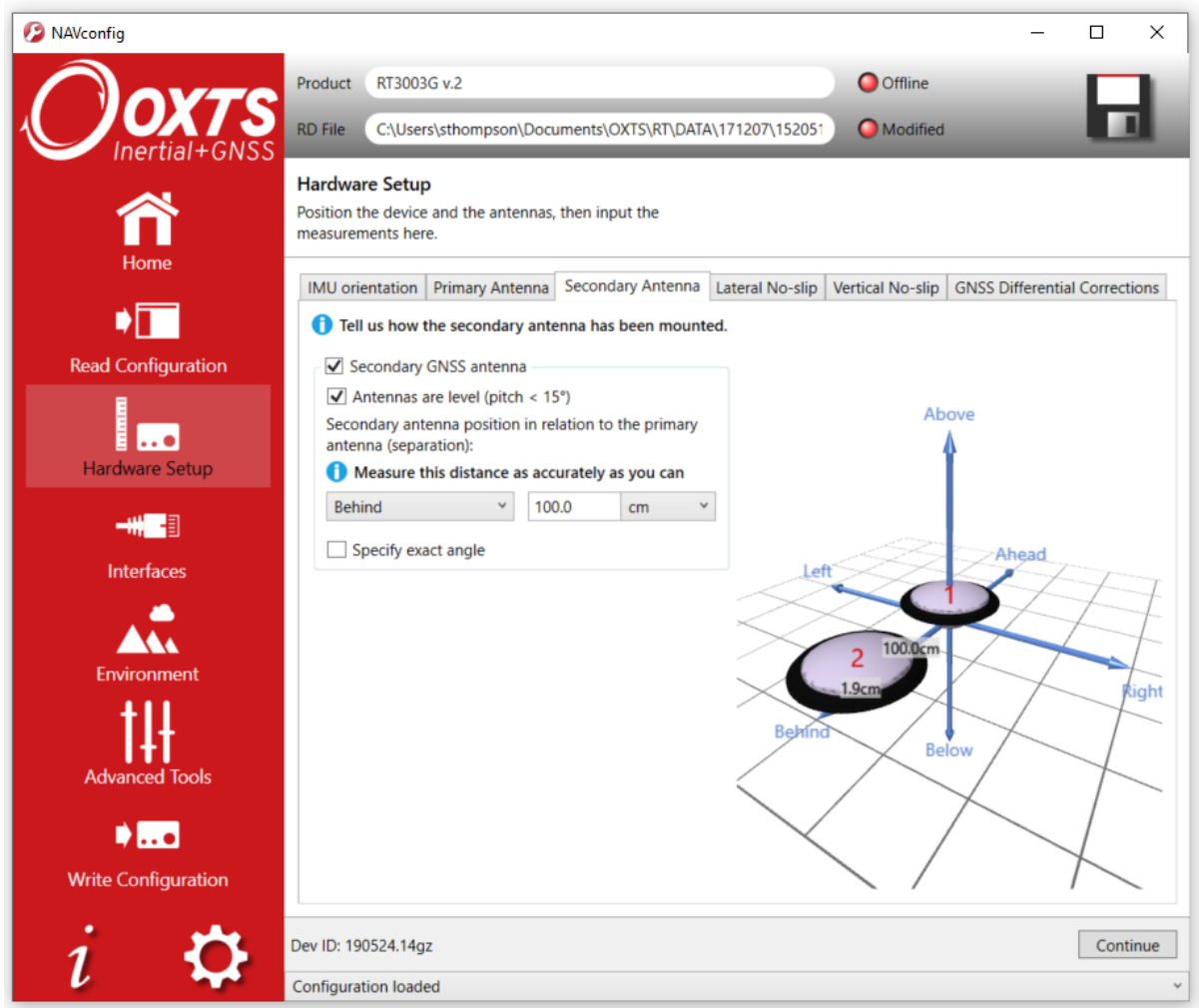
The RT does not estimate the distance between the two antennas. It is essential to get this right yourself, otherwise the system will not work correctly and the performance will be erratic. The measurement needs to be accurate to 5 mm, preferably better than 3 mm.

A wider separation will increase the dual antenna heading solution accuracy. The maximum recommended separation is 5 m, giving an accuracy of up to 0.05° in both static and dynamic conditions.

If the antennas are mounted at significantly different heights, or if the mounting angle is not directly along a vehicle axis (forward or right), then click the 'Use advanced settings' checkbox to enable advanced settings and specify the orientation and height offset.

Getting the angle wrong by more than 3° can lead the RT to lock on to the wrong heading solution. The performance will degrade or be erratic if this happens. If the angle between the antennas cannot be estimated within a 3° tolerance then contact OxTS support for techniques for identifying the angle of the antennas.

The 'Enable static initialisation' option is useful for slow moving vehicles or where it is essential to start the RT running before moving (for example in autonomous vehicles). Static initialisation is 99% reliable in open sky, but the reliability decreases in environments with high multipath. Static initialisation is also faster when the antenna separation is smaller. This can be configured in the Environment section.

The RT will improve the estimate of the secondary antenna orientation settings. Use the "Improve configuration" option to use the improved values.

Lateral No-slip and Vertical No-slip tabs

This feature uses characteristics of land vehicle motion to improve heading and slip angle and to reduce drift. Specifying the position of the non-steered wheels makes a huge difference to the lateral drift performance of the RT when GNSS is not available.

This feature must be disabled for airborne and marine systems where the lateral velocity can be significant. This feature is also not suitable for land vehicles that use all wheels to steer, i.e. no fixed wheels. The vertical settings should not be used if the vehicle can perform wheelies.

The Lateral No-slip feature applies heading correction when the land vehicle is not slipping. When the vehicle *is* slipping the lateral acceleration is usually large enough that the normal heading corrections provide excellent results. When combined with a wheel speed input the drift of the RT when GNSS is not available is drastically reduced.

Figure 22 shows the Lateral No-Slip tab.

Figure 22. NAVconfig Lateral No-slip tab in the Hardware setup section
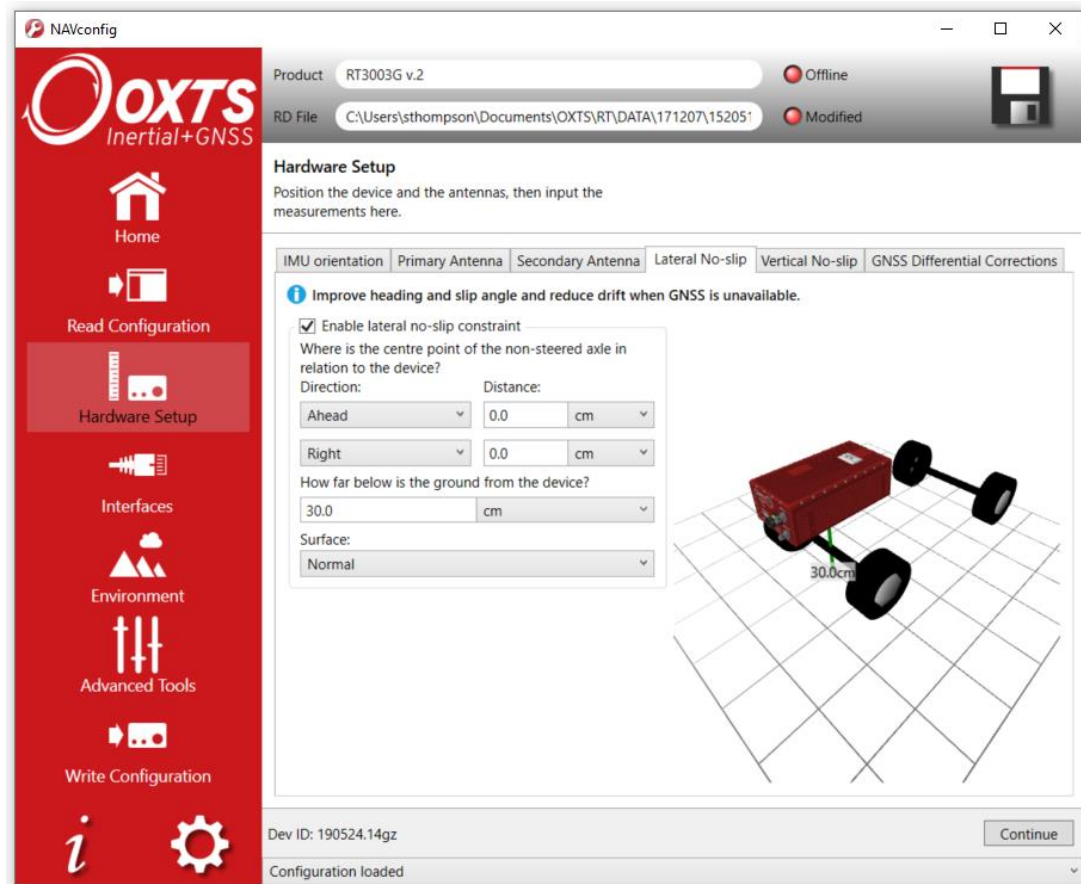
For the Lateral settings, the system needs to know the position of the non-steered axle (rear wheels on a front-wheel steering vehicle and vice versa). A position at road height, mid-way between the rear wheels should be used as shown in Figure 22. Vehicles with all wheels steering cannot use this feature reliably, although minor steering of the rear wheels does not significantly affect the results.

Figure 23. Measurement point for Lateral No-slip

Measuring from the RT, measure the distances to the non-steered axle position in each axis in the vehicle co-ordinate frame. Select the direction from the dropdown lists and enter the distances.

The measurements are made to an accuracy of 10 cm. Selecting an accuracy better than 10 cm does not improve results. Using an accuracy figure worse than 20 cm will increase the drift of the RT. Use the **Accuracies** tab in the Advanced Tools section to specify measurement accuracies individually.

The **Lateral No-slip** feature also requires some knowledge of the road surface. Select one of the predefined options from the dropdown list, Normal or Low friction (ice).

For the **Vertical No-Slip**, the system needs to know the position of the front axle. A position at road height, mid-way between the wheels should be used, like for the rear axle.

Measure the distances again from the RT and enter them into the cells, selecting the appropriate directions from the dropdown lists.

Figure 24. NAVconfig Lateral No-slip tab in the hardware Setup section
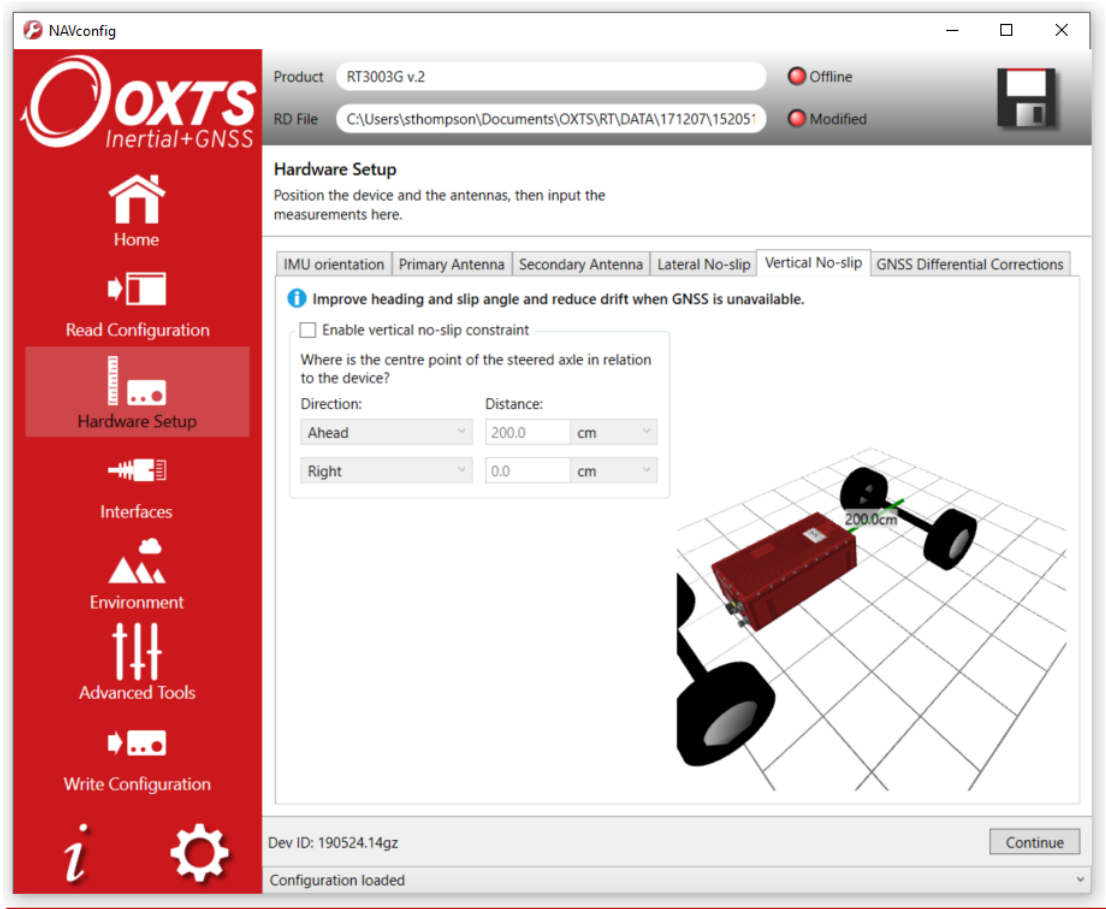
When using No-Slip features, the RT can estimate the slip angle offset of the RT compared to the vehicle. After the RT is initialised and warmed-up, use the Improve configuration option from the NAVconfig Home section to automatically read the RT's slip angle offset estimate. This ensures a slip angle of zero is measured when driving straight on a level track.

An RT can be configured to use several different differential correction message types on connector J3. Figure 25 shows the Differential corrections properties window and Table 21 gives details on the correction types available.

Figure 25. NAVconfig Differential corrections tab in the Hardware Setup section
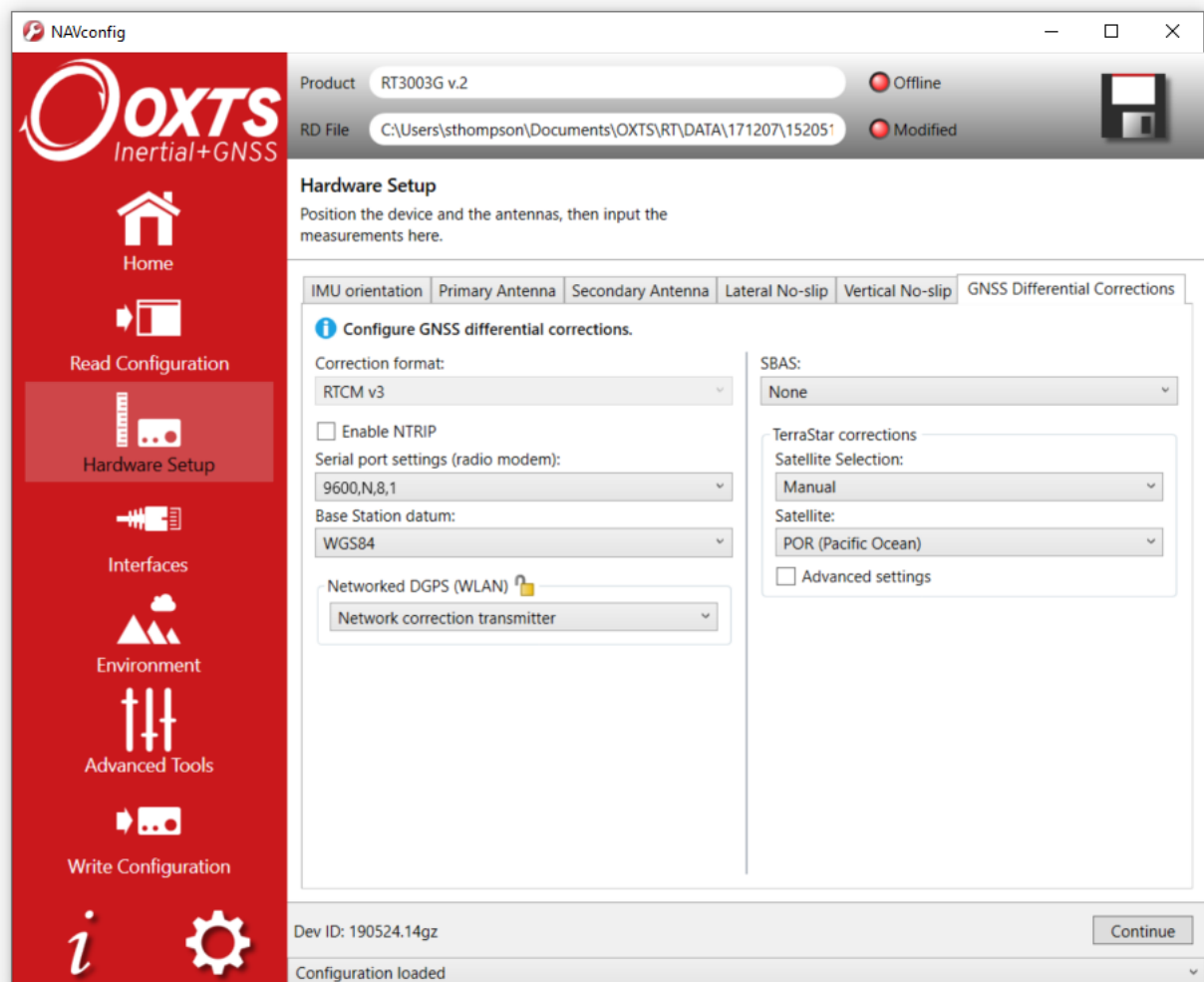
Table 21. NAVconfig Differential Correction formats

Correction type	Description
RTCA	RTCA is the standard adopted for aircraft. It was the first open standard to use 1 cm corrections. The RT-Base S and GPS-Base products use RTCA.
RTCM	RTCM is the most common open standard used for differential corrections.
RTCMV3	RTCMV3 is the latest version of RTCM. This option gives the best accuracy and should be used if your differential corrections are in Version 3 format.
CMR	This is a standard adopted by Trimble. The RT products support both CMR and CMR+ formats.
Advanced.	This option is reserved
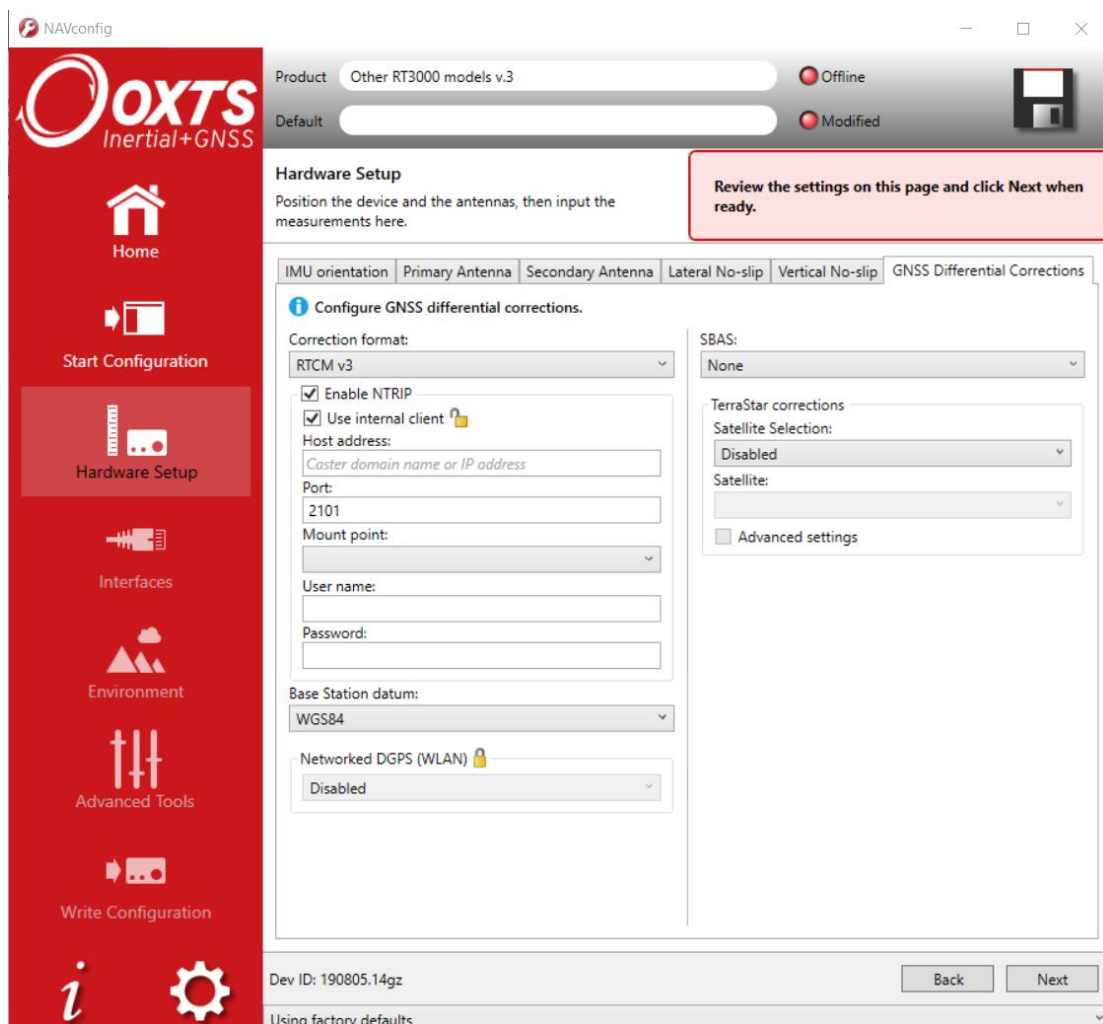
Select the Correction format you wish to use from the box and then select the baud rate from the Serial port settings (radio modem). The most common baud rates used for differential corrections are 4800 baud and 9600 baud. The RT-Base S and GPS-Base use 9600 baud. The values in the Data bits, Parity and Stop bit fields should be set to match the incoming signal.

NTRIP

When selected, the "Enable NTRIP corrections" checkbox box configures the RT for RTCMv3 corrections and sends an NMEA GGA message out from J3 back to the NTRIP server.

The RT3000 v3 and RT500 house an internal NTRIP client. Select 'Use Internal Client' to configure the settings of the NTRIP client inside the RT.

Figure 26. NTRIP Internal Client

When the 'Use internal Client' option is selected, several additional settings are provided and need to be configured.

The Host address needs to be entered to receive corrections. This is the domain name or IP address of the caster or service that will be used. This should be provided by the service provider.

The Port is set to 2101 by default. The port should not be changed, or corrections will not be received by the unit.

The Mounting point can be selected from the list available. This list will automatically populate, unless the service provider requires authentication when collecting the information. If the NTRIP service is protected by a login, the list of mounting points will have to be accessed manually and the mounting point typed into the field.

The User name and password for the correction stream need to be inputted for the RT to be able to receive the data from the caster. Please note that this is not the same user name and password as the account held with the service provider.

Networked DGPS (WLAN)

The **Networked DGPS (WLAN)** controls allow an RT to be configured to broadcast or receive differential corrections over WiFi when connected to an RT-XLAN. When **Network correction transmitter** is selected, an RT will broadcast differential corrections it is receiving via a radio modem from an OxTS base station, using its RT-XLAN. Other RT devices that are on the network as the broadcasting RT, will then be able to receive the DGPS messages and use them. To do this, the **Network correction receiver** option should be selected on those devices, and the IP address of the system carrying the radio modem should be selected from the box. Using this system reduces complexity in situations where multiple RTs need DGPS corrections as only one pair of radio modems needs to be used.

Networked DGPS (WLAN) can also use corrections received via NTRIP, rather than a local base station. As before, the RT that is connected to the NTRIP server should be configured with Network correction transmitter selected. Other RTs should be configured with Network correction receiver selected, and the IP address of the system that is configured as the transmitter should be selected in the box.

Regardless of whether DGPS corrections are received via NTRIP or a local base station, only RTCMv3 corrections are currently supported in networked DGPS mode.

SBAS

In Europe, North America, and Japan SBAS can be used for differential corrections. These services will improve the position accuracy of the RT. In North America the SBAS service is known as WAAS, in Europe it is known as EGNOS and in Japan it is known as MSAS. Select the option that is most suitable for the territory you are in.

TerraStar corrections

TerraStar corrections are configured on the GNSS Differential Corrections tab within the Hardware Setup section. You can choose between Manual or Automatic Satellite Selection and if you choose Manual you can select from a list of available options. Using the "Advanced Settings" checkbox you can also change the frequency and baud rate.

Interfaces section in NAVconfig

This section contains options for configuring the interfaces of the RT. Some of these settings are feature code controlled so may not be visible to all users on all devices.

Ethernet tab

The Ethernet settings include configuring the Ethernet data output rate, packet type and Triggers for the RT. You can also enable the Driving Robot interface and input the Driving robot IP if you are using a Driving robot with your RT.

The Ethernet output can either output NCOM or MCOM, or be disabled by using the Output packet dropdown list. When NCOM or MCOM is selected, the Data rate can be selected by using the dropdown list.

If a trigger has been configured as an event input, click the 'Output' on falling edge of trigger or Output on rising edge of trigger checkboxes to choose when the extra data packet is generated. If a trigger has been configured as an output trigger, click the 'Output on camera trigger' to generate extra data packets based on the output trigger settings configured earlier. These packets are interpolated to the time when the event occurred and may be output up to 30 ms late and out of order compared to the normal messages.

It is essential to enable these options in order to see trigger information in NCOM, or if the events have a rate higher than 1 Hz otherwise the output cannot communicate all of the events and some will be lost.

For the Driving robot, the default address (195.0.0.100) is listed in the dropdown list but can be changed if required by typing the correct address. When the ABD Steering Robot is enabled, the output smoothing is automatically enabled too.

Wi-Fi tab

To configure the Wi-Fi as an Access Point, click on the option and the field to configure the Network details and router details will become available to edit.

The Network name (SSID) will be by default OxTS INS (SN) This can be changed to another name but cannot contain any of the following characters: [<], [>], [&], ['] and ["]. It is possible to add a password to the network created. To enable this, select what security protocol to use, WPA or WPA2, and then enter the Passphrase.

For the router, the Gateway and Subnet mask can be changed if using a different IP range or to prevent IP clashes. The Gateway as referred to in NAVconfig is the IP address of the Gateway or Wi-Fi module in the RT.

To Configure the Wi-Fi to connect to an existing WLAN, you will need to have the Wi-Fi already enabled and have the Access Point disabled. If the Wi-Fi is not enabled, the RT will not be able to see what network it could connect to. If the Access Point is enabled, the RT will not connect to an existing network.

Under "*Wireless networks in range of device",* you can choose which network you wish to connect the RT to and drag the network to the box on the right. If the network is secured, a text box will be available to enter a password. This will contain the networks that the RT will connect to when they are in range.

Warning:

A network containing the following characters, [<], [>], [&], ['] and ["], will not be seen correctly and the RT will not be able to connect to the device. These characters cannot be used in the SSID of the RT.

If using an iPhone to hotspot, please be aware if the phone is called "[name]'s iPhone" as this has the non-usable ['']. To change the name of the hotspot, go to "Settings" > "General" > "About" and select "Name".

CAN Output tab

RT systems can be configured to send and receive data via a CAN bus. This allows RT data to be sent to external logging devices, and signals from a test vehicle's CAN bus to be logged alongside navigation data inside an RT.

By default, CAN communication is disabled. It is enabled by selecting the Enable CAN interface checkbox (see Figure 28). The default version is CAN 2.0. CAN-FD is also available.

Figure 27. NAVconfig CAN output configuration tab
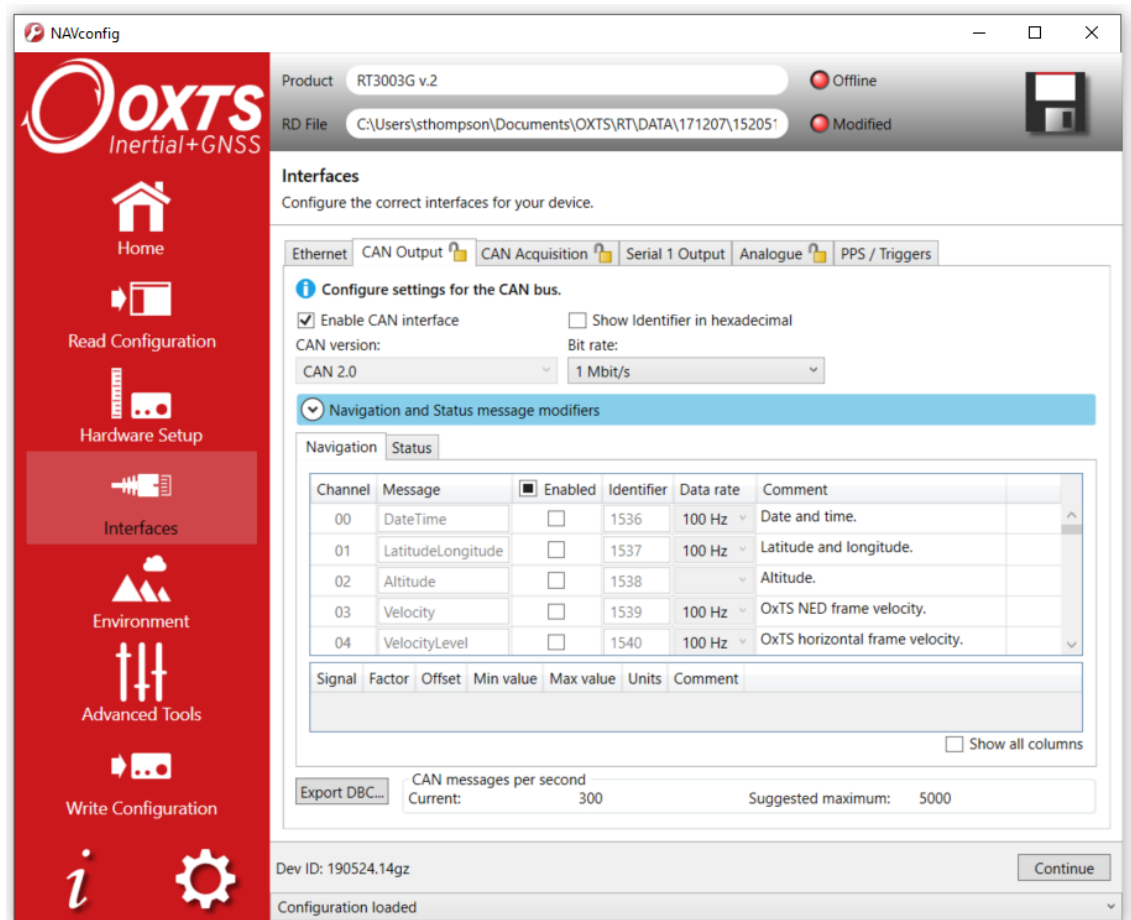
You can select individual messages or enable all messages by choosing them from the table displayed.

Depending on the baud rate selected, the suggested maximum CAN messages per second will change. A warning message will appear if the combined rate of all current navigation and status messages will overload the CAN bus at the selected baud rate.

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Disabling or reducing the frequency of navigation or status messages will remove the warning and ensure reliable operation of the CAN bus. Increasing the baud also works, but the baud rate must be common to all devices on the bus. When using an RT-ANA, the default baud rate is 1 MBaud.

The Export DBC file button generates a CAN DBC library listing all navigation and status messages that are enabled (not greyed-out). The DBC file does not include channels defined under the acquisition tab. The navigation status message binary format is described from Table 31 onwards. The status message binary format is the same as the NCOM status message binary format as described in the NCOM Description manual. Those status messages that do not have signals listed against them are not described at the signal level in the DBC file. The binary format of these messages is quite complex and as such the DBC file it not sufficient to describe the decoding process.

The Navigation tab is where navigation-related CAN messages are configured for output. The table can be sorted in ascending or descending order by clicking any column header. This is particularly useful when checking for enabled/disabled messages.

Figure 28. NAVconfig CAN Output configuration tab – Navigation
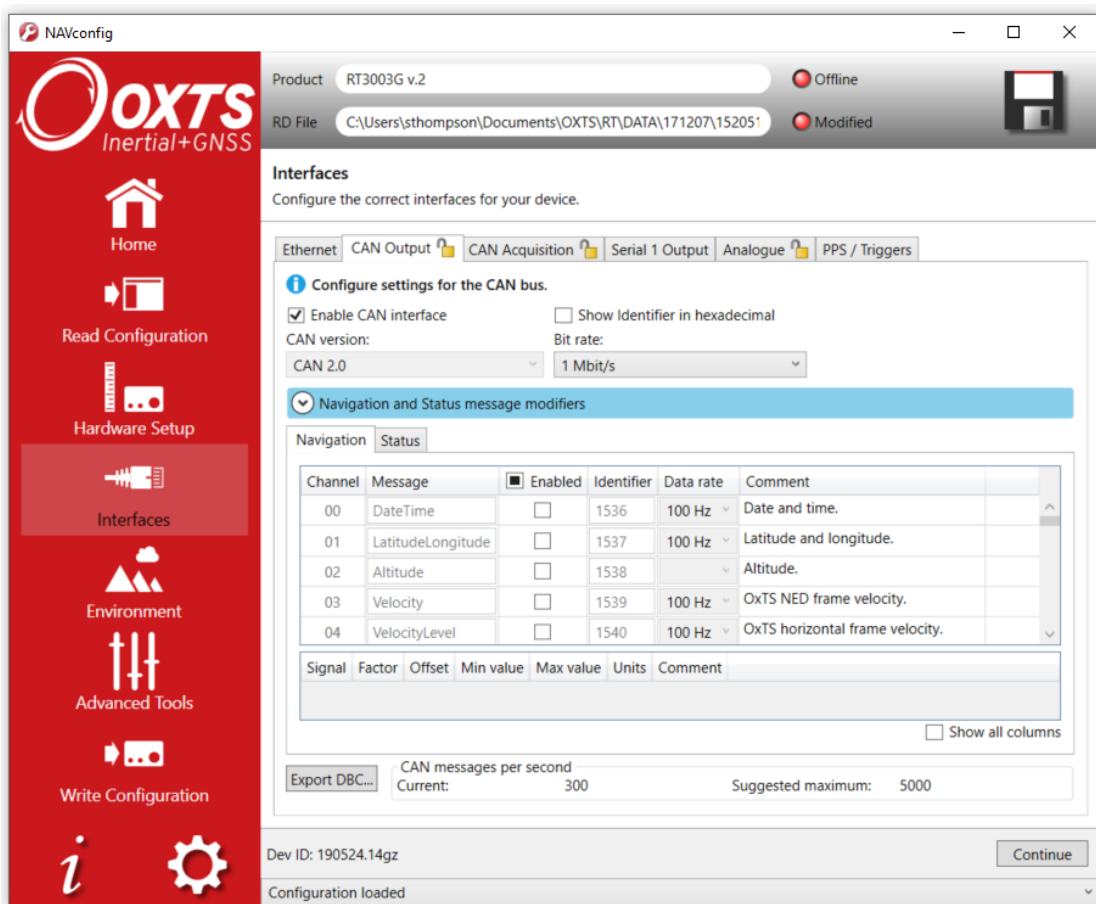
Each message can be enabled/disabled by clicking in the appropriate cell and selecting from the dropdown menu. The message Identifier is also changed by clicking in the cell. The identifier number should be defined in either hexadecimal or decimal format. Decimal values can be entered as normal. Hexadecimal values should have a letter "h" appended.

The Data rate can be set using the dropdown list that appears after clicking in each data rate cell. When a message's data rate changes or it is enabled or disabled, the caption at the bottom of the window displaying messages per second updates to reflect the new settings.

The Enabled checkbox quickly enables and disables all messages.

The **Status** tab lists all status messages, which are sent one after another in a repeating loop. Although 80 messages are shown in the list, 100 are actually used internally. If the data rate is set to 100 Hz, a status message will be sent every 10 ms. Some messages are transmitted more frequently than others because they appear in the list more than once. At a data rate of 100 Hz, each message in the Status tab will be transmitted on the CAN bus once per second.

The Prefix and Suffix boxes can be used to quickly add alpha-numeric strings to the beginning and end of all message names, while the Identifier offset box allows users to quickly apply an offset to all CAN IDs. These tools are useful when IDs conflict with other equipment and changes need to be made to many channels.

Positive and negative integer values can be entered into the Identifier offset box in both decimal and hexadecimal formats. Data entered in hexadecimal format should end with an "h". To remove the offset, type 0 in the identifier offset box.
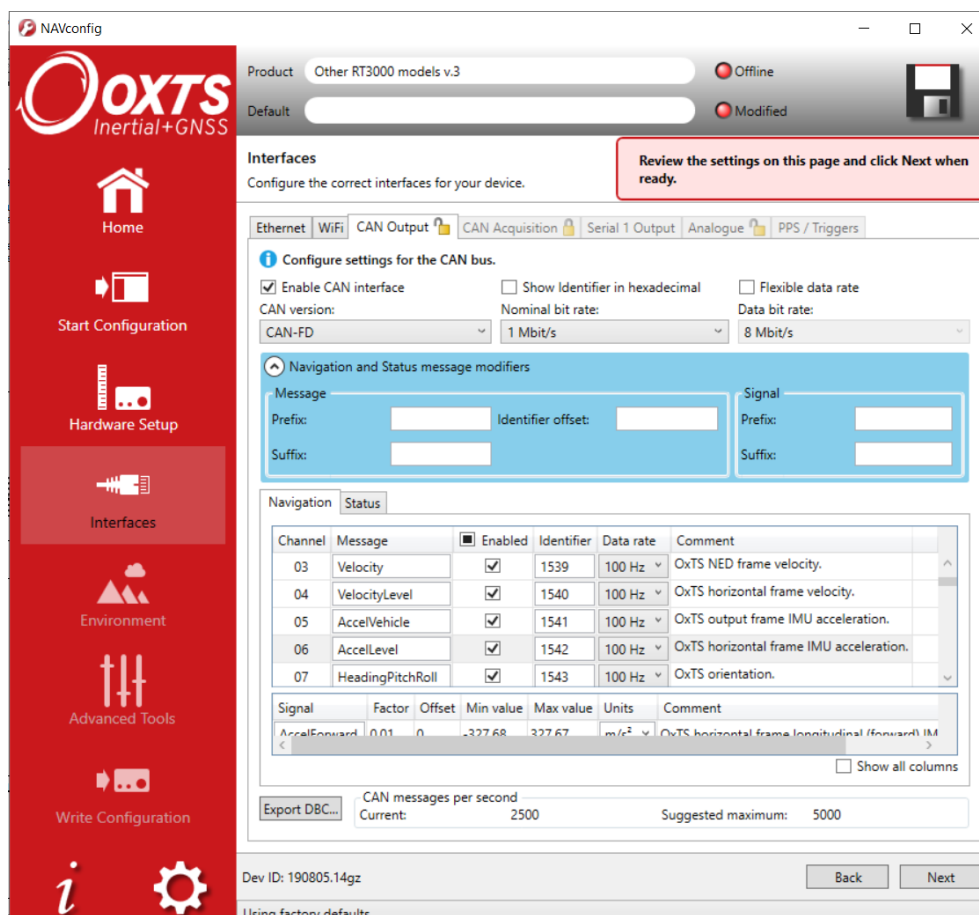
The Enabled checkbox quickly enables and disables all status messages.

The Message name, Signal name and Units can be edited in the table. Changes made using NAVconfig are independent of the DBC file, and will not affect it or be saved.

CAN FD (CAN with Flexible Data-Rate) is an extension to the original CAN bus protocol specified in ISO 11898-1. CAN FD was created to accommodate increases in bandwidth requirements within automotive networks. The CAN FD protocol has brought the software closer to "real time" through the minimisation of delays between an instruction and transfer of data (latency) and higher bandwidth.

Enable CAN-FD by selecting it from the CAN version dropdown. Figure 29 displays the options available when configuring the RT for CAN-FD output.

Figure 29. CAN-FD output configuration

Choose a Nominal bit rate from the dropdown list.

If you want to adjust the Flexible data rate, select the checkbox and then you can choose the Data bit rate from the additional dropdown list and specify the sample points.

CAN Acquisition tab

The CAN Acquisition tab is where incoming CAN signals are defined. These signals can be viewed in real time along with the RT's native data using NAVdisplay, or later using NAVgraph.

Channels are added to the acquisition list by clicking on the 'Load DBC file' button and selecting a valid CAN DBC file. The top 12 messages in the list acquisition list are logged at the INS update speed of 100 Hz or 250 Hz. This is not adjustable.

The Message name, Signal name and Units can be edited in the CAN Signal Properties window (Figure 30). This is opened by double-clicking any signal. Changes made using NAVconfig are independent of the DBC file and will not affect it or be saved.

Figure 30. CAN Acquisition tab
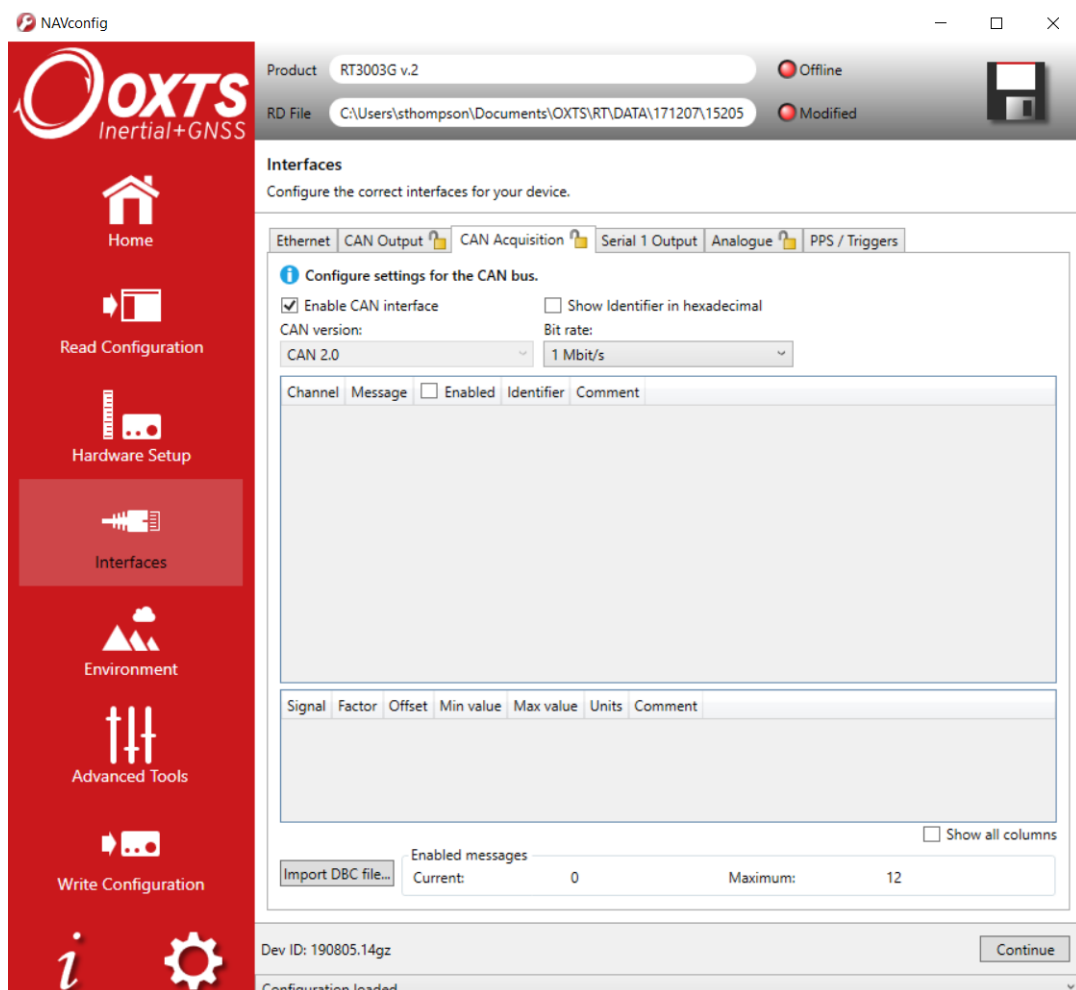
Serial 1 Output tab

The serial port can be configured to output different types of message (see Table 22).

Select a Packet type and Baud rate. By default, data on the serial port is output using 8-N-1, although odd/even parity and two stop bits are available by using Advanced commands. Please contact support@oxts.com for details on this.

If the NMEA packet type is selected, the NMEA tab will appear in the properties window. In this tab the NMEA messages to output on the serial port are selected by choosing the data rate for each message type from the dropdown lists and clicking the checkbox for when to generate the message.

NMEA messages can also be generated in response to event input triggers. Check the falling or rising edge checkbox to compute the message when the event occurs. The RT can also generate NMEA messages from pulses on the output trigger. These messages use interpolation to compute the values at the exact time of the event but may be output on the serial port up to 30 ms late and out of order compared to the normal messages. To enable these messages check the appropriate checkbox.

Table 22. Serial outputs

Option	Description
Disabled	The serial output is disabled. This option can be used to reduce the computational load and ensure that the Kalman filter runs quicker
NCOM	Normal output of the RT1003. NCOM data is transmitted at up to 125 Hz over serial. The format is described in the NCOM Description Manual. Software drivers exist for decoding the NCOM data
IPAQ	NCOM output at a reduced rate. The baud rate of the serial port is set to 19200 and the update rate is 25 Hz. It is used because the IPAQ cannot manage to receive the data reliably above 25 Hz
IPAQ+	NCOM output at a reduced rate and polled. Windows Mobile 5 on IPAQs crashes if the inMOTIONx is sending data when the IPAQ is turned on. Using IPAQ+ the IPAQ will poll the RT1003; the RT1003 will not send data while the IPAQ is off, preventing the turn-on crash of the IPAQ
NMEA	The NMEA outputs conform to the National Marine Electronics Association Standard (NMEA 0183 version 3.01). The NMEA sentences available are GPGGA, GPHDT, GPVTG, GPZDA, GPGST, PASHR, GPRMC, GPGSV, GPGSA, PTCF, GPPPS, PRDID, GPROT, GPGGK, and GPUTC. The NMEA 0183 description manual gives details of the fields output in the NMEA sentences
Javad I+RTK	A special set of messages output in GREIS format to be used with Javad receivers. For assistance please contact OxTS for support
MCOM	Used for marine applications. Identical to NCOM output but with the addition of heave measurements
TSS1	TSS1 format outputting acceleration, heave, roll and pitch
TSSHHRP	TSSHHRP format.
EM3000	Suitable for use with Simrad EM3000 multibeam sounders
EM1000	Suitable for use with Simrad EM1000 multibeam sounders

Note that it is easy to overload the serial port if there are too many events. The software computes the number of characters that will be output each second and displays this at the bottom of the window. A serial port data overflow warning message will appear if the data rate is too high for the selected baud rate; to fix this it is necessary to lower the data rate of the selected NMEA sentences or increase the baud rate.

Selecting "Allow extended length messages" enables the full GGA and RMC messages to be output, which are longer than the NMEA specification allows. Please see the NMEA 0183 Description manual for more details. Selecting "Output approximate values before initialisation" forces output of the raw GNSS measurements before the RT is initialised. Currently just the position is output and this is the position of the antenna, not the inertial measurement unit. Note that there will be a jump (from the antenna to the inertial measurement unit) when initialisation occurs.

Analogue tab

The Analogue option is used for configuring the RT-ANA companion product. There are 16 channels in the RT-ANA, numbered from 0 to 15. The Measurement, Range, and Min and Max values for all 16 channels can be configured. Click on a specific cell to change the settings.

Note: The CAN bus must be configured correctly for the analogue outputs to work correctly.

PPS / Triggers tab

The output trigger on the digital I/O generates a pulse based on distance. Select the distance interval to generate the pulses on from the dropdown list, or type in a value. The output has 0.8 V or less for a low and 2.4 V or more for a high. The pulse width is 1 ms.

NAVconfig Environment section

This section contains settings related to the environment you will be collecting data in, including the device initialisation conditions. This section is not broken down into tabs but contains several selectable options and pre-defined values on one screen.

Initialisation

Static initialisation is disabled by default.

If static initialisation has not been enabled, the RT will need to be initialised by driving forwards in a straight line to initialise the heading to the track angle. The initialisation speed is the speed at which the vehicle must travel to activate the initialisation.

The default initialisation speed is 5 m/s. However, some slow vehicles cannot achieve this speed. For these vehicles adjust the initialisation speed to a different value.

If a speed less than 5 m/s is selected, then care should be taken to make sure that the RT is travelling straight when it initialises.

Vehicle starts

Select a predefined value from the dropdown list.

If you know the vehicle will be level when starting (to within about 5°) select 'Level'. This saves about 40 s during the initialisation process since the RT does not have to take the time to compute an initial roll and an initial pitch. In high vibration environments **Not Level** may not work and so the RT can only start if the vehicle is level and the **Level** option has been specified.

GNSS environment

Select a predefined value from the dropdown list.

If the system is used predominantly in open-sky, then the Open skies setting should be used. In environments with a lot of GNSS multipath then Some obstructions or Frequent obstructions can be used depending on the environment. This will allow less accurate GNSS measurements to update the system and it also places more reliance on the inertial sensors compared to the GNSS.

Unless the open-skies setting is used, the RT will not report accuracies that meet its specifications.

Vibration levels

Select a predefined value from the dropdown list.

The Normal vibration level is adequate for most circumstances. The RT is very tolerant of vibration and has been used successfully in environments with more than 2 g RMS using the Normal setting. If the velocity innovations are very high, and many GNSS packets are being dropped, then this setting can be changed.

Typical situations where the **High** vibration setting should be used include those where vibration mounts have been used, or where the RT and the antenna are mounted on different sprung parts of the vehicle (e.g. the cab/chassis of a truck).

Heading lock

The heading of single antenna systems can drift when the RT remains stationary for long periods of time. To solve this, the RT includes an option to lock the heading to a fixed value when stationary. This option cannot be used if the vehicle can turn on the spot (i.e. with no forward velocity). With heading lock enabled the RT can remain stationary for indefinite periods of time without any problems. For vehicle testing this option is recommended.

There are four settings to choose from. Disabled should be selected if the vehicle can turn on the spot. The default setting Normal is best for most applications as it is least likely to cause problems in the Kalman filter. Tight and Very tight are better when trying to reduce position drift in poor GNSS environments and traffic jams.

Table 23 gives a more detailed description on each of the heading lock options.

Table 23. NAVconfig heading lock options

Heading lock	Description
Normal	This option assumes the heading of the vehicle does not change by more than 2° while the vehicle is stationary. The heading accuracy recovers quickly when the vehicle moves.
Tight	This option assumes the heading of the vehicle does not change by more than 0.5° while the vehicle is stationary. The recovery is fast if the heading of the vehicle does not change but will be slow if the vehicle turns before it moves.
Very tight	The option assumes the heading of the vehicle does not change by more than 0.3° while the vehicle is stationary. The recovery is fast if the heading of the vehicle does not change but will be slow if the vehicle turns before it moves. This option can cause problems during the warm-up period if the vehicle remains stationary for a long time and then drives suddenly.

Note: The heading of most vehicles *does* change if the steering wheel is turned while the vehicle is stationary. Junctions and pulling out of parking spaces are common places where drivers turn the steering wheel while not moving.

Garage mode

The Garage mode option is used to stabilise the RT's outputs when GNSS is not available. For example, GNSS can be blocked when the vehicle returns to the garage to have some modifications. Without Garage mode enabled, the RT may drift too far and may not be able to recover.

When Garage mode is active, the RT applies a gentle velocity update and assumes that the vehicle is stationary. This keeps the roll, pitch and velocity within acceptable limits while the RT has no GNSS. With heading lock also enabled, the RT can also keep the heading accurate while stationary.
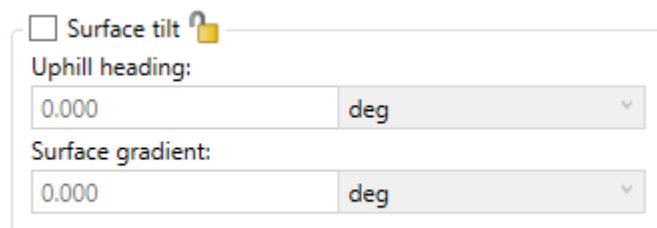
When using this option, try to keep the vehicle's movement inside the garage to a minimum and exit the garage through the same door the car entered.

Surface tilt

The surface tilt settings are used to compute the roll, pitch (and heading) compared to a flat inclined surface. The roll and pitch from the RT products are measured compared to gravity. Most test tracks are built at an angle so rain water runs off and the track dries faster. As the vehicle drives up the incline, the pitch shows a positive value; as the vehicle drives down the incline the pitch shows a negative value; the value changes with a sinusoidal pattern as you drive round a circle. The roll angle shows a similar effect.

Using the surface tilt option, the roll and pitch compared to the inclined surface can be output as well. The NAVdisplay software contains a tool for working out the surface angles. NAVconfig can be used to configure the surface's angle if it has been measured already. These settings can be input in the Environment section within NAVconfig. Figure 32 shows the Surface tilt properties settings.

Figure 31. NAVconfig Surface tilt properties in the Environment section within NAVconfig.
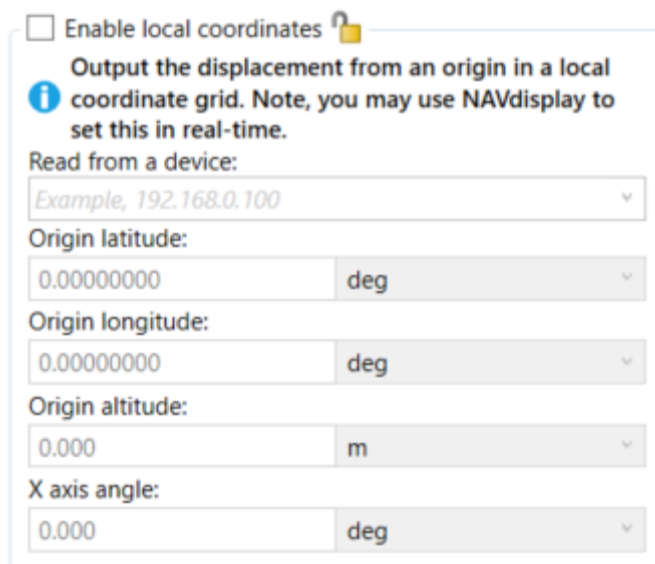
Enter the heading (compared to true north) of the uphill direction and the gradient of the surface.

The RT does not change the roll and pitch outputs because of these settings. Instead there are additional outputs, surface roll, surface pitch and surface heading that are output and the transformation is applied to these outputs. Note that for surfaces with a small gradient the surface heading is almost the same as heading.

Enable local coordinates

The RT can output the displacement from an origin in a local co-ordinate grid. To use this option a "zero" location or origin must be chosen; the latitude, longitude and altitude for the origin must be entered into the RT. If an RT-Base S is available, then these will be shown on the LCD. A rotation can also be specified to rotate the xy directions.

Figure 32. NAVconfig Enable local co-ordinates in the Environment section

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Advanced Tools section

This section contains several settings for Advanced users. By default, these settings are not switched on so you should navigate through the various tabs to review the settings that apply to your application.

Displace Output tab

The RT can displace or move its outputs to another location in the vehicle. This simulates the RT being mounted at the new location, rather than at its actual location. This function displaces all of the outputs (position, velocity, acceleration) to this new location.

To enable output displacement, click the checkbox and enter the offsets to the new location in the vehicle. The offsets are measured from the RT in the vehicle co-ordinate frame. Select the directions from the dropdown lists and input the distances.

Note that the noise in the acceleration outputs will be much higher when output displacement is used. Typical installations in moving vehicles have angular vibrations of about 2 rad/s²; this equates to 2 m/s² of additional vibration of a 1 m output displacement. It will be necessary to filter the data if output displacement is used.

Acceleration filters tab

The RT is able to filter the linear acceleration and the angular acceleration before they are output. These filters affect the outputs on the CAN bus. On the NCOM output the non-filtered values are output together with the filter characteristics and the NCOM decoders provided by OxTS will implement the chosen filter. The linear acceleration and the angular acceleration can be configured separately.

Due to vibration the accelerations (both linear and angular) are noisy. In particular, angular acceleration is normally filtered when it is used. The RT can filter the acceleration outputs using a second order low-pass filter. The characteristics of the filter can be set and viewed in the Acceleration Filters tab in the Advanced Tools section of NAVconfig.

Designing the right filter is always a compromise between the noise reduction and the filter delay. To help choose the filter, the software will compute the maximum delay over the 0 to 5 Hz interval and the Noise Reduction Factor over the full bandwidth. The Noise Reduction Factor is the ratio of the filtered noise compared to the unfiltered noise assuming the vibration is white (i.e. same amplitude across the frequency spectrum). A graph showing the delay with respect to frequency can also be plotted. The delay is the *additional* delay of the filter and not the total delay of the acceleration output. The RT has other delays, like calculation delay, too.

Figure 33. NAVconfig Acceleration Filters tab in the Advanced Tools section
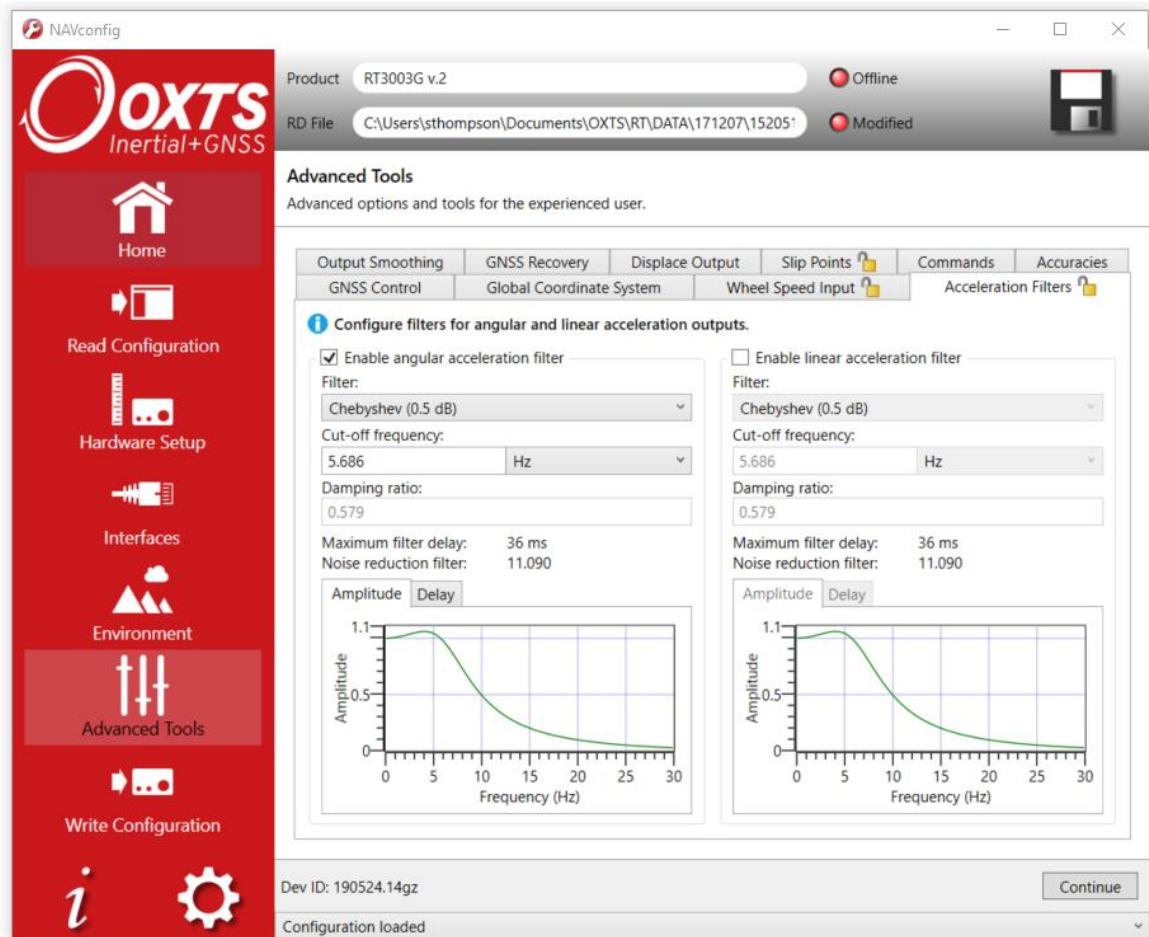
Wheel Speed Input

The RT can be factory configured to include a wheel speed input. This reduces the drift in outputs when GNSS is not available. It is essential to use the Lateral and Vertical No-slip slip features at the same time as wheel speed corrections.

As with the Lateral No-slip feature, the wheel speed input can only be used on land vehicles; aircraft and marine vehicles cannot use this option. The wheel speed must not be used on a steered wheel, it must be used on a wheel that is measuring the forward direction of the vehicle.

Figure 34 shows the wheel speed configuration window. To enable the wheel speed input, ensure the checkbox is checked. If this option is disabled, the RT will ignore corrections from the wheel speed even if it is connected.

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Figure 34. NAVconfig Wheel Speed Input tab in the Advanced Tools section
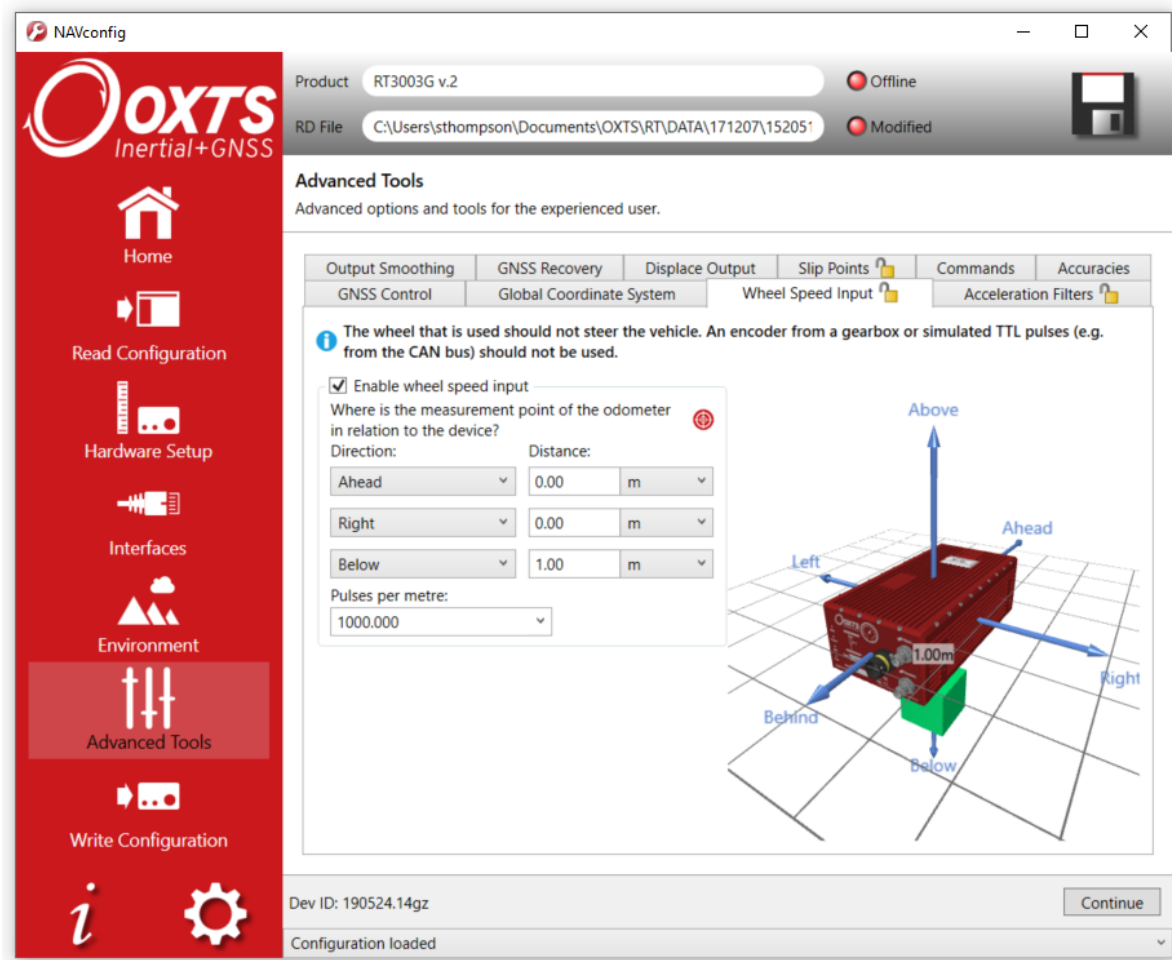
The distances from the measurement point on the RT to the measurement point of the wheel speed encoder in the vehicle coordinate frame should be input. The directions can be selected from the dropdown lists. If the wheel speed is from a prop shaft then the distance should be measured half way between the two wheels. The illustrations in the image will change depending on the settings you choose, to help visualise the position of the RT in relation the wheel speed sensor.

Measurements by default are made to an accuracy of 10 cm. Using higher precision for the measurement does not improve the results. Using an accuracy figure worse than 20 cm will increase the drift of the RT. The accuracy can be specified exactly in the Accuracies tab in the Advanced Tools section along with other measurements such as antenna position.

Enter the pulses per metre of the wheel speed. A value that is accurate to 10% is sufficient unless you know the figure more accurately. The RT will improve this scaling factor itself when GNSS is available. The Improve Configuration utility can be used to apply a more accurate value calculated by the RT from a calibration run. If this option is used then the RT should be allowed to recalibrate the scaling value occasionally to account for tyre wear.

The wheel speed corrections will not be as effective in reducing the drift of the RT if the wheel speed is measuring two wheels (i.e. after a differential), since the actual position of the wheel is required for accurate navigation. If a post-differential encoder must be used then the accuracy cannot be guaranteed.

For best results, a front wheel drive vehicle should be used with the wheel speed on a rear wheel. The wheel speed pulses from driven wheels are less accurate.

Output smoothing tab

When the Kalman filter in the RT determines that there is some error to correct, this error is applied smoothly rather than as a jump. The output smoothing controls how fast the correction is applied to the outputs. This option is particularly useful for autonomous vehicles or path-following robots as a rapid change in position can lead to a large change in the steering angle.

Figure 36 shows the Output smoothing tab in the Advanced Tools section within NAVconfig. Click the checkbox to enable output smoothing and unlock the properties for editing.

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Figure 35. NAVconfig output smoothing properties window
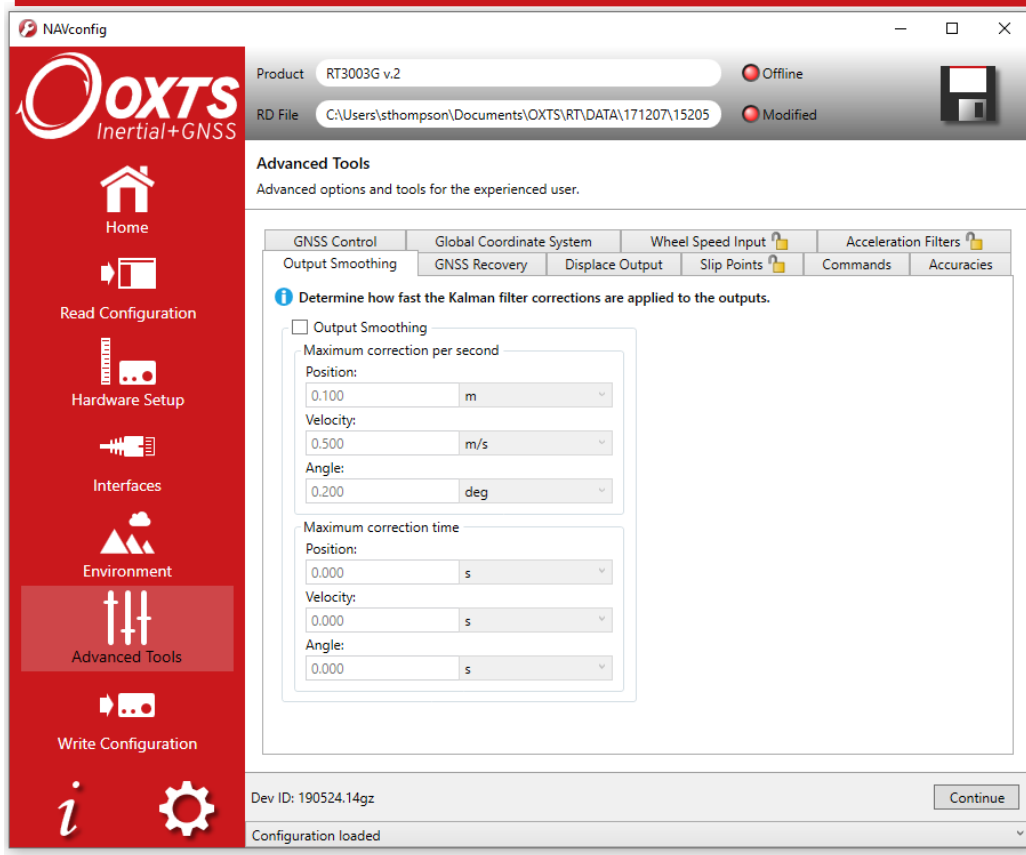
The smoothing of the position, velocity and orientation corrections can be controlled independently. Enter the maximum correction that can be applied every second. For example, if 0.1 m is entered for the position smoothing then the RT will only correct a position error by a maximum rate of 0.1 m/s.

If a large error is accumulated (for example, if GNSS is not available for a long period of time) then it may take a very long time to apply the correction. Under these circumstances it may be preferable to "jump" the measurement to the correct value quickly. By specifying a time in the **Time limit** section for the correction, the RT will jump the measurement if it will take too long to correct.

Care should be taken not to make the smoothing too small. If these parameters are inappropriate, then the RT will not be able to make suitable corrections to the outputs and it will not work correctly.

Note: this function is designed to improve the data in real time. When post-processing the data using the forwards-backwards combined option, output smoothing should not be used as it may give unexpected results.

Slip Points tab
The RT can output the slip angle measurements at additional points (maximum of eight points) on the CAN bus; see Table 38 for the CAN message ID of the slip points. Figure 37 shows the tab for slip point configuration in the Advanced Tools section within NAVconfig.

In the Advanced Tools section within NAVconfig, you can select the number of Slip Points from the Slip Points tab. Select the number of Slip Points you wish to set up and enter the distances and directions from the RT to the Slip Point.

If you have Output displacement enabled, then the measurements are still from the RT and not from the output displacement point.

Figure 36. NAVconfig Slip Points tab

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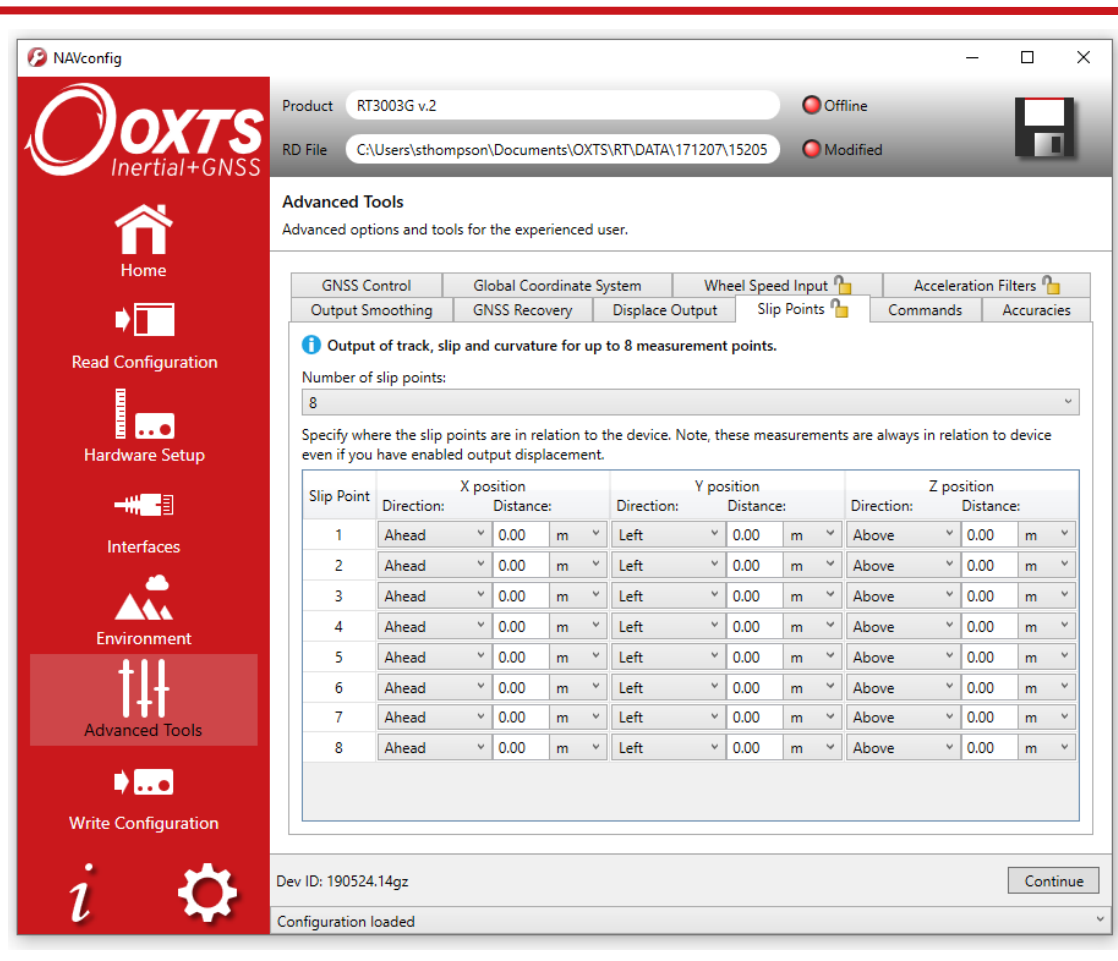
GNSS control tab

The GNSS control tab contains advanced options that control how the GNSS information is managed in the RT. The **GNSS Algorithm** tab can be used to select the algorithm used for merging the GNSS and the inertial data in the Kalman filter. The **Recovery** tab can be used to decide how to begin using GNSS measurements if they have been rejected or ignored for a period of time.

Figure 38 shows both tabs in the GNSS control properties window.

Figure 37. NAVconfig GNSS Control tab in Advanced Tools within NAVconfig
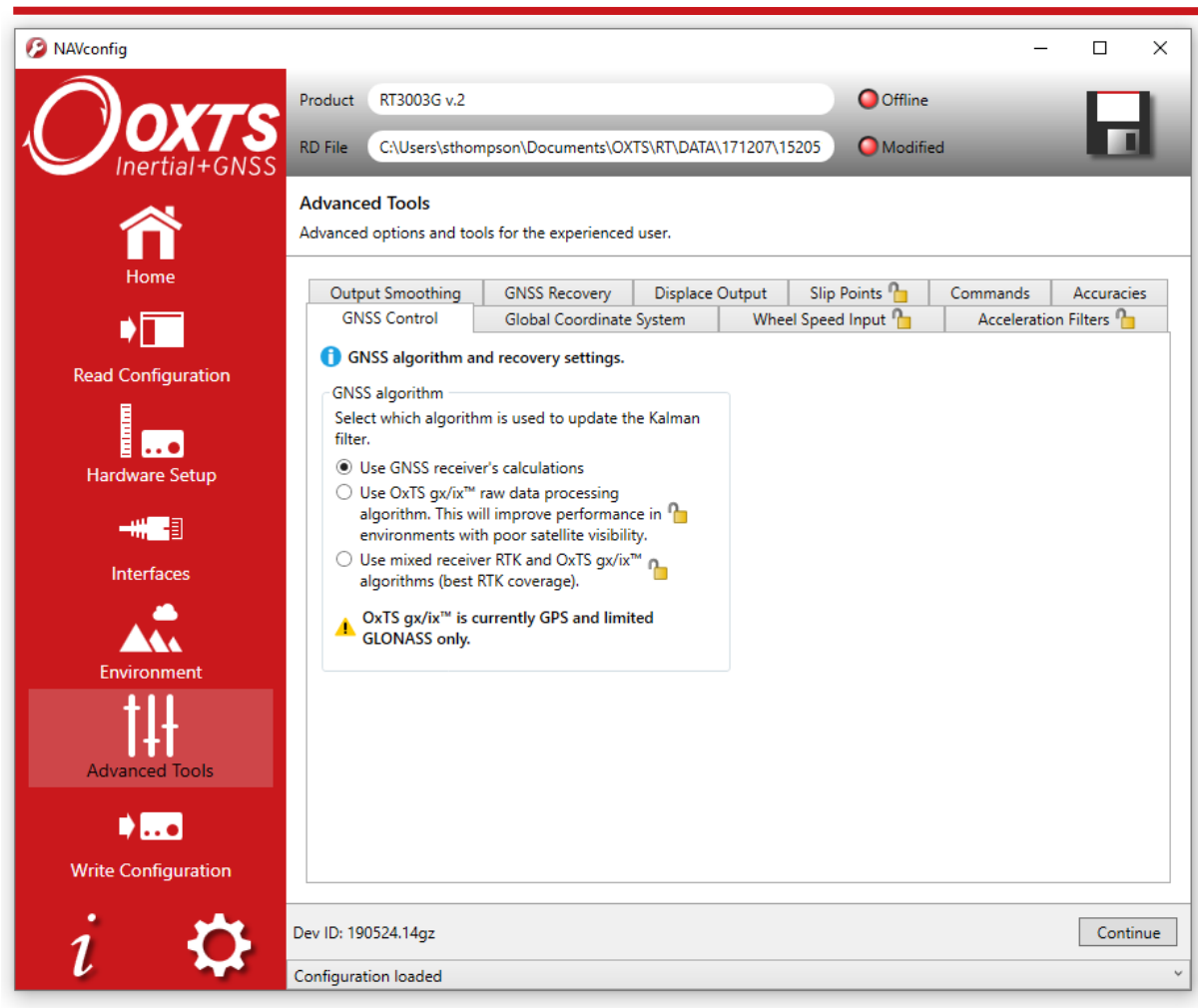
The **GNSS Control** tab gives a choice of two algorithms for computing the GNSS measurements. The default option is to use the algorithm provided by the GNSS receiver. Using this algorithm, the RT will accept position and velocity from the GNSS and use it to update the Kalman filter.

The gx/ix™ raw data processing algorithm uses the raw data from the GNSS and custom algorithms to compute position and velocity tailored to the needs of the Kalman filter. It also improves performance in poor GNSS environments using single satellite aiding technology and tightly coupled GNSS and inertial measurements. Gx/ix™ mode is recommended to achieve the highest accuracy in environments where RTK lock may be difficult to maintain. There is also a third option to use a mix of the two algorithms in order to gain the benefit from each mode in real time.

Note: gx/ix™ processing is a new technology and is still being developed and improved. As such there are some limitations to its compatibility. Table 24 details the current compatibilities of gx/ix™ mode.

Table 24. gx/ix™ compatibility

GNSS mode	Real-time	Post-process
GPS SPS	✔	✔
GPS DGPS	✔	✔
SBAS	x	x
RTK	x	✔
GLONASS SPS & DGPS	✔	✔
GLONASS RTK	✔	✔

Note: only RTCM V3 format differential corrections are supported in gx/ix™ mode.

GNSS Recovery tab

The GNSS Recovery tab controls how the RT will accept or reject GNSS measurements. The RT will automatically reject GNSS updates that it believes are not correct. However, there is a limit on the number of GNSS measurements the RT will reject. Once this limit has passed the RT will accept the GNSS update since it is possible the GNSS is correct and the inertial measurements are not. The GNSS control determines how long the RT should wait before forcing the GNSS to be accepted. Both the velocity and the position can be controlled separately.

In the default state the RT will reject up to 20 GNSS measurements before it forces the GNSS to be accepted. However, in high multipath environments, and when wheel speed is used, it may be desirable to reject more GNSS measurements. Select the 'Start believing measurements after' option and enter the number of GNSS measurements to reject before the system starts believing it again.

The RT families have different GNSS receivers which have different update rates for position and velocity. Table 29 shows the update rates of the RTs.

Table 25. GNSS update rates

Product family	Position	Velocity
RT3000	2 Hz	10 Hz
RT500	2 Hz	10 Hz

This means for example, that if you wish an RT3000 to start believing both position and velocity GNSS measurements after 30 s, the device it should be configured to start believing measurements after 60 position updates and 300 velocity updates.

Global Coordinate System tab

The RT can output position relative to different coordinate frames. You can change the coordinate frame settings in the Global Coordinate System tab within Advanced Tools in NAVconfig, shown in Figure 39.

Figure 38. NAVconfig Global Coordinate System properties window
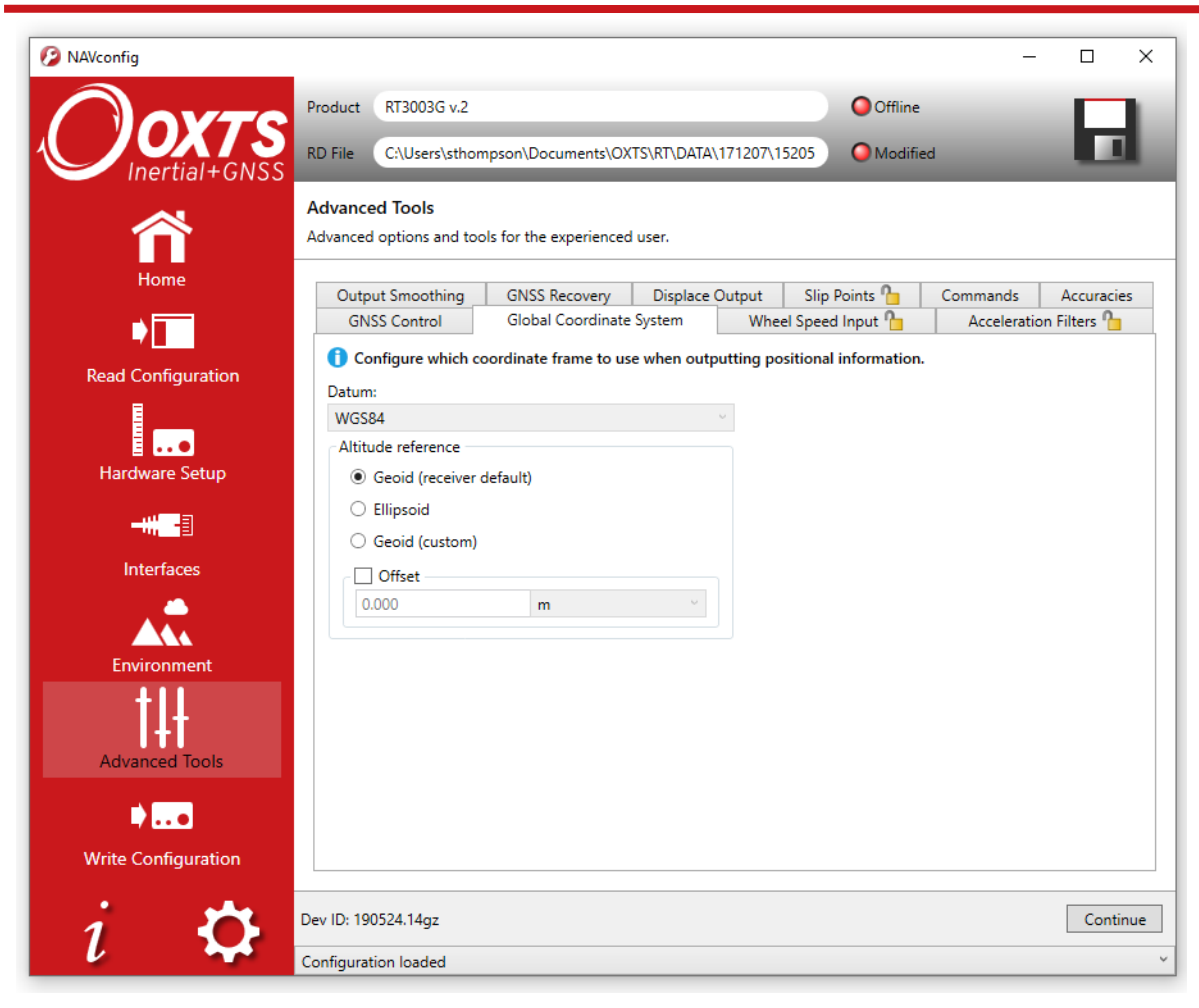
From the Global Coordinate System tab you can choose which reference datum to output latitude and longitude relative to. The default system and the standard for GPS is the WGS 84 datum.

Note: Currently outputs will only reference datums other than WGS 84 in post-processing. Real-time outputs will still be referenced to WGS 84 even if another option is selected.

The **Altitude reference** can be compared to either ellipsoidal or geoidal height. If **Ellipsoid** is selected, the altitude will be output with respect to the reference ellipsoid selected in the coordinate datum section. If **Geoid (receiver default)** is selected, the altitude will be relative to the geoid used in the GNSS receivers. A **Custom geoid** file can be used for local variations. To download supported geoid files, go to http://support.oxts.com/local-geoid-files. The UGF file must be saved in C:\Users***username***\Documents\OXTS\Shared\Custom geoid files. Once the file is downloaded and saved in this location, it can be selected from the dropdown box.

A constant offset to the specified altitude reference can be applied by checking the **Set offset** box typing in a value into the cell.

Accuracies tab

The NAVconfig software uses default accuracies for the measurements made during setup. These include antenna positions, IMU orientation values and measurements for Advanced Slip settings. It is recommended that you stick to these default measurements. However, if you wish to apply specific and more accurate values for measurements then these can be edited in this Accuracies tab. Enter the values directly into the values field.

Commands tab

Using the Commands tab you can enter device-specific commands that apply specific features or perform actions onto the RT. The OxTS technical support team often use these and can provide you with a list of useful commands if you request them at support@oxts.com.

The Write Configuration section of NAVconfig

Changes to the RT settings must be sent using Ethernet or Wi-Fi. It is necessary to configure your computer's LAN and WLAN settings, so it is on the same network as the RT.

Figure 39 shows the Write Configuration page.

Figure 39. NAVconfig Write Configuration page
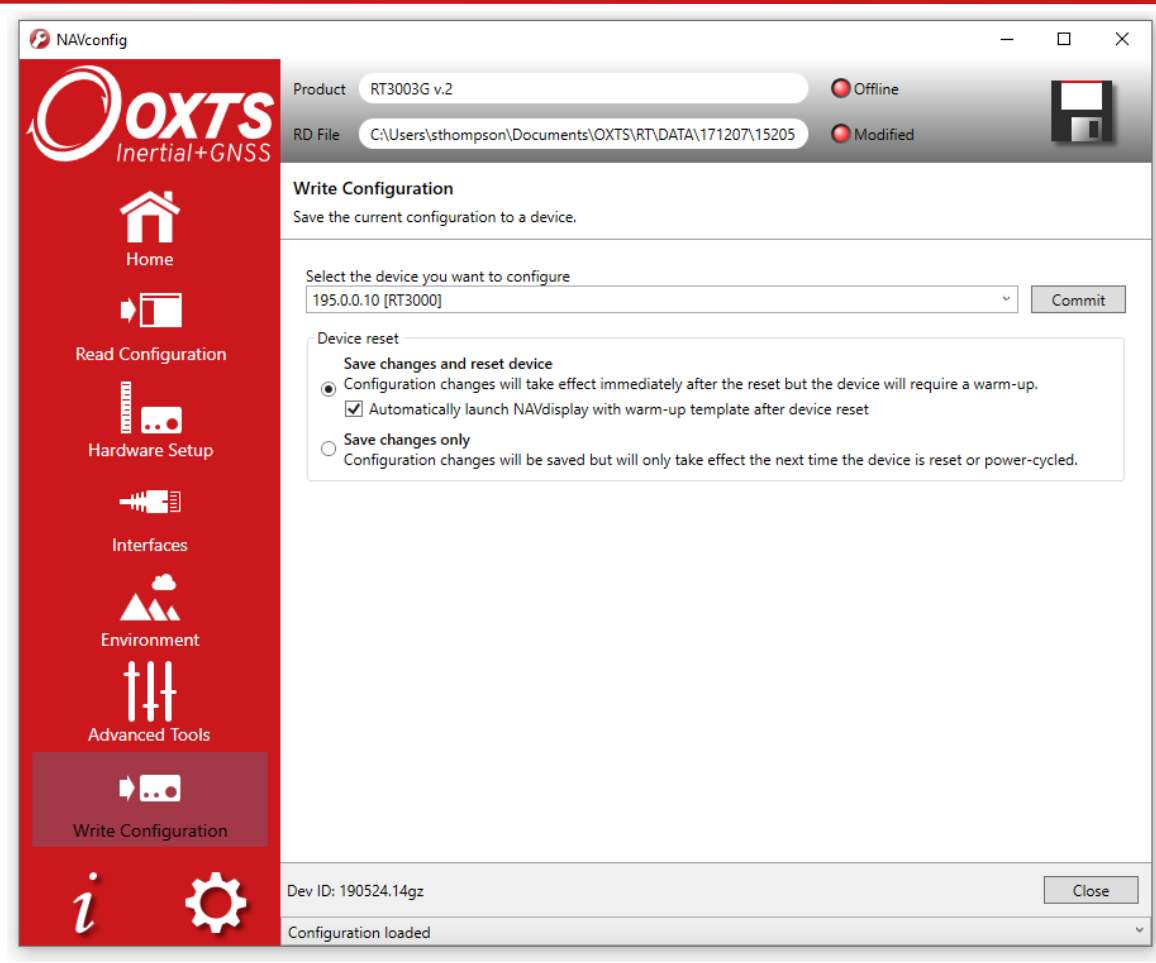
Enter the IP address of the RT you want to configure or select it from the dropdown list. The dropdown box will list all systems currently connected to the computer's network so ensure to select the correct system if there are multiple listed.

Choose whether to commit the configuration changes immediately to the unit or save them until the next time the unit is reset or power cycled.

Setting up the base station

For correct operation of the higher accuracy systems it is necessary to use a base station GNSS receiver. All of the systems can be successfully used without a base station, however, the specification will only be met if a base station is used.

The base station is a separate GNSS receiver that monitors signals from the GNSS satellites. Using its knowledge of position it works out the errors in each satellite's signal. It also measures the carrier-phase of the signal for kinematic corrections. The carrier-phase observations and the satellite signal errors are sent from the base station GNSS to the RT via a radio modem (not provided).

The position of the base station GNSS antenna can either be determined by the base station GNSS receiver or can be surveyed in by a chartered surveyor. If the base station GNSS receiver determines its own position, through position averaging, then any error in the base station receiver will also result in error at the RT. In order to relate the RT signals to maps, or other items on the world, it is necessary to have a surveyor measure the position of the GNSS antenna and then tell the base station GNSS receiver what position to use.

For many applications it is not necessary to survey in the base station antenna since an absolute world-reference is not required. Instead, a local grid can be used.

Using the RT-Base S

The RT-Base S is a self-contained GNSS, radio modem and battery housed in an IP65-rated case. For instructions on how to use the RT-Base S see the *"RT-Base S User Guide"*.

The RT-Base S is supplied with a radio modem. This should be connected to the radio connector of the RT user cable supplied. This cable supplies power to the radio modem as well as sending the differential corrections to the RT.

Initialisation process

Before the RT can start to output all the navigation measurements, it needs to initialise itself. In order to initialise, the RT needs all the measurements listed in Table 26.

Table 26. Quantities required for initialisation

Quantity	Description
Time	Measured by internal GNSS.
Position	Measured by internal GNSS.
Velocity	Measured by internal GNSS.
Heading	Approximated to course over ground (with large error) when the vehicle moves. Dual antenna models have the option for static initialisation which does not require any movement.
Roll, pitch	Vehicle Level option: assumed zero with a large error. Otherwise: estimated over first 40 s of motion with large error.

The system will start when it has estimates of all of these quantities. Course over ground will be used as the initial heading when the system exceeds the value set as the initialisation speed (default of 5 m/s), unless static initialisation has been selected. If the system is mounted level in the vehicle, then the Vehicle Level option will enable the system to start immediately. Otherwise the system takes about 40 s to find approximate values for roll and pitch.

For the initialisation process to work correctly, the RT requires the user to tell it which way it is mounted in the vehicle, otherwise the course over ground will not be close enough to the heading.

Real-time outputs

During the initialisation process the system runs 1 s behind, allowing GNSS information to be compared to information from the inertial sensors. After initialisation the system has to catch-up from this 1 s lag. It takes 10 s to do this. During the first 10 s the system cannot output data in real time, the delay decays to the specified latency linearly over this 10 s period.

The system turns the SDNav LED orange to show the outputs are not real-time. When the system is running in real time this LED is green.

Warm-up period

During the first 15 minutes of operation the system will not conform to specification. During this period the Kalman Filter runs a more relaxed model for the sensors. By running a more relaxed model the system is able to:

- Make better estimates of the errors in the long term (if it does not get these correct then they become more difficult to correct as time goes on).

- Track the errors in the inertial sensor during their warm-up period (when their errors change more quickly than normal).

During this period it is necessary to drive the vehicle or the errors will not be estimated and the specification will not be reached. The NCOM output message (and CAN outputs) includes status information that can be used to identify when the required specification has been met. These are plotted in the example below.

The warm-up period is a concern to some customers but it is often very simple to overcome. Below is an example of a good warm-up procedure that did not involve a lot of work for the user. In this example the key features are:

- The RT was configured well – the GNSS antenna position, Advanced slip options and dual-antenna separation were measured accurately in advance.

- The RT was turned on as soon as possible. In this case it took us 15 minutes to get all the other equipment sorted out. The RT was stationary for most of this period – which is not a problem.

- Although in this example the RT was receiving corrections from a base station while stationary, it is not necessary. The base station should be working before the dynamic driving starts so the RT can use the best information to self-calibrate (if a base station is not being use this does not apply).

- There are 6 minutes during which the car was driven in figures of eight. From the graphs you can see the RT3003 is accurate almost after the first figure of eight; after that the improvement is very small.

The trick is to turn the RT on early; do not reconfigure it (which resets it) or cycle the power.

Figure 41 shows the route driven and Figure 42 shows the accuracy estimated by the Kalman filter for various output parameters during the first 25 minutes. The quality of initialisation would have been the same if the stationary period was 10 minutes, followed by 5 minutes of driving. The time on the graphs is the time from initialisation. In this example the RT3003 was initialised 25 s after starting up; the quality of initialisation would be the same if it had been not been initialised for the first 10 minutes, then initialised and driven for 5 minutes.

Figure 40. Example warm-up driving route
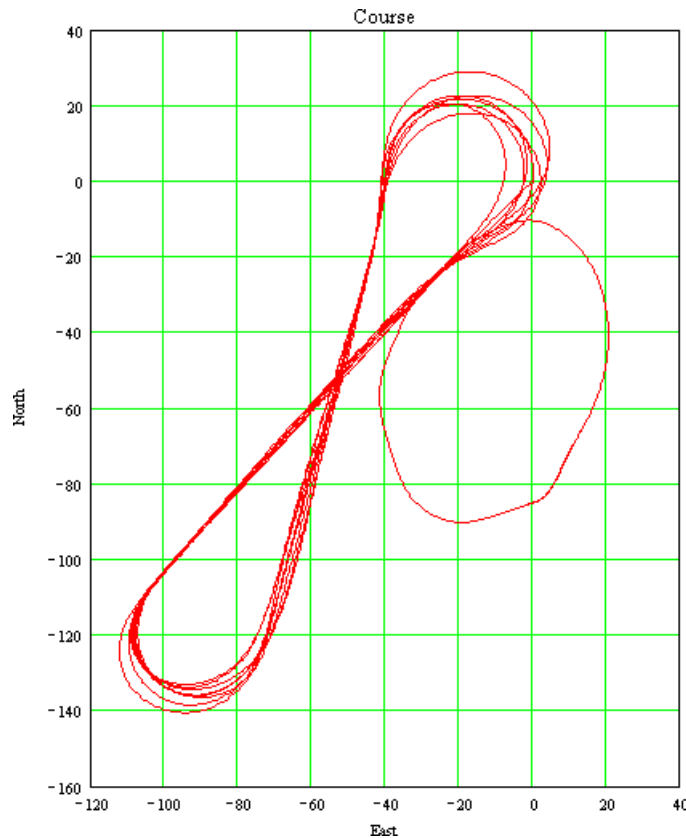
At the start there is just a small amount of motion to get the RT3000 initialised. During this time the Kalman filter cannot improve the position accuracy because the position of the GNSS antenna is not known accurately and cannot be estimated without motion. The accuracy of the velocity, roll and pitch steadily improves as the Kalman filter places more and more weight on the inertial sensors. At this point the heading accuracy is worse than the scale of the graph (**(d)** in Figure 41); the heading is not accurate and the dual antenna system cannot measure the angle of the GNSS antennas compared to the inertial sensors, so the dual antenna cannot provide accurate information.

Just after 500 s the RT3000 is driven (it is the small loop on the east side in Figure 40, not the figures of eight). This small amount of driving is sufficient for the Kalman filter to gain confidence in the antenna position and to improve the alignment of the two GNSS antennas compared to the inertial sensors. After this period the position accuracy is better than 1 cm and the heading is better than 0.2°.

Figure 41. Example warm-up accuracy estimates
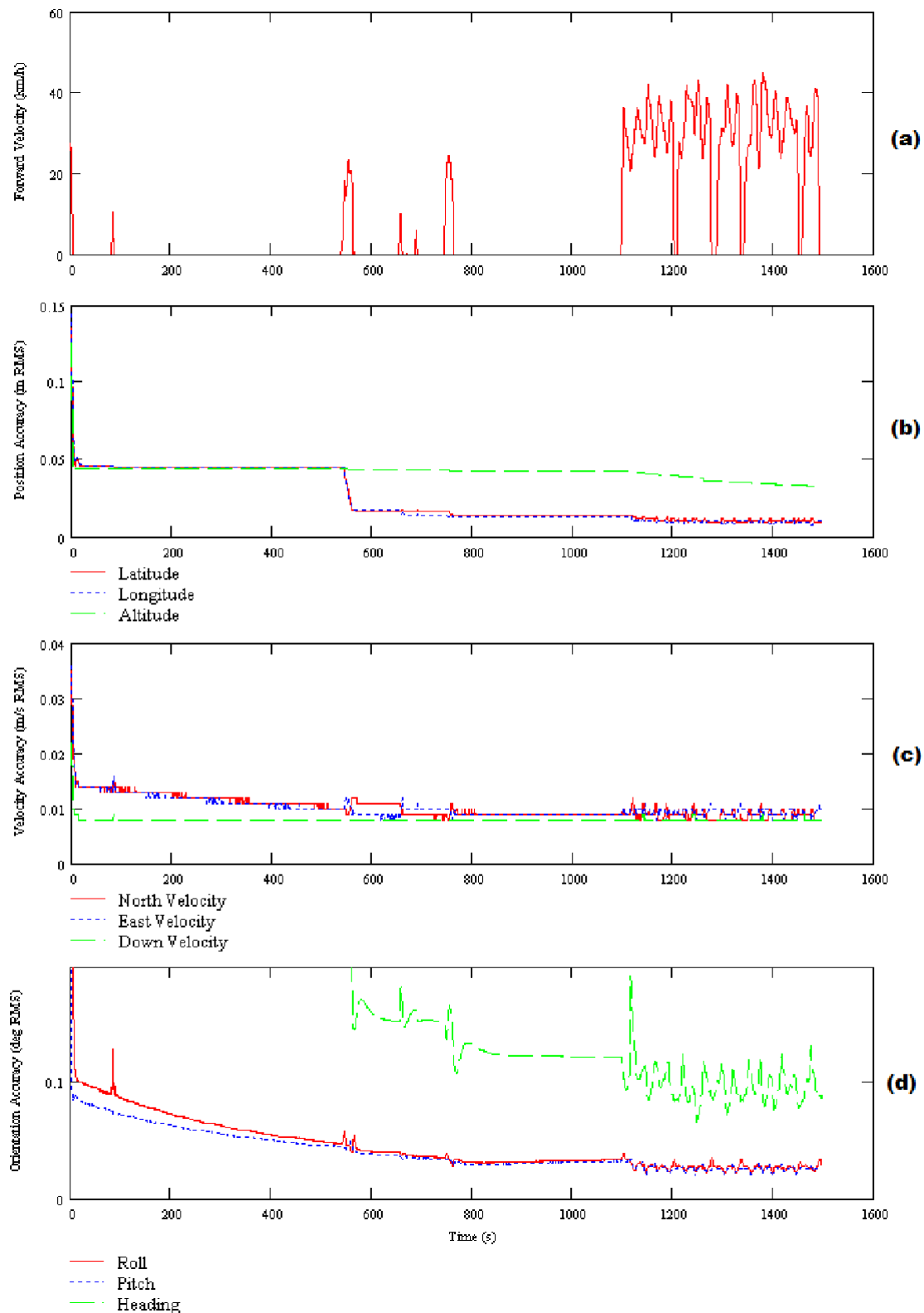
(**a**) Forward velocity. (**b**) Position accuracies. (**c**) Velocity accuracies. (**d**) Orientation accuracies.

You can see the RT is nearly at specification after just this small amount of driving. However, experience tells us the Kalman filter will continue to make some improvements (not obvious) during the first few figures of eight. The main part of the motion occurs after 1100 s when the car was driven in a figure of eight for 6 minutes.

These are fairly large figures of eight driven at relatively low speeds. Notice the brake stops in the velocity graph (**(a)** in Figure 41) where the speed falls to zero. These are important parts of the warm-up – so as many states in the Kalman filter as possible can be updated.

Notice how close to the specification the RT is even without the figure of eight manoeuvres. A proper warm-up is recommended in order to achieve the highest level of accuracy. However the effect is small and only significant when you need the full performance of the RT.

Improving the configuration after a warm-up

Committing the configuration to the RT

After the warm-up process has been completed you can commit the improved settings to the RT using NAVconfig. The RT takes its improved orientation, antenna positions and wheel speed sensor position from values generated in real time during the warm-up and uses them to improve accuracies.

To commit improved settings to the RT, first open NAVconfig and select 'Improve configuration'. Figure 43 shows this option on the NAVconfig home section.
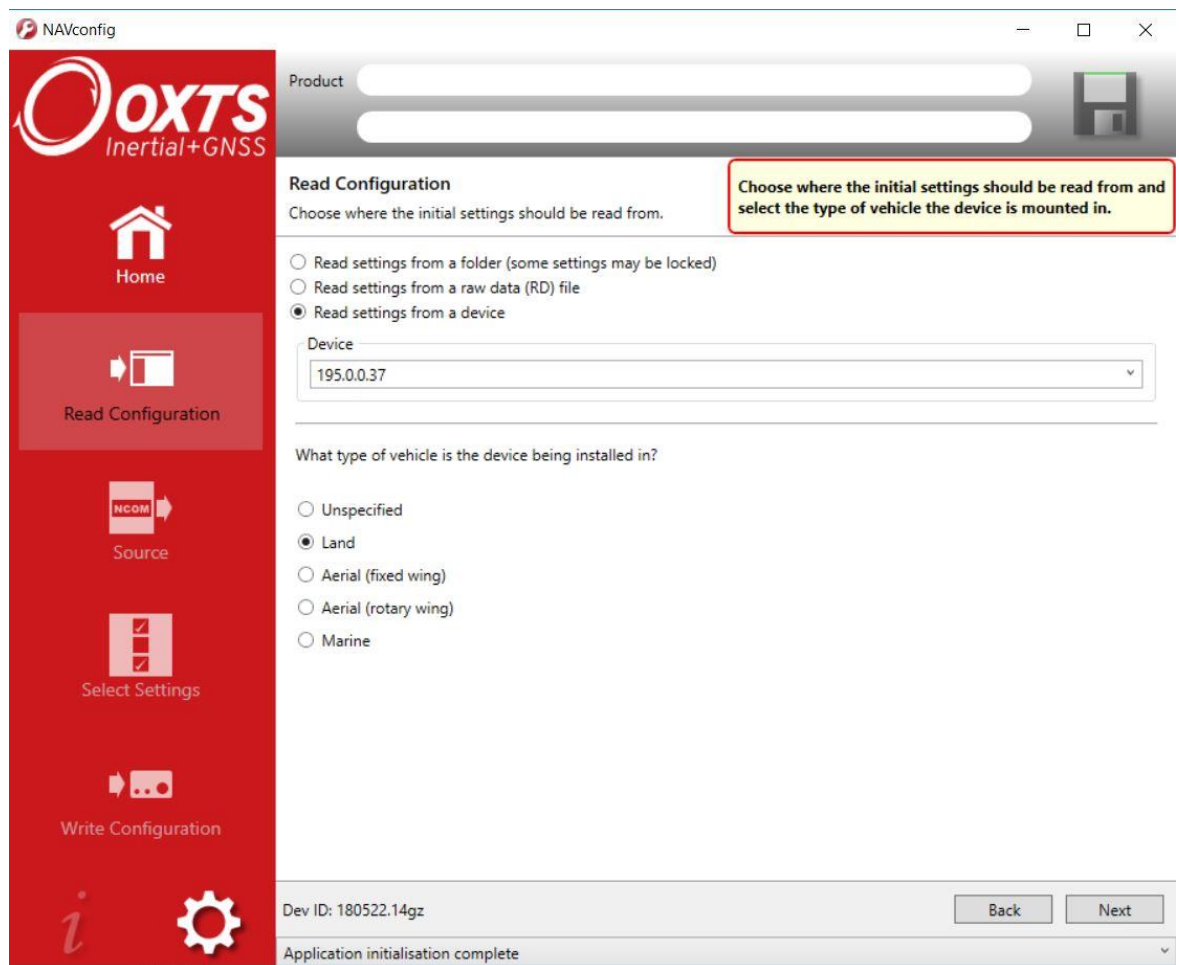
Figure 42. NAVconfig Home section
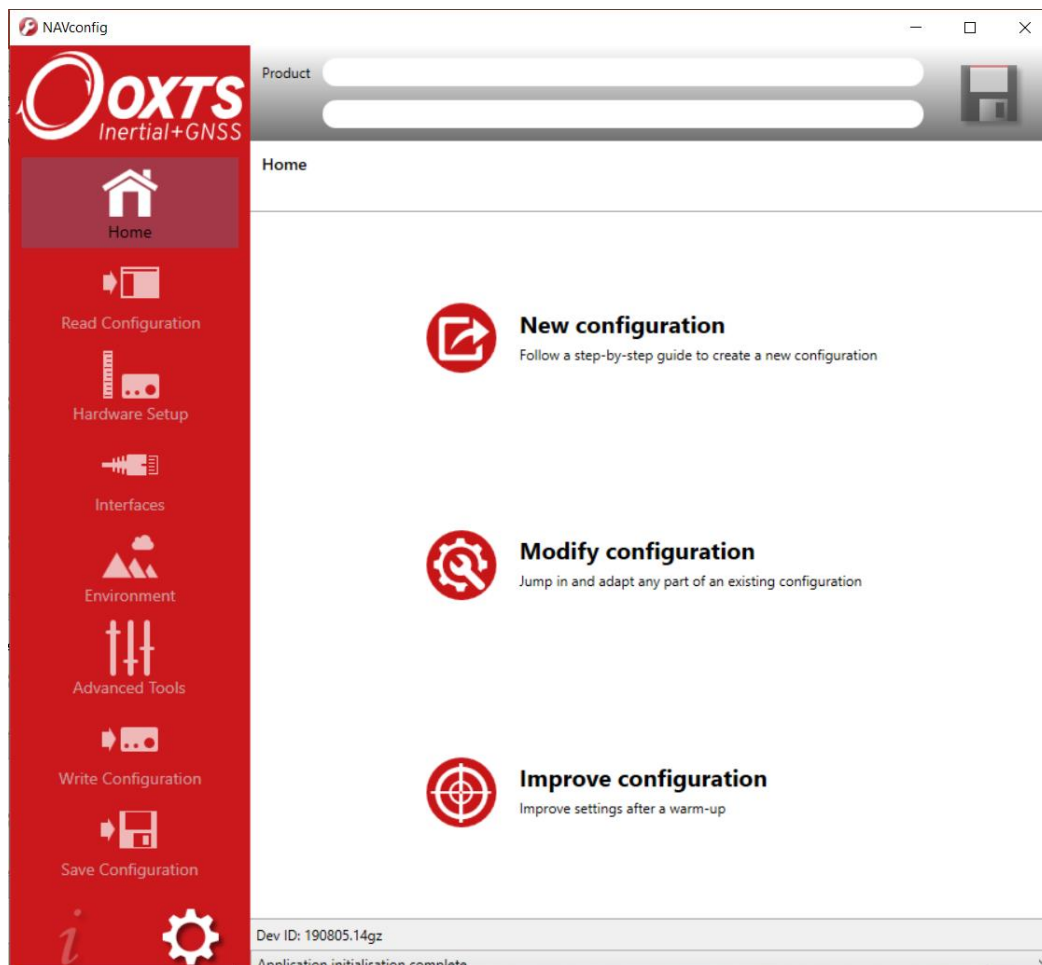
Read configuration section in NAVconfig improved configuration wizard

If you are connected to a device via Wi-Fi or Ethernet, then select "Read settings from a device" and choose the device from the available list. If the file has been logged to the PC already then you can choose 'Read settings from a data (RD) file' or 'Read settings from a folder' by locating the file or folder on your PC.

Figure 43. NAVconfig Read Configuration

Click 'Next' to continue.

Confirm whether the improved data should be read from: The Device, or a File. Click 'Next' to continue.

Figure 44. NAVconfig Improve configuration data source
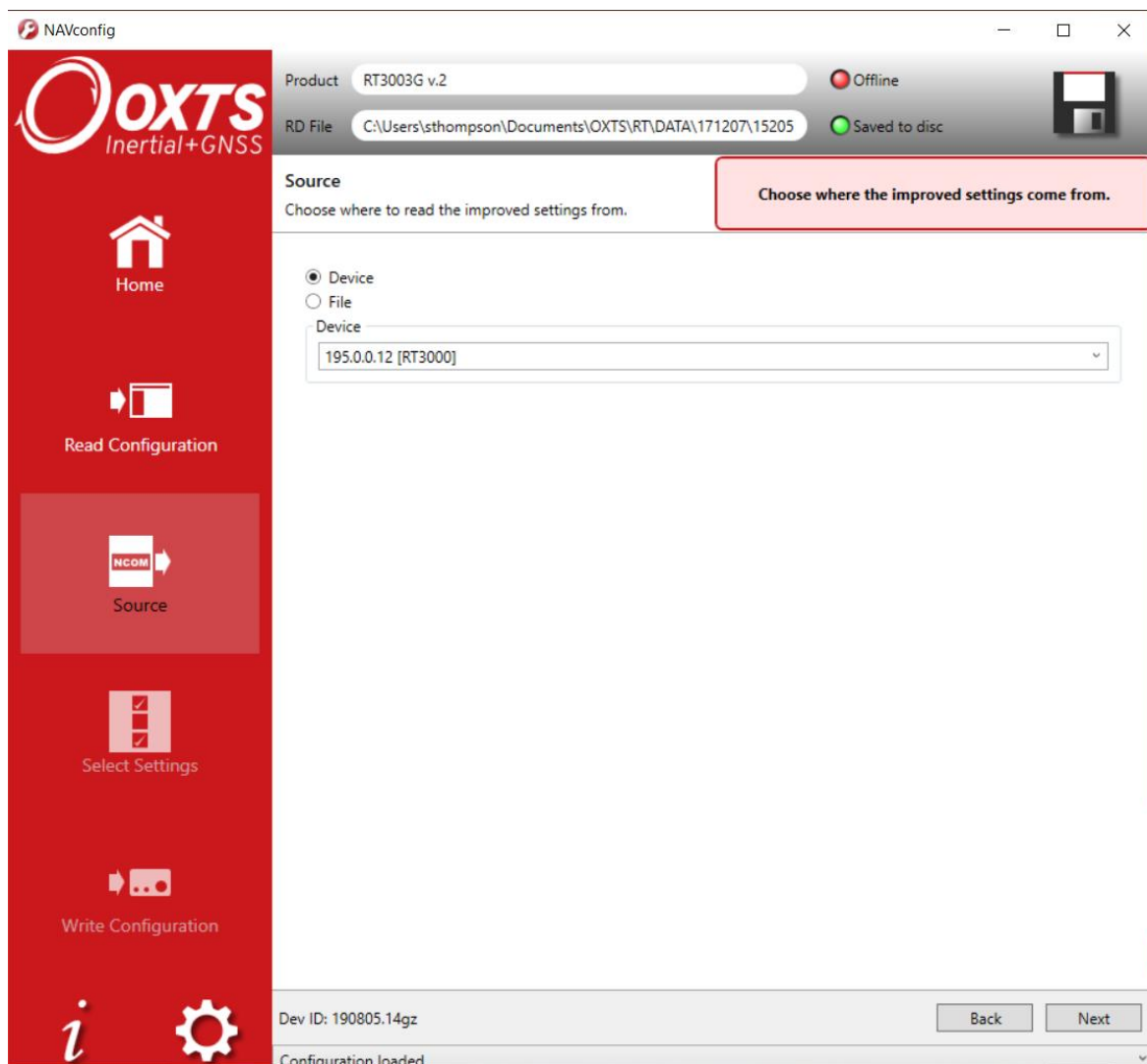
The Select Settings screen will appear. From the list displayed, select the settings that you wish to view. These will be determined according to what is enabled on your device.

Figure 45. NAVconfig Improve configuration Select Settings

 Select the settings that you wish to improve in the configuration from the options available. By clicking the down arrows, you can expand the settings and view the values that have been improved after the warm-up. It is recommended that you review these before clicking 'Next' to continue.

The final stage of the improved settings wizard is to write the configuration to the device and apply the improved settings with new accuracies. You can choose whether to commit the improved settings to the device after a rest or power cycle (recommended) or to apply them immediately (which does not get saved into the configuration file on the device). For the improved settings to apply to the device in the case where the device will remain in the car for some time, it is recommended that you apply the improved settings and reset the device.

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Figure 46. NAVconfig Improve Configuration Write Configuration
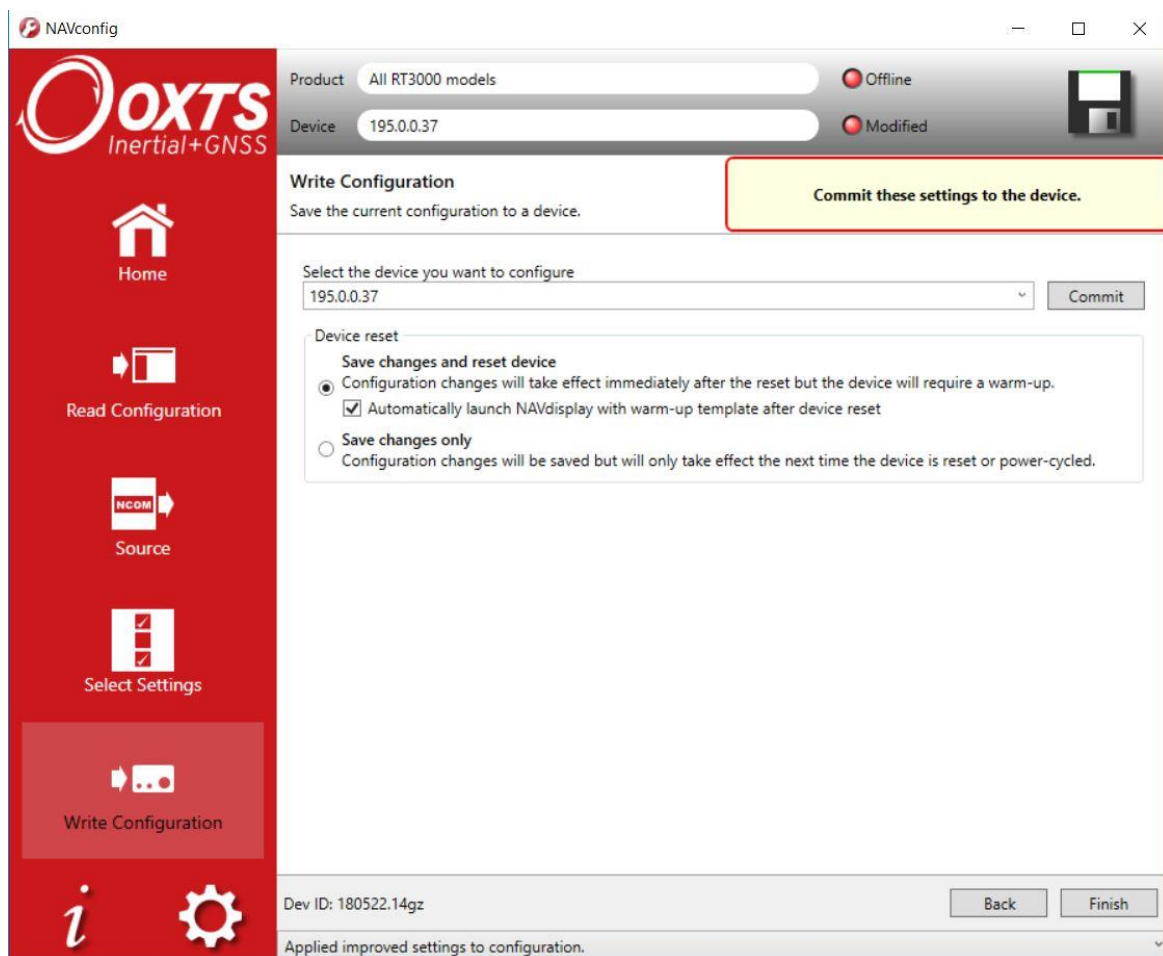
Before you write the improved settings to the device, choose whether you want to apply the settings immediately or after a power cycle.

Post-processing data

Data stored on the RT is in a raw, unprocessed format; these files have an RD extension. The advantage of this is it can be reprocessed with different configuration settings. For example, if the configuration was configured incorrectly when running in real time, then the configuration can be changed and the data can be reprocessed post-mission.

The software suite provided with the RT includes the NAVsolve software which can be used to reprocess the data. The NAVsolve Wizard also gives the user the ability to change the NCOM binary output format to text.

A full explanation of NAVsolve is given in the *"NAVsolve manual"*, which can be downloaded from the OxTS support website.

Laboratory testing

There are several checks that can be performed in the laboratory to ensure the system is working correctly. The most fragile items in the system are the accelerometers, the other items are not subject to shock and do not need to be tested as thoroughly.

Accelerometer test procedure

To check the accelerometers are working correctly, follow this procedure.

1.   Connect power and a laptop to the system.

2.   Commit a default setting to the RT using NAVconfig, then run NAVdisplay.

3.   Click the 'Calibration' button, then select the 'Navigation' tab and ensure the x, y, and z accelerations (values 19 to 21) are within specification when the RT is placed on a level surface in the orientations according to Table 31.

Table 27. Acceleration measurement specifications

Orientation			Acceleration measurement
x	y	z	
Flat	Flat	Down	z-acceleration between –9.7 and –9.9 m/s^2
Flat	Flat	Up	z-acceleration between 9.7 and 9.9 m/s^2
Down	Flat	Flat	x-acceleration between –9.7 and –9.9 m/s^2
Up	Flat	Flat	x-acceleration between 9.7 and 9.9 m/s^2
Flat	Down	Flat	y-acceleration between –9.7 and –9.9 m/s^2
Flat	Up	Flat	y-acceleration between 9.7 and 9.9 m/s^2

This test is sufficient to ensure the accelerometers have not been damaged.

Gyro test procedure

To check that the gyros (angular rate sensors) are working correctly, follow this procedure:

1. Connect power and a laptop to the system.

2. Commit a default setting to the RT using NAVconfig, then run NAVdisplay.

3. Click the 'Calibration' button, then select the 'Navigation' tab and scroll to view the *x*, *y*, and *z* angular rates (values 30 to 32).

4. Rotate the RT according to Table 32 and check the angular rate measurements occur.

5. With the unit stationary, check all the angular rates are within ±5°/s. (In general they will be within ±0.5°/s, but the algorithm in the RT will work to specification with biases up to ±5°/s.)

Table 28. Angular rate measurement specifications

Orientation			Angular rate
x	y	z	
+ve	Zero	Zero	The *x*-axis should indicate positive rotation, others are small.
–ve	Zero	Zero	The *x*-axis should indicate negative rotation, others are small.
Zero	+ve	Zero	The *y*-axis should indicate positive rotation, others are small.
Zero	–ve	Zero	The *y*-axis should indicate negative rotation, others are small.
Zero	Zero	+ve	The *z*-axis should indicate positive rotation, others are small.
Zer	Zero	–ve	The *z*-axis should indicate negative rotation, others are small.

It is hard to do a more exhaustive test using the angular rate sensors without specialised software and equipment. For further calibration testing it is necessary to return the unit to OxTS.

Note that the RT is capable of correcting the error in the angular rate sensors *very* accurately. It is not necessary to have very small values for the angular rates when stationary since they will be estimated during the initialisation process and warm-up period. This estimation process allows the RT to go for long periods without requiring recalibration.

Testing the internal GNSS and other circuitry

To check all the internal circuits in the RT are working correctly and the navigation computer has booted correctly, use the following procedure:

1. Connect power to the system, connect the system to a laptop computer and run the visual display software (NAVdisplay).

2. Use Table 33, below, to check the status fields are changing.

Table 29. Status field checks

Field	Increment rate
IMU packets	100 per second or 250 per second, depending on product model.
IMU chars skipped	Not changing (but not necessarily zero).
GPS packets	Between 2 and 20 per second (depending on system).
GPS chars skipped	Not changing (but not necessarily zero).
GPS2 packets[1]	Between 2 and 20 per second (depending on system).
GPS2 char skipped[1]	Not changing (but not necessarily zero).

[1]The GPS2 related fields will only increase for dual antenna systems.

These checks will ensure the signals from the GNSS and from the inertial sensors are being correctly received at the navigation computer.

Using the orientation measurements

This section has been provided to clarify the definitions of heading, pitch and roll that are output by the RT.

The RT uses quaternions internally to avoid the problems of singularities and to minimise numerical drift on the attitude integration. Euler angles are used to output the heading, pitch and roll, and these have singularities at two orientations. The RT has rules to avoid problems when operating close to the singularities; if you regenerate the rotation matrices given below then they will be correct.

The Euler angles output are three consecutive rotations (first heading, then pitch and finally roll) that transform a vector measured in the navigation co-ordinate frame to the body co-ordinate frame. The navigation co-ordinate frame is the orientation on the earth at your current location with axes of north, east and down.

If V_n is vector V measured in the navigation co-ordinate frame and V_b is the same vector measured in the body co-ordinate frame the two vectors are related by:

$$V_n = C_{bn} \cdot V_b$$

$$V_n = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix} \cdot V_b$$

where:

ψ is the heading angle;
θ is the pitch angle and
ϕ is the roll angle.

Remember – heading, pitch and roll are usually output in degrees, but the functions *sin* and *cos* require these values in radians.

Operating principles

This short section gives some background information on the components in the RT 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. The section is provided as "interesting information" and is not required for normal operation.

Internal components

Figure 47 gives a schematic view of the components in the RT system.

Figure 47. Schematic showing the internal components of the RT
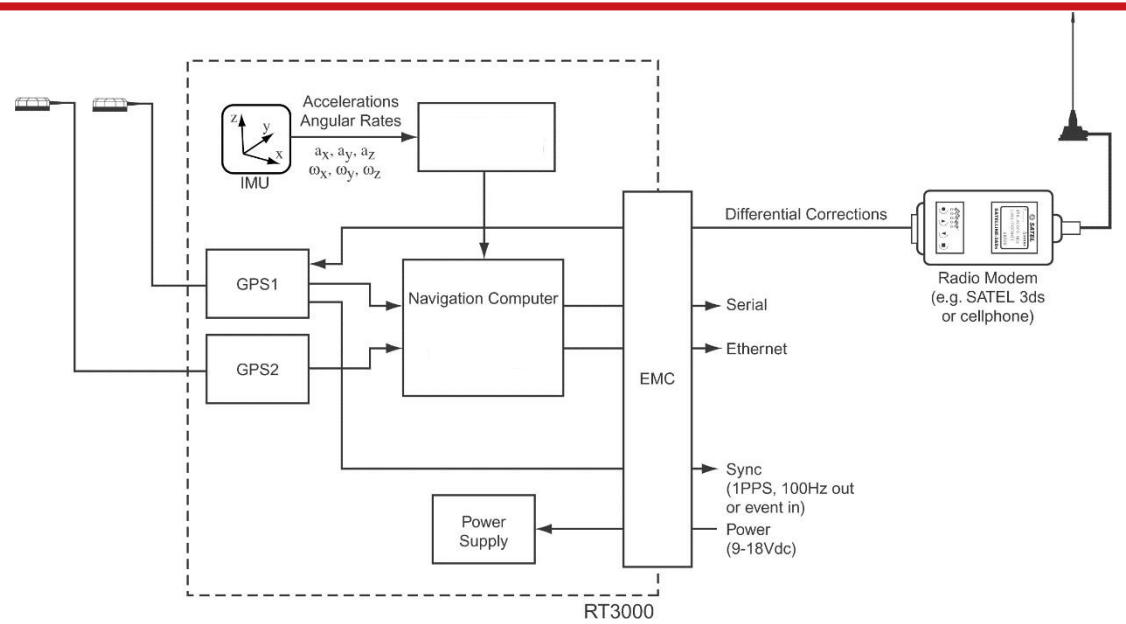
The schematic shows the layout for a dual antenna system, the second GNSS (GNSS2) and the second antenna are not fitted on single antenna systems.

The accelerations and angular rates are measured in the inertial measurement unit. The accelerometers are all mounted at 90° to each other so they can measure each direction independently. The three angular rate sensors are mounted in the same three directions as the accelerometers. A powerful, 40 MHz floating point DSP controls the ADC and, through advanced signal processing, gives a resolution of 20-bits. Digital anti-aliasing filters and coning/sculling motion compensation algorithms are run on the DSP. Calibration of the accelerometers and angular rate sensors also takes place in the DSP; this includes very high-precision alignment matrices that ensure that the direction of the acceleration and angular rate measurements is accurate to better than 0.01°.

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The sampling process in the inertial measurement unit is synchronised to GPS time so the 100 Hz or 250 Hz measurements from the RT are synchronised to GPS.

The navigation computer is a Pentium class processor that runs the navigation algorithms (more on this below). Information from the DSP and the two GNSS receivers is fed into the navigation computer. The navigation computer runs a real-time operating system (QNX) so outputs are made in a deterministic amount of time. The outputs from the navigation computer are available over Serial RS232, UDP broadcast on Ethernet or CAN bus.

On RT3000 products differential corrections can be supplied directly to the GNSS receiver to improve the positioning accuracy. The differential corrections can be supplied via radio modem from a base station, via cell phone from a base station or from a separate differential source, such as TerraStar or US Coastguard.

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 49 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 48. Schematic of the strapdown navigator
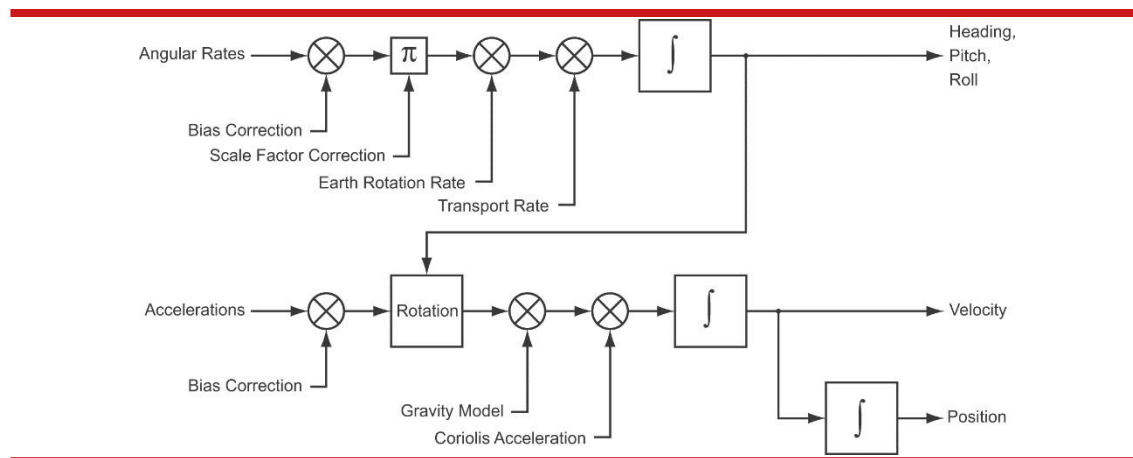
People familiar with inertial navigation systems will note that "angular rates" and "accelerations" are labelled as the inputs. In reality the DSP in the RT converts these to "change in angle" and "change in velocity" to avoid problems of coning and sculling.

Some other rotations are also missed in the diagram. The RT does not use a wander angle, so it will not operate correctly on the North and South poles.

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. These are represented internally using a quaternion (so the RT can work at any angle and does not have any singularities).

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.

The Kalman filter used in the RT 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.

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 RT; the Kalman filter is used to improve the position measurement made from two sources, inertial sensors and GNSS.

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

Consider a lift (or elevator) in a building. We might make measurements of acceleration and we might know what our position is when we pass a floor; these are the two measurements our system makes. A Kalman filter could be used to measure velocity in this situation even though no sensor measures velocity directly. The Kalman filter could also be used to measure the bias (or offset) of the accelerometer, thereby improving the system by providing on-line calibration. The bias of the accelerometer might mean the system always believes the lift arrives early at each floor; by changing the bias on the accelerometer the measurement of lift position can be made to correlate with the floor sensor more accurately.

The same principles are used in the RT. 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.

The Kalman filter in the RT has 24 states. These are position error (north, east, down); velocity error (north, east, down); heading error; pitch error; roll error; gyro bias (x, y, z); gyro scale factor (x, y, z); accelerometer bias (x, y, z); GNSS antenna position (x, y, z); GNSS antennas orientation (heading, pitch) and vehicle mounting angle (for advanced slip).

The errors are applied smoothly to the states. For example, if the Kalman filter wants to correct a position error of five centimetres in the north direction then this is applied slowly, rather than jumping directly to the new position. This helps applications that use the RT for control since any differential terms in the control algorithm do not have large step changes in them.

CAN messages and signals

In the default configuration the CAN bus uses identifiers 500h to 5FFh for RT status information; 600h to 60Fh for navigation information; 610h to 613h for RT-ANA messages and 620h to 623h for the additional slip points.

Using the configuration software it is possible to change the default message identifiers.

Only one status message is output per cycle (100 Hz or 250 Hz output rate) you do not get each status message at the specified rate.

All values from the RT are encoded in little-endian format (Intel-style).

Termination resistor

The CAN bus output does not include a termination resistor. It is essential to include a 120 Ω resistor at each end of your CAN bus – otherwise the CAN bus will not work.

CAN-DBC file

NAVconfig can output a CAN-DBC file that contains all the measurements the RT is configured to output.

CAN bus messages

Table 30 lists all the messages the RT outputs on the CAN bus and the identifiers that are used for each message. The signals in each message are listed in the tables that follow.

Table 30. CAN bus messages

Default identifier (hex)	Message name	Data contents	See table
1536 (600h)	DateTime	Date and time	Table 31
1537 (601h)	LatitudeLongitude	Latitude and longitude	Table 32
1538 (602h)	Altitude	Altitude	Table 33
1539 (603h)	Velocity	OxTS NED frame velocity	Table 34
1540 (604h)	VelocityLevel	OxTS horizontal frame velocity	Table 35
1541 (605h)	AccelVehicle	OxTS output frame IMU acceleration	Table 36
1542 (606h)	AccelLevel	OxTS horizontal frame IMU acceleration	Table 37
1543 (607h)	HeadingPitchRoll	OxTS orientation	Table 38
1544 (608h)	RateVehicle	OxTS output frame IMU angular rate	Table 39
1545 (609h)	RateLevel	OxTS horizontal frame IMU angular rate	Table 40
1546 (60Ah)	TrackSlipCurvature	Track, slip and curvature	Table 41
1547 (60Bh)	Distance	Distance	Table 42
1548 (60Ch)	PosLocal	Position in local co-ordinates	Table 43
1549 (60Dh)	VelYawLocal	Velocity and yaw angle in local co-ordinates	Table 44
1550 (60Eh)	AngAccelVehicle	OxTS output frame IMU angular acceleration	Table 45
1551 (60Fh)	AngAccelLevel	OxTS horizontal frame IMU angular acceleration	Table 46
1552..1555 (620h…613h)		Reserved for RT-ANA signals	
1568 (620h)	TrackSlipCurvaturePoint1	Measurement point 1 track, slip and curvature	Table 47
1569 (621h)	TrackSlipCurvaturePoint2	Measurement point 2 track, slip and curvature	Table 48
1570 (622h)	TrackSlipCurvaturePoint3	Measurement point 3 track, slip and curvature	Table 49
1571 (623h)	TrackSlipCurvaturePoint4	Measurement point 4 track, slip and curvature	Table 50
1572 (624h)	HeadingPitchRollFromSurf	Level surface orientation	Table 51
1573 (625h)	TrackSlipCurvaturePoint5	Measurement point 5 track, slip and curvature	Table 52
1574 (626h)	TrackSlipCurvaturePoint6	Measurement point 6 track, slip and curvature	Table 53
1574 (627h)	TrackSlipCurvaturePoint7	Measurement point 7 track, slip and curvature	Table 54

1576 (628h)	TrackSlipCurvaturePoint8	Measurement point 8 track, slip and curvature	Table 55
1577 (629h)	ApproxLatitudeLongitude	Approximate latitude and longitude	Table 56
1578 (62Ah)	ApproxAltitude	Approximate altitude	Table 57
1579 (62Bh)	ApproxVelocity	Approximate OxTS NED frame velocity	Table 58
1580 (62Ch)	Reserved		
1581 (62Dh)	FallingTrigger	Trigger 1 falling edge	Table 59
1582 (62Eh)	RisingTrigger	Trigger 1 rising edge	Table 60
1583 (62Fh)	PosLocalNE	Northing and easting in local co-ordinates	Table 61
1584 (630h)	MilliTime	Absolute GPS time	Table 62
1585 (631h)	Reserved		
1586 (632h)	Reserved		
1587 (633h)	IsoOrientation	ISO 8855 orientation	Table 63
1588 (634h)	IsoVsVelocity	ISO 8855 vehicle system velocity	Table 64
1589 (635h)	IsoVsAcceleration	ISO 8855 vehicle system acceleration	Table 65
1590 (636h)	IsoVsAngularVelocity	ISO 8855 vehicle system angular velocity	Table 66
1591 (637h)	IsoVsAngularAcceleration	ISO 8855 vehicle system angular acceleration	Table 67
1592 (638h)	IsoIsVElocity	ISO 8855 intermediate system velocity	Table 68
1593 (639h)	IsoIsAcceleration	ISO 8855 intermediate system	Table 69
1594 (63Ah)	IsoAngularVelocity	ISO 8855 intermediate system angular velocity	Table 70
1595 (63Bh)	IsoIsAngularAcceleration	ISO 8855 intermediate system angular acceleration	Table 71
1596 (63Ch)	IsoEfsVelocity	ISO 8855 earth-fixed system velocity	Table 72
1597 (63Dh)	IsoEfsAcceleration	ISO 8855 earth-fixed system acceleration	Table 73

The status information in NCOM is output over the CAN bus on Identifiers 500h to 5FFh. The offset from 500h is the same as the *Channel* number in the NCOM message definition. The bytes 0 to 7 are the same in the CAN message as in the NCOM packet.

Table heading definitions

The fields in the tables have the following meanings.

Offset (bits). This is the offset into the message where the signal starts. To compute the offset in bytes divide the value by 8.

Length (bits). This is the length of the signal in bits. To compute the length of the signal in bytes, divide the value by 8.

Type. This specifies either an unsigned value (U) or a signed value (S).

Units. This is the units for the signal.

Factor. This is the factor that the integer unit should be multiplied by to get the signal into the units given in the table.

Offset. This is the value of the signal when the integer value in the CAN message is zero. It is zero for all the RT signals and can usually be discarded.

Signals

The following tables describe the signals in each of the messages.

Table 31. Identifier 600h (1536), DateTime

						Description	Signal name
0	8	U	Year	1	0	Year within century (e.g. '16' during year 2016)	TimeYear
8	8	U	Year	100	0	Century (e.g. '20' during 2016)	TimeCentury
16	8	U	Month	1	0	Month	TimeMonth
24	8	U	Day	1	0	Day	TimeDay
32	8	U	s	0.01	0	Hundredths of current second	TimeHSecond
40	8	U	s	1	0	Seconds	TimeSecond
48	8	U	Min	1	0	Minutes	TimeMinute
56	8	U	Hour	1	0	Hours	TimeHour

Note: time is always reported as GPS time. Currently this is 16 s different from UTC.

Table 32. Identifier 601h (1537), LatitudeLongitude

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	32	S	°	1e-7	0	Latitude	PosLat
32	32	S	°	1e-7	0	Longitude	PosLon

Table 33 Identifier 602h (1538), Altitude

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	32	S	m	0.001	0	Altitude	Altitude

By default the altitude is output relative to mean sea level, not WGS 84. The datum can be changed using NAVconfig.

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Table 34. Identifier 603h (1539), Velocity

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s	0.01	0	OxTS NED frame north velocity	VelNorth
16	16	S	m/s	0.01	0	OxTS NED frame east velocity	VelEast
32	16	S	m/s	0.01	0	OxTS NED frame vertical (down) velocity	VelDown
48	16	U	m/s	0.01	0	Horizontal speed	Speed2D

The horizontal speed is the vector addition of north and east velocities. For forward speed (which can go negative) see message 604h.

Table 35. Identifier 604h (1540), VelocityLevel

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s	0.01	0	OxTS horizontal frame longitudinal (forward) velocity	VelForward
16	16	S	m/s	0.01	0	OxTS horizontal frame lateral (right) velocity	VelLateral

The forward velocity can go negative when driving backwards.

Table 36. Identifier 605h (1541), AccelVehicle

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s^2	0.01	0	OxTS output frame longitudinal (forward) IMU acceleration	AccelX
16	16	S	m/s^2	0.01	0	OxTS output frame lateral (right) IMU acceleration	AccelY
32	16	S	m/s^2	0.01	0	OxTS output frame vertical (down) IMU acceleration	AccelZ

Table 37. Identifier 606h (1542), AccelLevel

						Description	Signal name
0	16	S	m/s^2	0.01	0	OxTS horizontal frame longitudinal (forward) IMU acceleration	AccelForward
16	16	S	m/s^2	0.01	0	OxTS horizontal frame lateral (right) IMU acceleration	AccelLateral
32	16	S	m/s^2	0.01	0	OxTS horizontal frame vertical (down) IMU acceleration	AccelDown
48	16	S	m/s^2	0.01	0	Slip rate	AccelSlip

Table 38. Identifier 607h (1543), HeadingPitchRoll

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	U	°	0.01	0	Heading angle	AngleHeading
16	16	S	°	0.01	0	Pitch angle	AnglePitch
32	16	S	°	0.01	0	Roll angle	AngleRoll

Note: the range of the heading angle is 0 to 359.99, the range of the pitch angle is ±90° and the range of the roll angle is ±180°.

Table 39. Identifier 608h (1544), RateVehicle

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	°/s	0.01	0	OxTS output frame longitudinal (forward) IMU angular rate	AngRateX
16	16	S	°/s	0.01	0	OxTS output frame lateral (right) IMU angular rate	AngRateY
32	16	S	°/s	0.01	0	OxTS output frame vertical (down) IMU angular rate	AngRateZ

Table 40. Identifier 609h (1545), RateLevel

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	°/s	0.01	0	OxTS horizontal frame longitudinal (forward) IMU angular rate	AngRateForward
16	16	S	°/s	0.01	0	OxTS horizontal frame lateral (right) IMU angular rate	AngRateLateral
32	16	S	°/s	0.01	0	OxTS horizontal frame vertical (down) IMU angular rate	AngRateDown

See message 608h for roll angular rate. The definition of roll rate used in this manual is consistent with the Euler angles used to output roll, pitch and heading; therefore the roll angular rate is the same as the pitched *x*-angular rate or the body *x*-angular rate. The forward angular rate is the rotation about the axis which is horizontal.

Table 41. Identifier 60Ah (1546), TrackSlipCurvature

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	U	°	0.01	0	Track angle	AngleTrack
16	16	S	°	0.01	0	Slip angle	AngleSlip
32	16	S	1/m	0.0001	0	Curvature	Curvature

Note that the slip angle will be close to 180° when driving backwards.

Table 42. Identifier 60Bh (1547), Distance

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	32	U	m	0.001	0	Horizontal distance with hold	DistanceWithHold
32	32	U	m	0.001	0	Horizontal distance without hold	Distance

Note: Distance with hold will not increase when the RT measures a speed less than 0.2 m/s whereas the Distance field will drift by the noise of the RT when stationary. The distances start from zero when the RT-CAN unit is powered up.

Table 43. Identifier 60Ch (1548), PosLocal

						Description	Signal name
0	32	S	m	0.0001	0	Distance from origin along *x*-axis	PosLocalX
32	32	S	m	0.0001	0	Distance from origin along *y*-axis	PosLocalY

Note: The origin is set using the local co-ordinates option in NAVconfig. The convention used for the local co-ordinates uses a right-handed set with the *z*-axis up.

Table 44. Identifier 60Dh (1549), VelYawLocal

						Description	Signal name
0	16	S	m/s	0.01	0	Velocity along the *x*-axis	VelLocalX
16	16	S	m/s	0.01	0	Velocity along the *y*-axis	VelLocalY
32	16	S	°	0.01	0	Yaw angle	AngleLocalYaw
48	16	S	°	0.01	0	Track angle in local co-ordinates	AngleLocalTrack

Note: The convention used for the local co-ordinates uses a right-handed set with the *z*-axis up.

Table 45. Identifier 60Eh (1550), AngAccelVehicle

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	°/s²	0.1	0	OxTS output frame longitudinal (forward) IMU angular acceleration	AngAccelX
16	16	S	°/s²	0.1	0	OxTS output frame lateral (right) IMU angular acceleration	AngAccelY
32	16	S	°/s²	0.1	0	OxTS output frame vertical (down) IMU angular acceleration	AngAccelZ

Table 46. Identifier 60Fh (1551), AngAccelLevel

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	°/s²	0.1	0	OxTS horizontal frame longitudinal (forward) IMU angular acceleration	AngAccelForward
16	16	S	°/s²	0.1	0	OxTS horizontal frame lateral (right) IMU angular acceleration	AngAccelLateral
32	16	S	°/s²	0.1	0	OxTS horizontal frame vertical (down) IMU angular acceleration	AngAccelDown

Table 47. Identifier 620h (1568), TrackSlipCurvaturePoint1

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 1 track angle	AngleTrackPoint1
16	16	S	°	0.01	0	Measurement point 1 slip angle	AngleSlipPoint1
32	16	S	1/m	0.0001	0	Measurement point 1 curvature	CurvaturePoint1

Note that the slip angle of point 1 will be close to 180° when driving backwards.

Table 48. Identifier 621h (1569), TrackSlipCurvaturePoint2

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	U	°	0.01	0	Measurement point 2 track angle	AngleTrackPoint2
16	16	S	°	0.01	0	Measurement point 2 slip angle	AngleSlipPoint2
32	16	S	1/m	0.0001	0	Measurement point 2 curvature	CurvaturePoint2

Note that the slip angle of point 2 will be close to 180° when driving backwards.

Table 49. Identifier 622h (1570), TrackSlipCurvaturePoint3

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 3 track angle	AngleTrackPoint3
16	16	S	°	0.01	0	Measurement point 3 slip angle	AngleSlipPoint3
32	16	S	1/m	0.0001	0	Measurement point 3 curvature	CurvaturePoint3

Note that the slip angle of point 3 will be close to 180° when driving backwards.

Table 50. Identifier 623h (1571), TrackSlipCurvaturePoint4

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 4 track angle	AngleTrackPoint4
16	16	S	°	0.01	0	Measurement point 4 slip angle	AngleSlipPoint4
32	16	S	1/m	0.0001	0	Measurement point 4 curvature	CurvaturePoint4

Note that the slip angle of point 4 will be close to 180° when driving backwards.

Table 51. Identifier 624h (1572), HeadingPitchRollFromSurf

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	U	°	0.01	0	Heading relative to the road surface	AngleHeadingFromSurf
16	16	S	°	0.01	0	Pitch relative to the road surface	AnglePitchFromSurf
32	16	S	°	0.01	0	Roll relative to the road surface	AngleRollFromSurf

Note: the range of heading is 0 to 360°; the range of pitch is ±90°; the range of roll is ±180°. The road surface angle needs to be defined in order for these measurements to be active.

Table 52. Identifier 625h (1573), TrackSlipCurvaturePoint5

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 5 track angle	AngleTrackPoint5
16	16	S	°	0.01	0	Measurement point 5 slip angle	AngleSlipPoint5
32	16	S	1/m	0.0001	0	Measurement point 5 curvature	CurvaturePoint5

Note that the slip angle of point 5 will be close to 180° when driving backwards.

Table 53. Identifier 626h (1574), TrackSlipCurvaturePoint6

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 6 track angle	AngleTrackPoint6
16	16	S	°	0.01	0	Measurement point 6 slip angle	AngleSlipPoint6
32	16	S	1/m	0.0001	0	Measurement point 6 curvature	CurvaturePoint6

Note that the slip angle of point 6 will be close to 180° when driving backwards.

Table 54. Identifier 627h (1575), TrackSlipCurvaturePoint7

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	U	°	0.01	0	Measurement point 7 track angle	AngleTrackPoint7
16	16	S	°	0.01	0	Measurement point 7 slip angle	AngleSlipPoint7
32	16	S	1/m	0.0001	0	Measurement point 7 curvature	CurvaturePoint7

Note that the slip angle of point 7 will be close to 180° when driving backwards.

Table 55. Identifier 628h (1576), TrackSlipCurvaturePoint8

						Description	Signal name
0	16	U	°	0.01	0	Measurement point 8 track angle	AngleTrackPoint8
16	16	S	°	0.01	0	Measurement point 8 slip angle	AngleSlipPoint8
32	16	S	1/m	0.0001	0	Measurement point 8 curvature	CurvaturePoint8

Note that the slip angle of point 8 will be close to 180° when driving backwards.

Table 56. Identifier 629h (1577), ApproxLatitudeLongitude

						Description	Signal name
0	32	S	degrees	1e-7	0	Approximate latitude	ApproxPosLat
32	32	S	degrees	1e-7	0	Approximate longitude	ApproxPosLon

Before initialisation the approximate latitude and longitude message will have the GNSS measurement of latitude and longitude (at the GNSS antenna location). After initialisation it will contain the same latitude and longitude as message 601h.

Table 57. Identifier 62Ah (1578), ApproxAltitude

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	32	S	m	0.001	0	Approximate altitude	ApproxPosAlt

By default, the altitude is output relative to mean sea level, not WGS 84. See altitude in the NCOM description for information on how to change this. Before initialisation the approximate altitude message will have the GNSS measurement of altitude (at the GNSS antenna location). After initialisation it will contain the same altitude as message 602h.

Table 58. Identifier 62Bh (1579), ApproxVelocity

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s	0.01	0	Approximate OxTS NED frame north velocity	ApproxVelNorth
16	16	S	m/s	0.01	0	Approximate OxTS	ApproxVelEast

						NED frame east velocity	
32	16	S	m/s	0.01	0	Approximate OxTS NED frame vertical (down) velocity	ApproxVelDown
48	16	U	m/s	0.01	0	Approximate horizontal speed	ApproxSpeed2D

Before initialisation the approximate velocity message will have the GNSS measurement of velocity (at the GNSS antenna location). After initialisation it will contain the same altitude as message 603h.

Table 59. Identifier 62Dh (1581), FallingTrigger

						Description	Signal name
0	8	U		1	0	TTL signal level (0 low, 1 high, 255 unknown)	SignalLevelFalling
8	8	U		1	0	Trigger count, increments with each new trigger	TriggerCountFalling
16	16	U	s	0.0002	0	Time since last trigger	TriggerTimeFalling
32	32	U	m	0.001	0	Distance with hold since last trigger	TriggerDistanceFalling

Table 60. Identifier 62Eh (1582), RisingTrigger

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	8	U		1	0	TTL signal level (0 low, 1 high, 255 unknown)	SignalLevelRising
8	8	U		1	0	Trigger count, increments with each new trigger	TriggerCountRising
16	16	U	s	0.0002	0	Time since last trigger	TriggerTimeRising
32	32	U	m	0.001	0	Distance with hold since last trigger	TriggerDistanceRising

Table 61. Identifier 62Fh (1583), PosLocalNE

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	32	S	m	0.0001	0	Northing	PosLocalNorth
32	32	S	m	0.0001	0	Easting	PosLocalEast

Table 62. Identifier 630h (1584), MilliTime

						Description	Signal name
0	48	S	ms	1	0	Milliseconds since the start of GPS time	MilliTime
0	48	S	s	0.001	0	Seconds since the start of GPS time	MilliTimeSeconds
48	8	S	s	1	0	GPS UTC offset	UtcOffset

Note: MilliTime and MilliTimeSeonds both refer to the same bits on the CAN bus—however they are decoded twice with a different scale in the DBC file. MilliTime needs to be stored as a signed 64-bit integer value as the current value already exceeds the limits of a 32-bit integer, however this is not supported by all CAN software. To overcome that problem MilliTimeSeconds can be stored as a 32-bit double-precision value, however limitations in the double-precision format mean there may be an error of up to 5 ms and the resulting decimal numbers may contain rounding errors. Where possible MilliTime should be used, otherwise use MilliTimeSeconds with care.

Table 63. Identifier 633h (1587), IsoOrientation

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	°	0.01	0	ISO 8855 yaw angle	IsoYawAngle
16	16	S	°	0.01	0	ISO 8855 pitch angle	IsoPitchAngle
32	16	S	°	0.01	0	ISO 8855 roll angle	IsoRollAngle

Table 64. Identifier 634h (1588), IsoVsVelocity

						Description	Signal name
0	16	S	m/s	0.01	0	ISO 8855 vehicle system longitudinal	IsoVsLongitudinalVelocity

						Description	Signal name
						(forward) velocity	
16	16	S	m/s	0.01	0	ISO 8855 vehicle system lateral (left) velocity	IsoVsLateralVelocity
32	16	S	m/s	0.01	0	ISO 8855 vehicle system vertical (up) velocity	IsoVsVerticalVelocity

Table 65. Identifier 635h (1589), IsoVsAcceleration

						Description	Signal name
0	16	S	m/s²	0.01	0	ISO 8855 vehicle system longitudinal (forward) acceleration	IsoVsLongitudinalAcceleration
16	16	S	m/s²	0.01	0	ISO 8855 vehicle system lateral (left) acceleration	IsoVsLateralAcceleration
32	16	S	m/s²	0.01	0	ISO 8855 vehicle system vertical (up) acceleration	IsoVsVerticalAcceleration

Table 66. Identifier 636h (1590), IsoVsAgularVelocity

						Description	Signal name
0	16	S	°/s	0.01	0	ISO 8855 vehicle system roll (longitudinal angular) velocity	IsoVsRollVelocity
16	16	S	°/s	0.01	0	ISO 8855 vehicle system pitch (lateral angular) velocity	IsoVsPitchVelocity
32	16	S	°/s	0.01	0	ISO 8855 vehicle system yaw (vertical angular) velocity	IsoVsYawVelocity

Table 67. Identifier 637h (1591), IsoVsAgularAcceleration

						Description	Signal name
0	16	S	°/s²	0.1	0	ISO 8855 vehicle system roll (longitudinal angular) acceleration	IsoVsRollAcceleration
16	16	S	°/s²	0.1	0	ISO 8855 vehicle system pitch (lateral angular) acceleration	IsoVsPitchAcceleration
32	16	S	°/s²	0.1	0	ISO 8855 vehicle system yaw (vertical angular) acceleration	IsoVsYawAcceleration

Table 68. Identifier 638h (1592), IsoIsVelocity

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s	0.01	0	ISO 8855 intermediate system longitudinal (forward) velocity	IsoIsLongitudinalVelocity
16	16	S	m/s	0.01	0	ISO 8855 intermediate system lateral (left) velocity	IsoIsLateralVelocity
32	16	S	m/s	0.01	0	ISO 8855 intermediate system vertical (up) velocity	IsoIsVerticalVelocity

Table 69. Identifier 639h (1593), IsoIsAcceleration

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s²	0.01	0	ISO 8855 intermediate system longitudinal (forward)	IsoIsLongitudinalAcceleration

							acceleration	
16	16	S	m/s²	0.01	0		ISO 8855 intermediate system lateral (left) acceleration	IsoIsLateralAcceleration
32	16	S	m/s²	0.01	0		ISO 8855 intermediate system vertical (up) acceleration	IsoIsVerticalAcceleration

Table 70. Identifier 63Ah (1594), IsoIsAngularVelocity

							Description	Signal name
0	16	S	°/s	0.01	0		ISO 8855 intermediate system roll (longitudinal angular) velocity	IsoIsRollVelocity
16	16	S	°/s	0.01	0		ISO 8855 intermediate system pitch (lateral angular) velocity	IsoIsPitchVelocity
32	16	S	°/s	0.01	0		ISO 8855 intermediate system yaw (vertical angular) velocity	IsoIsYawVelocity

Table 71. Identifier 63Bh (1595), IsoIsAngularAcceleration

							Description	Signal name
0	16	S	°/s²	0.1	0		ISO 8855 intermediate system roll (longitudinal angular) acceleration	IsoIsRollAcceleration
16	16	S	°/s²	0.1	0		ISO 8855 intermediate	IsoIsPitchAcceleration

						system pitch (lateral angular) acceleration	
32	16	S	°/s²	0.1	0	ISO 8855 intermediate system yaw (vertical angular) acceleration	IsoIsYawAcceleration

Table 72. Identifier 63Ch (1596), IsoEfsVelocity

						Description	Signal name
0	16	S	m/s	0.01	0	ISO 8855 earth-fixed system east velocity	IsoEfsEastVelocity
16	16	S	m/s	0.01	0	ISO 8855 earth-fixed system north velocity	IsoEfsNorthVelocity
32	16	S	m/s	0.01	0	ISO 8855 earth-fixed system vertical (up) velocity	IsoEfsVerticalVelocity

Table 73. Identifier 63Dh (1597), IsoEfsAcceleration

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description	Signal name
0	16	S	m/s²	0.01	0	ISO 8855 earth-fixed system east acceleration	IsoEfsEastAcceleration
16	16	S	m/s²	0.01	0	ISO 8855 earth-fixed system north acceleration	IsoEfsNorthAcceleration
32	16	S	m/s²	0.01	0	ISO 8855 earth-fixed system vertical (up) acceleration	IsoEfsVerticalAcceleration

Revision history

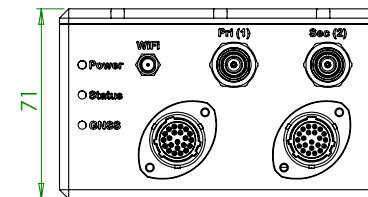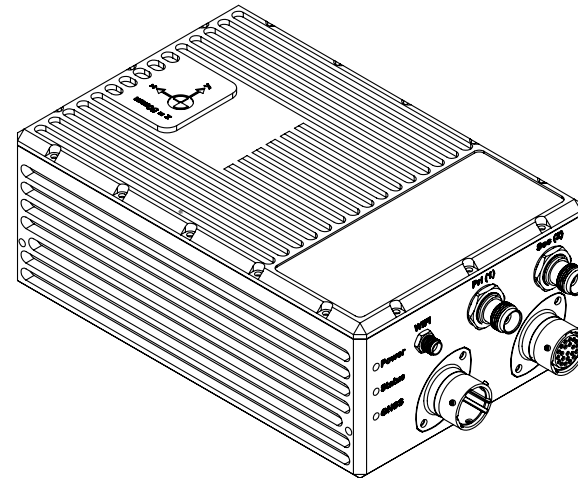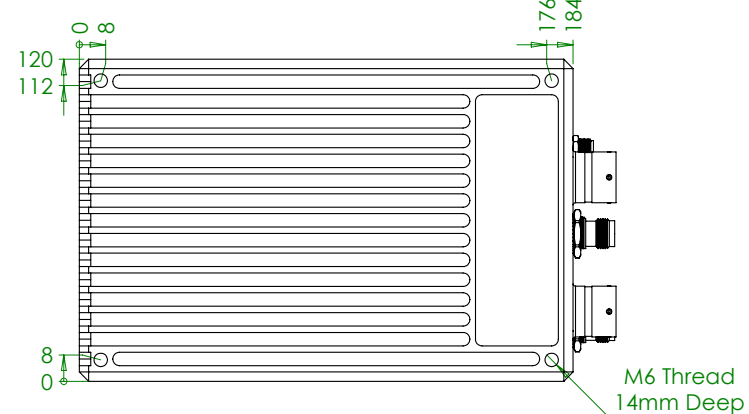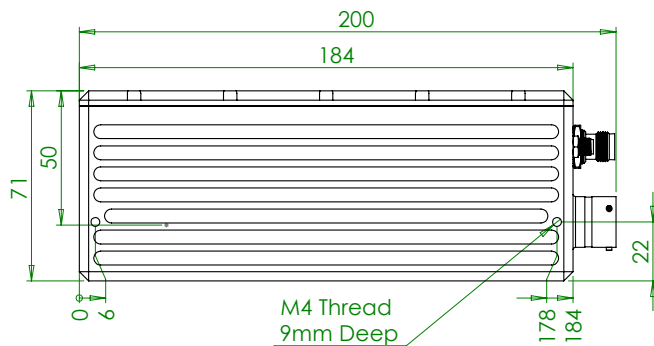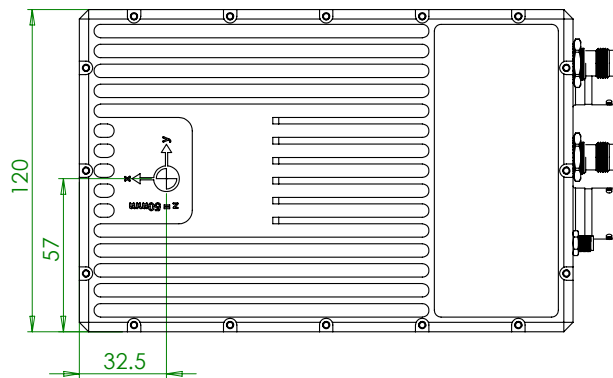### Table 74. Revision history

Revision	Comments
071120	Merged RT2000, RT3000 and RT4000 manuals.
080121	Heading Lock changes. Surface Attitude CAN IDs.
080303	Improved RT2500 specification. Heading Lock "Loose" changed to "Normal".
080804	Surface tilt added to RT Config. Specification changes for "1σ". Clarified positioning modes and accuracies.
090630	Added power cable drawing, updated all drawings. 50 Hz trigger described. Added fields for GNSS position mode. Added description of sign conventions. Recommended PC IP address described. Ethernet Output options described. Other small changes.
100125	Added MGCOM1 protocol. Clarifications to rotation order and dual-antenna section
100312	Added RT2002. Updated for latest software. Added CAN message descriptions for additional slip points and approximate outputs. Separated some specifications in to a separate table. Improved warm-up description.
100624	Added RT2004 product.
101124	Updated for RT Config software changes. Triggered NMEA outputs. PTCF output. Camera output on Ethernet. Clarified power output on RT2000 differential connector. Added information about GNSS pitch constraint for improving static initialisation. Altitude datum options. Other minor corrections.
110505	Added the recommended fuse information; added GNSS antenna drawings.
111115	Updated CE/FCC statement for new internal design. Added linear acceleration filter. Added gx processing. Added software disclaimer. ECCN revision.
130221	Updated RT2000 specifications. Updated for RT Config software changes. Added CAN acquisition section. Updated screenshots for new GUI. Aligned document style. Updated user cable part number.
131024	Updated screenshots to NAVconfig. Removed obsolete products. Updated RT's input voltage. Altered document structure.
140325	Minor revisions.
140501	PPP Service changes, specification updates and other minor revisions.
140611	NAVconfig updates and new images and text for v2 2nd Generation.
141117	Specification and regulator testing changes. Other minor revisions.
150312	Added vertical advanced slip and coordinate frame configuration options.
150620	Updated screenshots, added networked corrections, and CAN prefix. Other minor corrections.
160105	New CAN definitions added, new frames of reference.
160413	Added RT2500 GLONASS options. Added radio cable modem drawing.
190902	RT500 and RT3000 manual re-written to support new generation products and switch to new version of NAVconfig.

Drawing list

Table 75 lists the available drawings that describe components of the RT system. Many of these drawings are attached to the back of this manual. Note that the '*x*' following a drawing number is the revision code for the part. If you require a drawing, or different revision of a drawing, that is not here then contact Oxford Technical Solutions.

Table 75. List of available drawings

Drawing	Description
14A0085	RT500, RT3000 system outer dimensions drawing
14C0038	RT500, RT3000 primary user cable
14C0213	RT500, RT3000 Aux user cable
77C0002B	RT500, RT3000 power cable

120
57
32.5

200
184
71
50
22
0
6

M4 Thread
9mm Deep

176 178
184 184

120
112
0
8

8
0

M6 Thread
14mm Deep

71

71

Power
WiFi
Pri (1)
Sec (2)
Status
GNSS

THIRD ANGLE PROJECTION		DRAWING NO: 14A0085		REV: A
NOT TO SCALE				SHEET 1 OF 1
		TITLE:		
DRAWN BY	sbedford	RT3000/500 Drawing		
DATE	13/08/2019			
MATERIAL		Oxford Technical Solutions		
WEIGHT	1.5kg	77 Heyford Park Upper Heyford Oxfordshire OX25 5HD		
A3		www.oxts.co.uk		

OXTS
Inertial+GPS

Connector/Boot Details

|		
J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9-Way Male D-type and shell	FEC 1342694
J3	DGPS Option: 9-Way Male D-type and shell	FEC 1342694
J3	Radio Option: 15-Way Male D-type and shell	FEC 1342696
J4	9-Way Male D-type and shell	FEC 1342694
J5	9-Way Female D-type and shell	FEC 1342695
J6	See notes	
J7	4-Way M12 Male plug	HARTING 21033291401
	D-type Plug Crimp Contacts	FEC 1560032
	D-type Socket Crimp Contacts	FEC 1560034

14C0038D

J1

9   24

XX
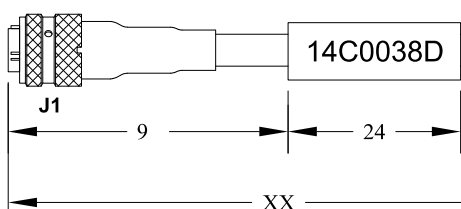
Length XX is denoted in the part ordered by the final digits of the part number in centimetres. 40cm is the default length if not specified.

For example 14C0038x-100 specifies a cable length of 100cm. (x is the revision)

Tail Lengths

L2	300mm
L3	300mm
L4	300mm
L5	300mm
L6	300mm
L7	300mm

Tail lengths for J2-J7 given by L2-L7, from junction to connector face

J2 RS-232
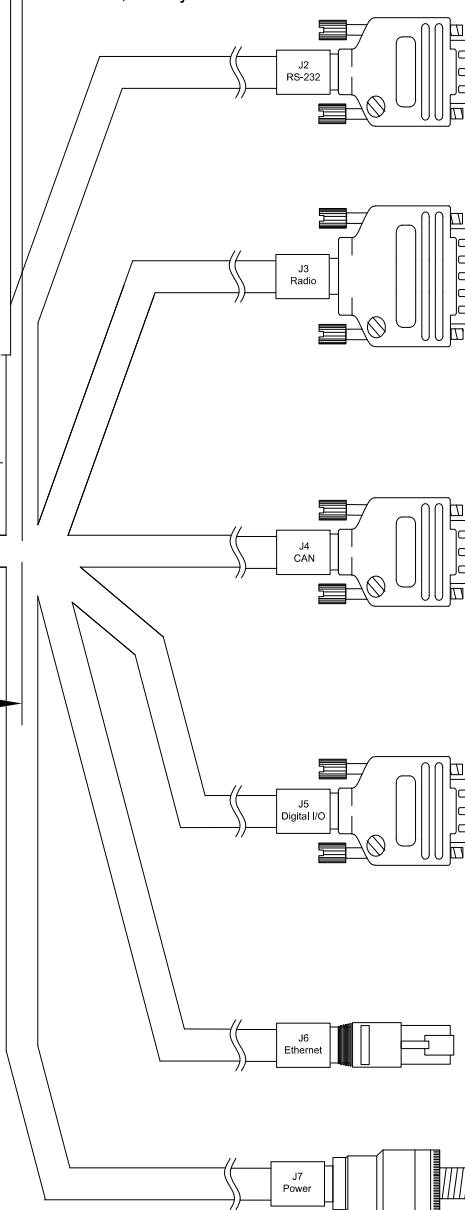
Pin	Function	Conn
2	Nav Data RS232 RX	J1-4
3	Nav Data RS232 TX	J1-3
5	RS232 Common	J1-12

J3 Radio

	Radio			DGPS Alternative	
Pin	Function	Conn	Pin	Function	Conn
1	+Supply	J3-14	2	GPS Data RS232 RX	J1-7
7	RS232 Common	J1-16	3	GPS Data RS232 TX	J1-6
8	Supply Return	J7-3	5	RS232 Common	J1-16
9	Radio Data RX	J1-7			
11	Radio Data TX	J1-6		Sleeved and made safe	J7-1
14	+Supply	J7-1		Sleeved and made safe	J7-3
15	+Supply	J7-1			

J4 CAN

Pin	Function	Conn
2	CAN -	J1-10
3	CAN Ground	J1-17
6	CAN Ground	J4-3
7	CAN +	J1-9

J5 Digital I/O

Pin	Function	Conn
1	Digital 1	J1-11
2	Digital 2	J1-8
3	Digital 3	J1-15
4	Digital 4	J1-19
5	Digital 5	J1-5
6	Digital Ground	J1-18
7	Digital Ground	J1-18
8	Digital Ground	J1-18
9	Digital Ground	J1-18

See manual for details of the signals on Digital 1 to Digital 5

J6 Ethernet

Pin	Function	Conn
1	Ethernet (ETX +)	J1-20
2	Ethernet (ETX -)	J1-13
3	Ethernet (ERX +)	J1-21
6	Ethernet (ERX -)	J1-14

J7 Power

Pin	Colour	Function	Conn
1	Brown	+Supply	J1-1
2	White	Sleeved and made safe	
3	Blue	Supply Return	J1-2
4	Black	Sleeved and made safe	

|..........|..........|..........|
0   10   20   30
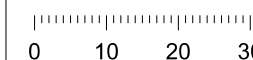
Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

Notes:

J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1.

Wire Types:
J7-1, J7-3   16/0.2
All others   7/0.2
J1-13 & J1-20 Twisted pair
J1-14 & J1-21 Twisted pair

All cables outers fully braided (no gaps) and connected to J1-22, J1 shell rear anodising plating removed and J7 shell (through cable assembly braiding). All gaps in shielding due to wiring joints to be shielded (electrically connected and mechanically entirely emcompasing to all shielding)

Please populate all unused pins with empty crimps.

Ensure that the cable legend text precisely matches that given in diagram.

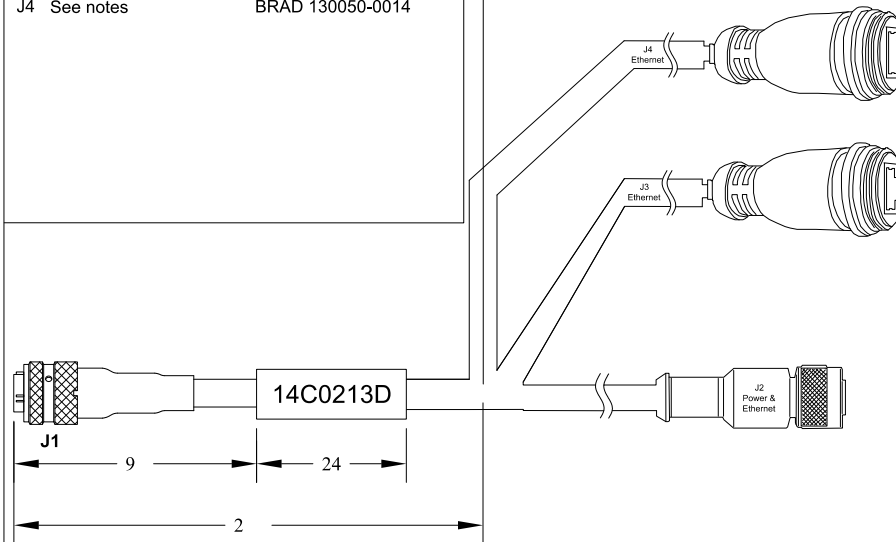|	
Date:	27/03/19
Part #:	14C0038D
Document:	RT3000 User Cable
Sheet:	1 of 1

Connector/Boot Details

J1   Deutsch AS612-35PN   TE AS612-35PN
J2   See notes   Harting
                             21033292801
J3   See notes   BRAD 130050-0014
J4   See notes   BRAD 130050-0014

Tail lengths for J2-J4 given by
L2-L4, from junction to connector face

J4
Ethernet

Pin	Function	Conn
1	Ethernet (ETX +)	J1-7
2	Ethernet (ETX -)	J1-6
3	Ethernet (ERX +)	J1-5
6	Ethernet (ERX -)	J1-17

J3
Ethernet

Pin	Function	Conn
1	Ethernet (ETX +)	J1-15
2	Ethernet (ETX -)	J1-2
3	Ethernet (ERX +)	J1-21
6	Ethernet (ERX -)	J1-1

14C0213D

J1

9

24

2

J2
Power &
Ethernet

Pin	Function	Conn
1	Tx+	J1-14
2	Tx-	J1-20
3	Rx+	J1-13
4	Power Supply +	J1-11
5	Power Supply +	J1-11
6	Rx-	J1-12
7	Power Supply -	J1-10
8	Power Supply -	J1-10

Tail Lengths

L2   400mm
L3   400mm
L4   400mm

Notes:

All cables outer sheath black and fully shielded. No gaps in shielding for any part of the cable

J2 is a shielded M12 8 Pole Female screened cable consisting of 2 individual foil screened pairs (Twisted pairs between: J2 Pins 1<->2, 3<->6), wired to and terminated at J1 for the ethernet and the two power connections for PoE which can be a single wire terminated at J2 or a 4 pair ethernet cable can be used with 1 twisted pair being used for each power line and terminated at J1.

J3 and J4 are shielded RJ45 socketed leads wired to and terminated at J1.

Wire Types to J1 if extending required
Pins 11, 10 Strands x Strand Size: 16/0.2 or both lines of a 7/0.2 twisted pairs.

Twisted pairs between: Pins 14<->20, 13<->12 Strands x Strand Size: 7/0.2, 2<->15, 1<->21, 7<->17, 5<->6 (from lead assemblies)

ALL cables outers fully braided and connected to J1-22 and J1, J2, J3 and J4 shells (through cable assembly braiding).

All gaps in shielding due to wiring joints to be shielded (electrically connected and mechanically entirely emcompasing to all shielding)

J1 AS612 conector, plating removed from rear, screen completely surrounding and securly fixed to it.

Please populate all unused pins with empty crimps.

Ensure that the cable legend text precisely matches that given in diagram.

Legends to be black text on yellow

0   10   20   30

Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

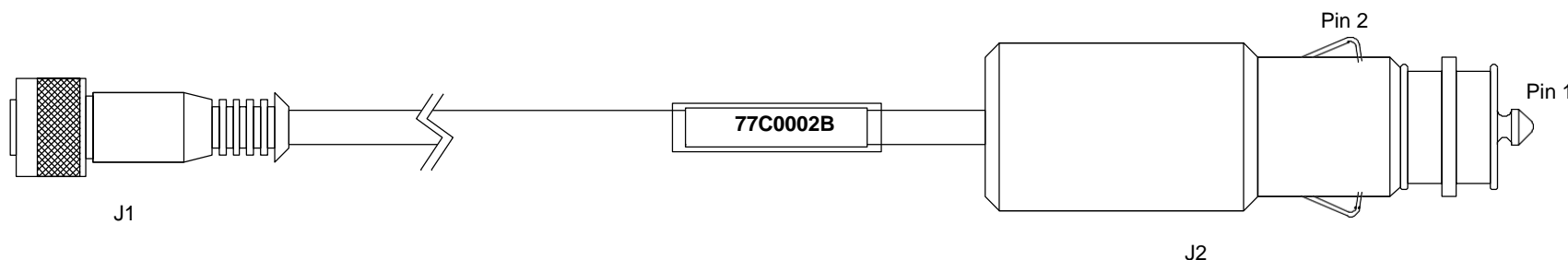|	
Date:	15/07/19
Part #:	14C0213D
Document:	
RT3000 Aux User Cable	
Sheet:	1 of 1

Pin Definitions

J1-1 (Brown) Positive 12V Power supply (9–18V d.c.)
J1-2 (White) Positive 12V Power/Charger supply (11–18V d.c.)
J1-3 (Blue) 0V/GND
J1-4 (Black) 0V/GND

3 4
2 1
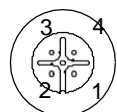
View from front
of socket

Pin 2

Pin 1

77C0002B

J1

J2

Print Size: A4

Scale: 1:1

Units: mm

Tolerances: 1mm

Projection: N/A

Notes:

10/04/02
Alternative Part Number added

Parts

RS291-5881 M12 4w 5m PVC straight Connector
FEC 658-376 Car Cigarette Lighter Plug
RS399-524 Yellow Heat Shrink 6.4mm
RS399-934 Clear Heat Shrink 6.4mm

(Alternative Part: RS 266-0250
Car Cigarette Lighter Plug - 8A fused)

Fuse

Littelfuse Part Number 0214005 (5A Torpedo Type Fuse, 25 x 6mm, 36V)

Connections

J1-1 (Brown) – J2-1
J1-2 (White) – J2-1
J1-3 (Blue) – J2-2
J1-4 (Black) – J2-2

Date: 05/05/11

Part #: 77C0002B

Document:
RT2000 Power Cable

Sheet: 1 of 1