IG-0001

Hexagon | NovAtel®
Autonomous Integration Guide

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Introduction

Hexagon I NovAtel is a global leader in positioning technology driving the safest, most advanced autonomous vehicle solutions.

Our solutions are empowering an autonomous future by providing a full line of GNSS (Global Navigation Satellite Systems) and GNSS+INS (Inertial Navigation System) products, software services, and engineering services contributing to hundreds of research and development platforms used to safely accelerate the advancement of robotics and autonomy.

We are THE trusted partner, facilitating customized technical development and integration as well as providing expertise in specialized applications including safety of life.

This Integration Guide describes topics relevant for the integration of NovAtel products in autonomous applications.

SPAN®

SPAN integrates NovAtel's industry leading GNSS technology with Inertial Measurement Units (IMUs) to create a deeply coupled GNSS+INS solution at data rates up to 200 Hz, for the position, velocity, and attitude. The addition of SPAN greatly benefits an autonomous vehicle in several aspects, which are outlined below. For more information on installing a SPAN system, please [click here].

Attitude Determination

SPAN provides an attitude solution at a very high rate, up to 200 Hz. This delivers the roll, pitch, and azimuth of the vehicle – which is an integral aspect of autonomous vehicle control. The integration of an IMU also ensures that the position solution uses the orientation of the vehicle to ensure more accurate positioning when operating on uneven terrain.

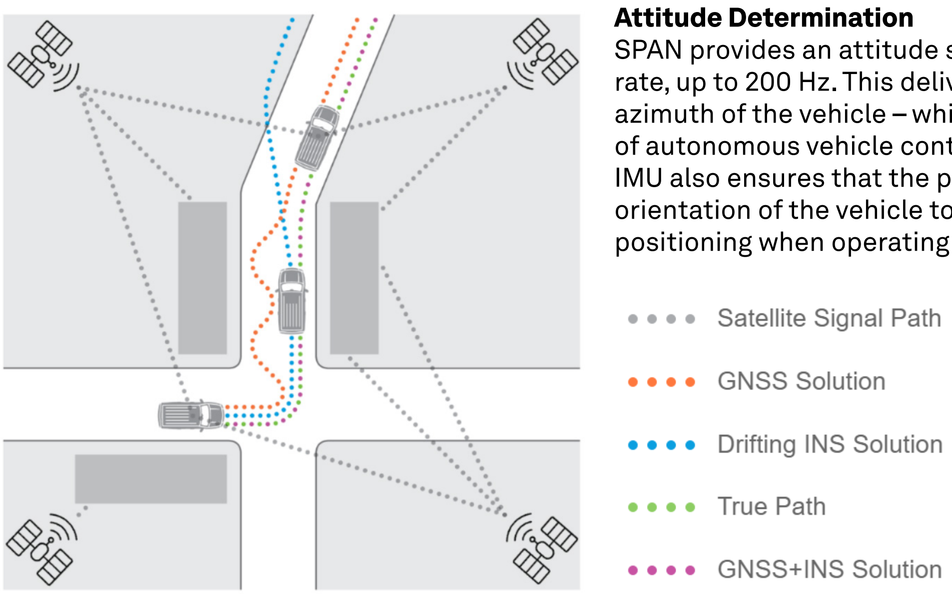


Figure 1: How SPAN works.

Solution Reliability
SPAN® technology is a deeply coupled GNSS+INS solution. This means that the SPAN engine uses GNSS position, velocity information, and raw GNSS measurements as well as rotation and acceleration information from the IMU. The INS filter also supplies feedback to the positioning engine providing improvements to the measurement reliability and tracking robustness of the system. This becomes incredibly important when operating in GNSS restricted or denied environments, such as urban canyons, tunnels, dense foliage, tree lines, etc. Being able to use raw GNSS measurements ensures that if the number of satellites drops due to poor satellite visibility, the SPAN engine can continue to use GNSS measurements as updates to constrain the solution. This ensures a more reliable and available solution than a GNSS-only solution - which becomes unavailable when the number of satellites drops below the minimum required to compute a position.

Azimuth and Velocity Improvements from SPAN
Azimuth determination on a single antenna GNSS-only system is referred to as the Course Over Ground. This is computed using the position delta between epochs and is a very simplistic method, which is not effective if the vehicle is slow moving or stationary. With the integration of an IMU, SPAN can effectively provide a GNSS+INS fused azimuth solution that is much more accurate.

SPAN also provides the user with a GNSS+INS velocity solution that offers numerous benefits over velocity determination using GNSS alone:

Increased output rate **200 Hz**, compared to the standard 20 Hz for GNSS-only.

Velocity is output in **all three dimensions**.

Typically GNSS-only velocity is computed as the average change in position over time of consecutive position solutions (so it is an average velocity) – SPAN provides an **instantaneous velocity**.

SPAN velocity will be **more accurate** than GNSS alone, especially at lower velocities.

Since the SPAN PVA (position, velocity, attitude) solution is computed through a Kalman filter, the velocity solution will be **less noisy** (i.e. smoother) than a GNSS-only one.

Low latency velocity output from SPAN because the algorithm integrates instantaneous accelerations from the IMU to compute the velocity.

Additional Sensor Input
A Distance Measurement Instrument (DMI), otherwise known as a wheel sensor, can provide additional accuracy and reliability to a NovAtel SPAN solution. OEM7 firmware supports wheel sensor input from up to four wheel sensors.

A DMI can be integrated several different ways – directly to a PwrPak7, to select IMU's, to a UIC (Universal IMU Controller), or via an intermediate processor to an OEM7 receiver. For more information on integrating a DMI, please click here.

ALIGN® Solution

ALIGN uses dual antenna or dual/multi receiver combinations to provide precise heading and pitch output for dynamic applications. NovAtel OEM7 products offer both ALIGN Heading and ALIGN Relative Positioning options. For more information on configuring ALIGN, refer to ALIGN Configurations.

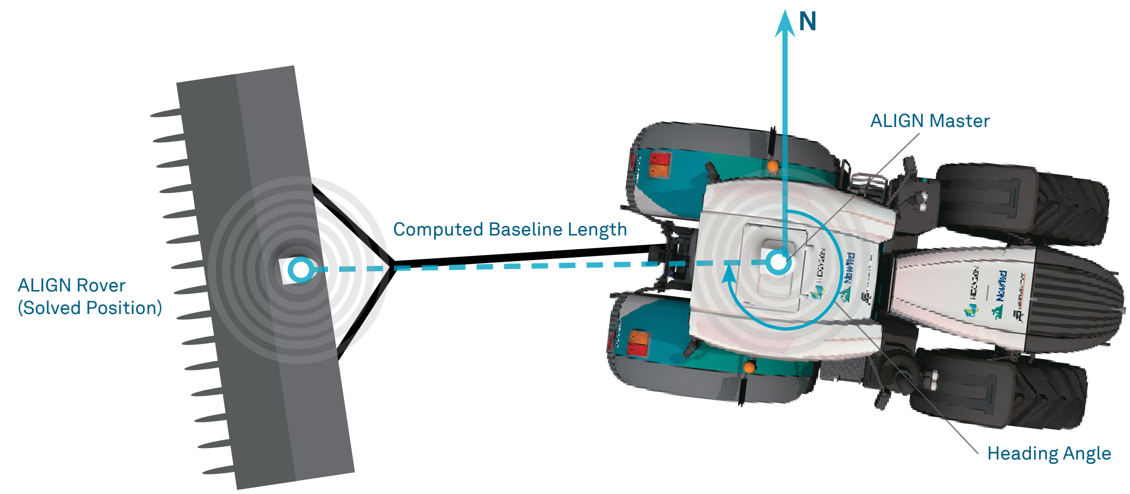


Figure 2: Example of a Relative Positioning ALIGN solution between a tractor and an implement.

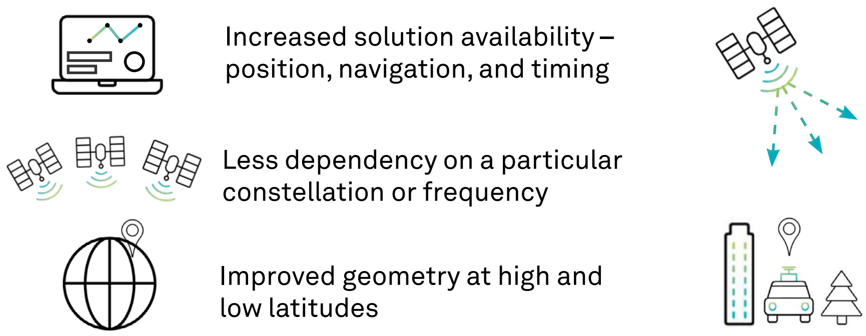
Dual Antenna ALIGN with SPAN

Having ALIGN heading from dual antennas available on an autonomous vehicle is especially beneficial for use with SPAN, as it allows for instantaneous SPAN alignment in kinematic or static conditions. Using the ALIGN heading for alignment is referred to as aided transfer alignment, which uses the RTK-quality, GNSS-derived ALIGN heading from the dual antenna installation to initialize the SPAN system.

During operation, the ALIGN heading updates are used to help constrain the azimuth drift of the INS solution whenever possible. This is of the greatest value with lower-quality IMUs and in environments with low dynamics where the attitude error is less observable.

Signal Availability

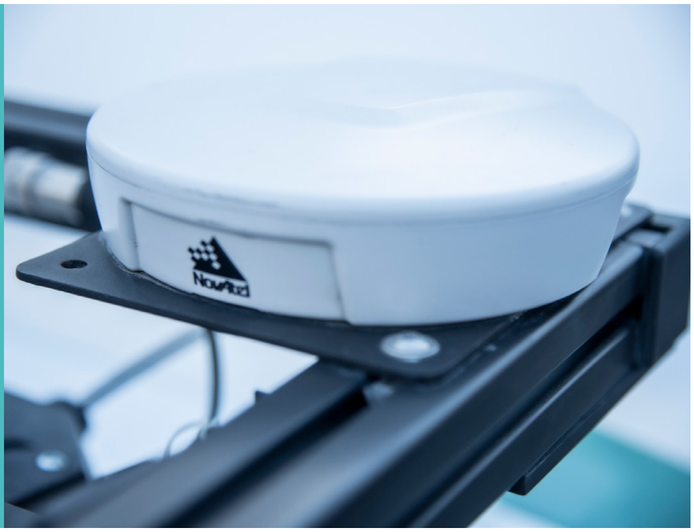
The value of having multi-constellation (GPS, GLONASS, Galileo, and BeiDou) and multi-frequency tracking on a GNSS receiver is ultimately better reliability and availability for the user. Having a multi-constellation and multi-frequency software model on an OEM7 receiver ensures the following for autonomous applications:



- Increased solution availability – position, navigation, and timing
- Less dependency on a particular constellation or frequency
- Improved geometry at high and low latitudes
- More frequencies provide improved ionospheric error removal
- Increased visibility when operating in obstructed environments, such as near buildings and foliage

Product Mounting Considerations

It is important to determine the optimal mounting location for the NovAtel GNSS antenna(s), the GNSS receiver, and the IMU (if applicable). This should take into consideration the other equipment installed on the autonomous vehicle, to ensure the best performance of the NovAtel products.



Vibration

Vibration on a vehicle can be problematic for the IMU and GNSS antenna. Heavy vibration can mask real world motion or be misidentified as movement so the vibration can negatively affect the solution quality. Similarly, high vibration can also negatively affect GNSS antenna performance. The following should be taken into consideration when mounting the IMU and antenna:

- Ensure the IMU and antenna (or antennas) are rigidly mounted to the vehicle and cannot move due to dynamics. The GNSS signal is received at the antenna phase center whereas the IMU raw data and INS solution is computed at the IMU center of navigation. The separation between IMU and antenna must therefore be constant.
- Mount the IMU as far as possible from external sources of vibration.
- Mount the IMU as close as possible to the vehicle pivot point
- If INS performance is being hindered by vehicle vibrations, consider using dampening mounts to minimize vibrations. Use dampening mounts with caution as there is always a risk of removing actual motion.

Lever Arm Measurements

For SPAN® installations, the lever arm measurements which are the translations in meters from the IMU center of navigation to the antenna phase center(s) must be measured as accurately as possible, preferably in millimeters.

- These can be measured in the IMU body frame or the vehicle frame, which must be specified along with the standard deviations for the measurements in the SETINSTRANSLATION command.
- The standard deviations indicated by the user should represent the level of accuracy of the measurements
- Care should be taken to ensure the measurements are as accurate as possible at least more accurate than the GNSS position type being used. For high accuracy solution types such as RTK or PPP, the lever arms must be measured to at least the corresponding centimetre accuracy level (or better) or this will result in an offset of the INS solution.

The different frames referred to in SPAN are defined here.

For a detailed example on lever arm and rotational offset measurements, refer to **SPAN Translations & Rotations.**

Rotational Offsets

Along with the lever arm measurements, the rotational offsets must also be known for SPAN installations.

- The rotational offsets are measured from the IMU body frame to the frame of interest.
- The order of the rotations is always Z,X,Y and the rotations are right handed.
- The rotational offsets are entered using the SETINSROTATION command.

Dual Antenna

- If using a dual antenna setup, mount the primary and secondary antennas as far apart as possible. A minimum separation distance of 1 meter is recommended to ensure the best possible heading accuracy.
- We recommend having both antennas at constant heights, especially in applications where large pitch/roll will be experienced.
- It is not necessary to mount the GNSS antennas in line with the forward axis of the vehicle.
    - For SPAN installations, the mounting locations are taken into consideration using the user-specified lever arms for the two antennas, and the dual antenna heading is automatically rotated before being applied to the SPAN solution. The HEADINGOFFSET command is not intended for use with dual-antenna SPAN. See SPAN ALIGN Installation.
    - For GNSS-only installations, the HEADINGOFFSET command can be used to apply user specified offsets to the ALIGN heading and pitch values to have them correspond with the vehicle frame.
- Ensure both antennas are far from any obstructions. If using SPAN, the GNSS-derived heading must be verified to RTK quality levels before it is fed into the INS. Being close to obstructions lengthens this process or in some cases even prevents the update from taking place.

GNSS Interference

RF (Radio Frequency) interference on GNSS signals can cause reduced performance or even the loss of positioning in severe cases. There are several objects commonly found on an autonomous vehicle that can potentially cause GNSS interference. Examples of potential interferers include:

- Cameras
- Flashing Beacons
- LED lights
- USB 3.0 Devices
- Wi-Fi systems
- Cellular transmitting device
- LiDAR
- Poorly shielded or unshielded communication cables

If it is determined that there is a source of interference affecting the GNSS performance, the following steps can be taken:

- Mount the GNSS antenna(s) as far away as possible from interferers
- Use high quality, shielded communication cables
- Add shielding (such as copper tape) around the connectors, enclosures, and/or cables of the suspected interference source(s)
- Use the Interference Toolkit (ITK) to detect the interference and enable interference mitigation.

For detailed information on how to use ITK, click here.

Multipath

Multipath

Multipath occurs when an RF signal arrives at the receiving antenna from more than one propagation route (multiple propagation paths - thus multipath). In simple terms, this means that it is caused by the GNSS signal bouncing off objects (such as buildings, cars, trees, etc.) before it arrives at the antenna. This contributes to error in the position solution.

When mounting the GNSS antenna, this can be taken into consideration to avoid potential multipath:

- Install the antenna(s) as high as possible on the vehicle, away from other objects on the vehicle. Place the antenna so that unobstructed line-of-sight reception is possible from horizon to horizon and at all bearings and elevation angles from the antenna.
- Try to place the antenna as far as possible from obvious reflective objects, especially reflective objects that are above the antenna's radiation pattern horizon.
- Use a high quality GNSS antenna.

For more information on multipath, refer to [APN – 008 RF Signal Propagation and Multipath.]

Correction Services

NovAtel offers various correction level capabilities on OEM7 receivers. OEM7 hardware supports SBAS, DGNSS, RTK (via radio or NTRIP (Network Transport of RTCM data over IP) input), and PPP (Precise Point Positioning) corrections to drive your autonomous application further.

TerraStar Correction Services deliver PPP corrections to OEM7 receivers. The corrections are delivered via L-band or Internet to the OEM7 receiver and provide sub-meter or centimetre-level positioning accuracy.

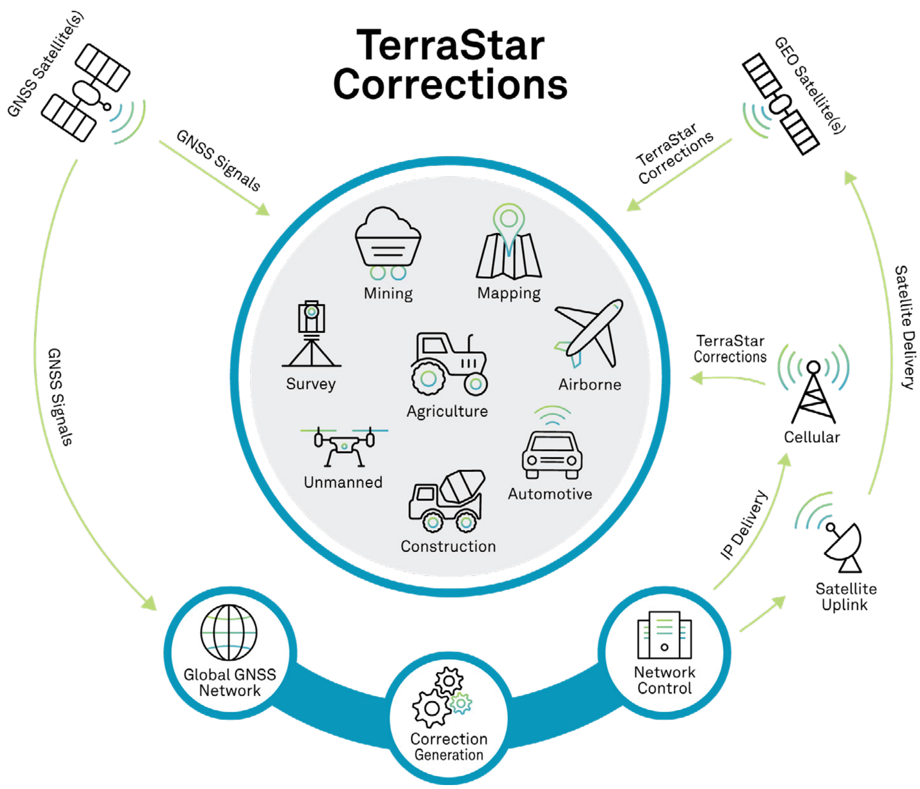


Figure 3: How TerraStar Correction Services works.

For detailed information on the different correction levels offered, refer to **TerraStar Correction Services.** For general information on using PPP corrections, refer to **APN-061: Using TerraStar Corrections.** For information on using internet delivery, refer to **APN-089: IP Delivery for Global TerraStar Corrections.**

HxGN SmartNet is the recommended network RTK provider. SmartNet has more reference stations around the world than any other GNSS correction service provider, which means high accuracy and reliable NTRIP correction coverage wherever it's needed. For more information, refer to HxGN SmartNet.

Communication Interfaces

NovAtel OEM7 products are designed with flexibility in mind, to ease integration of our products into any autonomous system. The communication interfaces OEM7 products offer include:

- LVCMOS Serial (RS232 or RS422)
- USB 2.0
- CAN (Controller Area Network)
- Ethernet
- Wi-Fi

For high-rate data logging applications, Ethernet is typically recommended. Refer to the specific Product Sheet to determine which communication interfaces are available.

NovAtel® OEM7 Driver Built on ROS™

To support customers using ROS™ (Robot Operating System) in their autonomous system, NovAtel has developed an open-source, purpose built ROS™ driver **novatel_oem7_driver** for use with NovAtel OEM7 receivers. The driver, developed by NovAtel engineers, provides an optimized interface enabling users to accelerate autonomous development projects by quickly incorporating NovAtel OEM7 receivers into custom applications. The driver is available for immediate installation in binary form through the ROS Distribution, or as source code available in GitHub.

With the release of a NovAtel-developed OEM7 driver built on ROS, developers can now confidently access the critical data needed to build autonomy algorithms for off-road autonomous vehicles, ride-share programs, and other applications. Data from numerous sensors can be combined to help move projects into higher levels of autonomy faster without the need to adapt community-developed drivers. For detailed information on the structure and usage of the driver, refer to the NovAtel OEM7 Driver Wiki page.[1]

Interference Toolkit

NovAtel's Interference Toolkit (ITK) provides the user tools to detect and mitigate any potential interference on and off the autonomous vehicle. OEM7 receivers are enabled by default to detect interference, which can be monitored via command line or easily viewed using NovAtel Application Suite or Set Up & Monitor (web).

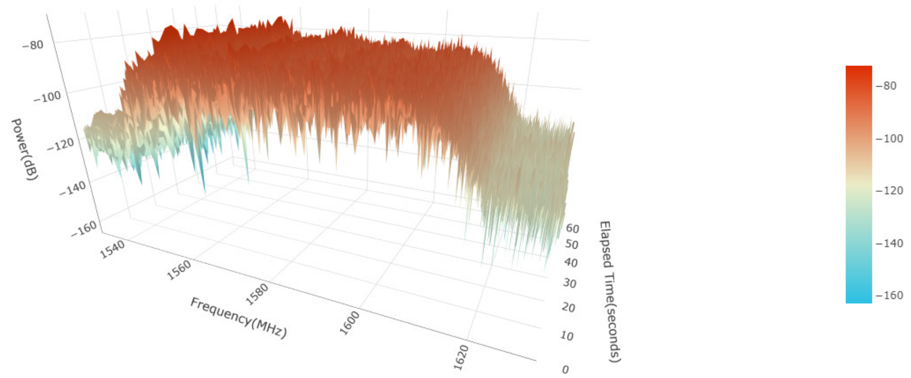


Figure 4: Monitoring signals real time using the ITK feature in NovAtel Application Suite.

Once ITK has been used to detect and locate the interference, it is recommended to first attempt to remove the source of interference. If the interference can't be fully and completely removed, ITK mitigation features can be used to reduce or eliminate the impact on GNSS tracking using customizable Notch and Bandpass filters, or High Dynamic Range (HDR) mode. To access ITK interference mitigation features, the OEM7 receiver software model must be upgraded. For detailed information on how to use ITK, click here.

[1] *ROS [and/or the "nine dots" ROS logo and/or any other ROS trademark used] is a trademark of Open Robotics.*

Appendix A: Additional Resources

References

NovAtel Product Offering

NovAtel Applications Notes

NovAtel Support

To help answer questions and/or diagnose any technical issues that may occur, the NovAtel Support website is a first resource.

Remaining questions or issues, including requests for test subscriptions or activation resends, can be directed to NovAtel Support. To enable the online form and submit a ticket, first select a "Product Line" and then an associated "Product" from the list.

However, before contacting Support, it is helpful to collect data from the receiver to help investigate and diagnose any performance-related issues. In those cases, if possible, collect the following list of logs (the LOG command with the recommended trigger and data rate is included):

```
LOG RXSTATUSB onchanged
LOG ALMANACB onchanged
LOG RAWEPHEMB onchanged
LOG GLORAWEPHEMB onchanged
LOG TRACKSTATB ontime 1
LOG SATVIS2B ontime 60
LOG BESTPOSB ontime 1
LOG RANGEB ontime 1
LOG RXCONFIGA once
LOG ITDETECTSTATUSB onchanged
LOG VERSIONA once
LOG PORTSTATSB ontime 10
```

For SPAN® systems, also include the following logs:

```
LOG RAWIMUSXB onnew
LOG INSUPDATESTATUSB onnew
LOG INSPVAXB ontime 1
LOG INSCONFIGA onchanged
```

Documentation

Complete details on receiver installation, operation, and the logs and commands described in this application note can be found in the OEM7 Receiver Documentation Portal.

Contact Hexagon | NovAtel

support.novatel@hexagon.com 1-800-NOVATEL (U.S. and Canada) or 1-403-295-4900
For the most recent details of this product: https://www.novatel.com/#latestNews