PRODUCT SPECIFICATION

# VN-310 DUAL GNSS/INS

## User Manual



VECTORNAV

# CONTENTS



### VectorNav Support

Whether you are looking for details on the VN-310 or assistance with your application, a wealth of information is available to assist you in product design and development. Check out the *Inertial Systems Primer* on our website, and be sure to register for access to a wide range of resources:

| PRODUCT SPECIFICATIONS | TECHNICAL NOTES | APPLICATION NOTES |
| --- | --- | --- |
| User Manual | Time Synchronization | Gimbal Stabilization & Pointing |
| Interface Control Document | Hard & Soft Iron Calibration | Satellite Communications |
| Datasheet | External GNSS Aiding | Lidar Mapping |
| Quick Start Guide | Firmware Update | Aerial Photogrammetry |

All VectorNav products are backed by our customer-focused, robust and responsive support ecosystem. Our team is committed to supporting you through your entire product life-cycle, from concept design to in-field support. Please feel free to contact us by phone or email, our global team of engineers and representatives is ready to work with you through every challenge you know of, and every challenge you don't.

+1.512.772.3615 support@vectornav.com

# 1 INTRODUCTION

## 1.1 TACTICAL SERIES OVERVIEW

The Tactical Series product line is built on a temperature-calibrated, high-performance, tactical-grade inertial measurement unit (IMU) and offers robust inertial navigation solutions for a wide range of applications and operating environments. Within the series are three distinct products: an IMU/AHRS (VN-110), a GNSS-aided inertial navigation system (GNSS/INS) (VN-210), and a Dual GNSS/INS (VN-310). The VN-110 is perfect for applications requiring calibrated IMU data or a real-time, drift-free attitude solution, particularly in systems that do not have GNSS visibility. The VN-210 combines its inertial sensor data with the onboard GNSS measurements to provide a full, robust navigation solution that is proven to excel in the most challenging dynamic conditions. The VN-310 is designed for applications that require a highly accurate inertial navigation solution under both static and dynamic operating conditions, particularly in environments with unreliable magnetic heading and good GNSS visibility. For help in determining which sensor is best for your particular application, please contact the VectorNav Sales or Support team.

## 1.2 PRODUCT DESCRIPTION

The VN-310 is a high-performance, tactical-grade dual GNSS-aided inertial navigation system (Dual GNSS/INS) that incorporates the latest advancements in inertial sensor and GNSS technology, including a set of 3-axis accelerometers, 3-axis gyroscopes, 3-axis magnetometers, a barometer (VN-310E only), and two multi-frequency GNSS receivers. Using advanced Kalman filtering algorithms, the VN-310 optimally combines high-bandwidth inertial sensor measurements with low-bandwidth GNSS measurements to provide high-accuracy, low-latency position, velocity, and attitude estimates. Extending beyond the capabilities of a standard GNSS/INS system, the VN-310 utilizes GNSS compassing techniques to ensure accurate heading measurements in both static and dynamic conditions without any reliance on magnetic sensors.

## 1.3 FACTORY CALIBRATION

MEMS inertial sensors are subject to several common sources of error: bias, scale factor, misalignment, temperature dependencies, and gyro g-sensitivity. All VN-310 sensors undergo a rigorous calibration process at the VectorNav factory to calculate the necessary coefficients to compensate for these error sources. Calibration parameters calculated during this process are permanently stored in flash memory on each individual sensor and digitally applied to the real-time measurements. The VN-310 is available with the following calibration option:

- Thermal Calibration—this option extends the calibration process over multiple temperatures to ensure performance specifications are met over the full operating temperature range of −40 °C to +85 °C.

## 1.4 OPERATION OVERVIEW

The VN-310 has a built-in microprocessor that runs a robust INS extended Kalman filter which estimates the position, velocity, and attitude of the sensor. The VN-310 INS filter couples position and velocity measurements from the onboard GNSS with inertial sensor measurements from the onboard accelerometers, gyroscopes, magnetometers, and optionally the barometric pressure sensor (VN-310E only). This coupling provides high-accuracy attitude estimates when the sensor is subjected to dynamic motion and also provides position and velocity estimates at high output rates.

When the VN-310 is in motion, the INS filter determines the attitude by comparing the GNSS measurements to the onboard accelerometer measurements, and the magnetometer measurements are ignored by the INS filter. Compared to an attitude and heading reference system (AHRS), the heading accuracy is improved since the INS filter does not rely on measurements of Earth's background magnetic field and magnetic disturbances do not have an effect on the attitude solution. In addition, the VN-310 pitch and roll estimates are robust to induced accelerations caused by dynamic motion of the sensor. Under static and low-dynamic conditions, the heading angle is no longer observable based on only the correlation between the GNSS position and velocity and the IMU accelerometer. In these conditions, the VN-310 utilizes GNSS compassing techniques to derive accurate heading measurements, without any reliance on the magnetometer.

## 1.5 GNSS COMPASSING CAPABILITY

The VN-310 differs from a standard GNSS/INS system in that it has the capability to accurately estimate heading in both static and dynamic conditions through the use of the GNSS compass. A GNSS compass operates using a form of the real-time kinematic (RTK) positioning technique known as moving baseline RTK. Through this technique, a GNSS compass compares the carrier phase measurements between two GNSS antennas and determines the relative positioning of the two antennas to millimeter-level accuracy in an inertial frame of reference. If the VN-310 also knows the position of the two antennas relative to each other in the body-frame, then it can calculate a heading angle in real time with a high degree of accuracy.

It is important to note that this heading estimate is derived directly from differencing the two GNSS receiver measurements at a single point in time and as such it is not dependent upon velocity. The accuracy of the heading estimate is dependent on the quality of the GNSS signal, the distance between the two antennas, and the user's measurement uncertainty in this distance measurement.

## 1.6 ADVANCED GNSS POSITIONING

In systems requiring higher positioning accuracy than standard GNSS can provide, advanced GNSS positioning techniques can be employed. The VN-310 supports both real-time kinematic (RTK) positioning and post-processing kinematic (PPK) positioning, which uses a multiple-receiver system to improve the positioning performance to centimeter-level accuracy. Additional information on using the VN-310 for RTK and PPK positioning can be found in Sections 4.5 and 4.6. While the VN-310 does not natively support Precise-Point Positioning (PPP), an external GNSS receiver that utilizes PPP can be integrated with the VN-310 as discussed in Section 1.7.

## 1.7 EXTERNAL IMU AND GNSS RECEIVER SUPPORT

The VN-310 is designed to provide unprecedented modularity with support for a range of external inertial and positioning technologies, allowing users to take advantage of the superior navigation algorithms of the VN-310 while enhancing its capability. By pairing an external IMU with the VN-310, the sensor can incorporate higher-end IMU technology, such as fiber optic gyroscopes, into its onboard filters leading to increased attitude and positioning performance, particularly in GNSS-challenged applications. The VN-310 also natively supports external GNSS receivers offered by NovAtel, Septentrio, and uBlox, in addition to receivers using ICD-GPS-153 protocol, such as SAASM or M-code receivers. This feature is particularly beneficial for users looking to increase the operational performance of the sensor or its robustness in contested environments while retaining existing drivers and interfaces to the VN-310. Please reach out to VectorNav Support for more information on interfacing the VN-310 with an external IMU or an external GNSS receiver.

## 1.8 MEASUREMENT OUTPUT OPTIONS

Outputs from the VN-310 include:

- Time
  - Time since sensor startup
  - Time relative to I/O synchronization events
  - GPS time
  - UTC time
- Attitude estimates
  - Yaw-Pitch-Roll (YPR)
  - Quaternion
  - Direction Cosine Matrix (DCM)
- INS filtered position and velocity estimates
  - Position in Latitude, Longitude, and Altitude (LLA)
  - Position in Earth-Centered, Earth-Fixed frame (ECEF)
  - Velocity in North-East-Down frame (NED)
  - Velocity in Earth-Centered, Earth-Fixed frame (ECEF)
- GNSS position and velocity measurements at 5 Hz
  - Position in Latitude, Longitude, and Altitude (LLA)
  - Position in Earth-Centered, Earth-Fixed frame (ECEF)
  - Velocity in North-East-Down frame (NED)
  - Velocity in Earth-Centered, Earth-Fixed frame (ECEF)
- Angular rate measurements
  - Raw (factory-calibrated) angular rate
  - Bias-compensated angular rate
- Acceleration measurements
  - Raw (factory-calibrated) acceleration
  - Bias-compensated acceleration
- Magnetic measurements
  - Raw (factory-calibrated) magnetic measurements
  - Real-time HSI-compensated magnetic measurements
- Barometric pressure (VN-310E only)
- Uncertainties
  - Yaw-Pitch-Roll
  - Position
  - Velocity

## 1.9 PACKAGING OPTIONS

The VN-310 is available in two different packaging options: an IP 68 rated anodized aluminum enclosure certified to MIL-STD and DO-160G standards (VN-310) and a board-mount embedded module (VN-310E). The VN-310 is well suited for the most demanding military and aerospace applications while the ultra-compact VN-310E delivers unprecedented size and weight advantages for SWaP-C constrained applications.

### 1.9.1 Ruggedized Package

The VN-310 consists of the sensor installed and calibrated in an IP 68 rated anodized aluminum enclosure certified to MIL-STD and DO-160G standards.

Features:

- IP 68 rated anodized aluminum enclosure
- Compact size: 56 x 56 x 31 mm
- Multi-band GNSS receiver with RTK/PPK support
- Ruggedized 10-pin Fischer connectors
- Single power supply: 12 to 34 V
- Communication interface: Serial RS-422 (Optional RS-232 on primary port)
- Low power requirement: < 115 mA at 24 V

VN-310


FIGURE 1.1

### 1.9.2 VN-310 Development Kit

The VN-310 Development Kit includes the VN-310 sensor along with all the necessary cabling required for operation. Three cables are provided in each Development Kit: one cable to connect the main port to a DB-15 connector, a second interface cable used to connect the DB-15 connector to a USB interface, and a third pigtail cable that can be used for custom cable development. The Development Kit also includes all the relevant documentation.

Features:

- VN-310 sensor
- 10 ft Tactical Series Main Port DB-15 cable
- 6 ft Tactical Series Main Port DB-15 to USB (with +24V wall adapter) cable
- 10 ft Tactical Series Main Port Pigtail cable
- User Manual, Interface Control Document, & Quick Start Guide
- 16 ft Magnetic mount GNSS antenna
- Hard-shell carrying case

VN-310 Development Kit

FIGURE 1.2

### 1.9.3 Embedded Package

For embedded applications, the VN-310 is available in a miniature, board-mount device.

Features:

- Small size: 31 x 31 x 12 mm
- Low weight: 15 g
- Single power supply: 3.2 to 3.5 V
- Multi-band GNSS receiver with RTK/PPK support
- Communication interface: Serial TTL
- Low power requirement: < 480 mA at 3.3 V

VN-310E


FIGURE 1.3

### 1.9.4 VN-310E Embedded Development Kit

The VN-310E Embedded Development Kit provides the VN-310E embedded sensor installed onto a small PCB, allowing for easy access to all the features and pins on the VN-310E. Communication with the VN-310E is provided by USB and RS-232 serial communication ports. A 24-pin header provides easy access to each of the critical pins. The VN-310E Embedded Development Kit also includes all the necessary cabling and documentation.

Features:

- Pre-integrated VN-310E sensor
- Board Size: 76 x 76 x 14 mm
- 24-pin 0.1 inch header to access the VN-310E pins
- Onboard USB to serial converter
- Onboard TTL to RS-232 converter
- DIP Stick
- User Manual, Interface Control Document, & Quick Start Guide
- 16 ft Magnetic mount GNSS antenna
- U.FL to U.FL antenna adapter
- Hard-shell carrying case

VN-310E Embedded Development Kit

FIGURE 1.4

## 1.10 REFERENCE FRAMES

The VN-310 provides its output data in either the sensor-frame, body-frame (which is coincident with the sensor-frame by default), or a navigation frame. The VN-310 uses a right-handed reference frame.

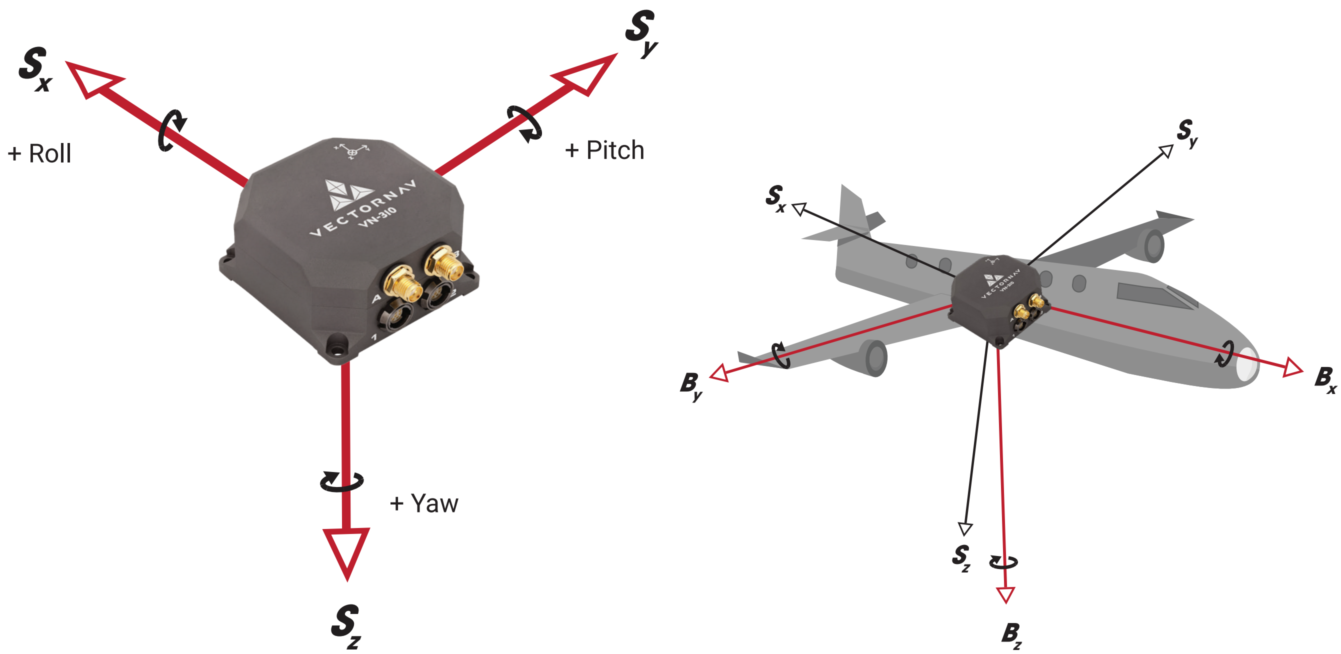
### 1.10.1 Sensor-Frame

The sensor-frame on the VN-310 is aligned as shown in Figure 1.5a. The x-axis points forward, the y-axis points rightward, and the z-axis points downward. A positive yaw angle is defined as a positive right-handed rotation around the z-axis; a positive pitch angle is defined as a positive right-handed rotation around the y-axis; a positive roll angle is defined as a positive right-handed rotation around the x-axis. The sensor-frame is shown on the top of the sensor's casing.

### 1.10.2 Body-Frame

In many cases, the user may want to read the VN-310 output values in an arbitrary reference frame (body-frame), whether due to mechanical offsets, a mounting misalignment, or system-level integration. The new reference frame is often the mounting platform, vehicle, aircraft, camera, LiDAR sensor, external INS, or any other body rigidly attached to the sensor. The new frame may be rotated any amount relative to the sensor-frame using a reference frame rotation (RFR) which can be applied via the Reference Frame Rotation register (Register 26). Figure 1.5b shows an example of such a case where an RFR is needed to rotate the sensor-frame to the body-frame.

**Reference Frames**




(a) Sensor-Frame (b) Example Requiring an RFR

**FIGURE 1.5**

# 2 INITIAL SETUP

The VN-310 has been designed to require minimal configuration by the end user for normal operation. This section provides a high-level overview of the recommended steps that the end user should follow to ensure proper operation of the VN-310 in the intended application.

## 2.1 DEFAULT BEHAVIOR

Unless otherwise noted, the following holds true:

- Changes to register settings take effect immediately
- Default baud rate (UART-1): 115200
- Default baud rate (UART-2): 115200
- Default ASCII output message (UART-1): VNINS at 40 Hz
- Default ASCII output message (UART-2): None
- Default user low-pass filtering window size of 4 for accelerometer, gyroscope, and temperature data
- Default user low-pass filtering window size of 0 for magnetometer and pressure data
- Default VPE heading mode: Relative Mode

## 2.2 MOUNTING RECOMMENDATIONS

When mounting the VN-310 and its antennas onto an aircraft, vehicle, or other platform, careful consideration must be made to ensure optimal performance from the sensor. The following sections detail the recommended guidelines to observe during the installation of the VN-310 and its antennas.

### 2.2.1 VN-310 Mounting Recommendations

In order to provide a navigation solution for a particular platform, the VN-310 needs to be able to directly measure the motion of that platform. To do so, the VN-310 must be **rigidly mounted** to the platform. Additionally, any cabling used to connect to the sensor, or its carrier board in the case of the VN-310E, should be properly **strain-relieved** to prevent stress on the sensor. Failure to rigidly secure the sensor to the desired platform can introduce erroneous IMU measurements that will negatively impact the performance of the sensor. The use of vibration dampeners or flexible mounts prevents the VN-310 from directly measuring the motion of the platform and are generally not recommended.

There are no assumptions made as to the installation alignment of the VN-310, thus the sensor can be mounted to the platform in **any orientation** and at **any location**. Once mounted, if the sensor-frame does not align with the desired body-frame, then a Reference Frame Rotation (RFR) will be required to map the sensor-frame to the body-frame. In addition, if the estimated position and velocity is desired at a point other than the sensor's mounting location, the INS Reference Point Offset will need to be applied. More information on each of these registers can be found in Sections 2.3.2 and 2.3.3.

### 2.2.2 Antenna Mounting Recommendations

In order for the VN-310 to operate, the following requirements **must** be taken into account when mounting the GNSS antennas:

- The GNSS antennas must be mounted with an **unobstructed view** of the sky without any objects or structures placed between them. The GNSS compass requires the two antennas have direct line of sight (LOS) to a shared set of at least 6 satellites (preferably 10 or more). If the antennas do not have a clear view of the sky, the number of shared satellites will be drastically reduced and can prevent the GNSS compass from functioning.
- To prevent multipath interference, ensure the GNSS antennas are mounted directly on top of a **ground plane** or large metal surface. Because a GNSS compass operates by tracking the carrier phase measurements, it is sensitive to multipath interference which occurs when GNSS satellite signals reflect off of solid objects resulting in the signal taking multiple paths to reach the antenna. Using a ground plane as shown in Figure 2.1 prevents multipath signals from reflecting up from the ground to the bottom of the GNSS antenna. A ground plane does not need to be electrically grounded and can be as simple as a piece of foil.
- The GNSS antennas must be **rigidly mounted** with respect to the sensor. The VN-310 obtains optimal estimates of the position, velocity, and attitude by combining the measurements from the inertial sensors and GNSS together. These estimates can only be derived if the inertial sensors and GNSS are measuring the same motion of the platform. As a result of this rigidity requirement, the GNSS antennas must also be rigidly mounted with respect to each other such that the GNSS compass baseline distance between the antennas is fixed.

**Ground Plane Installation**

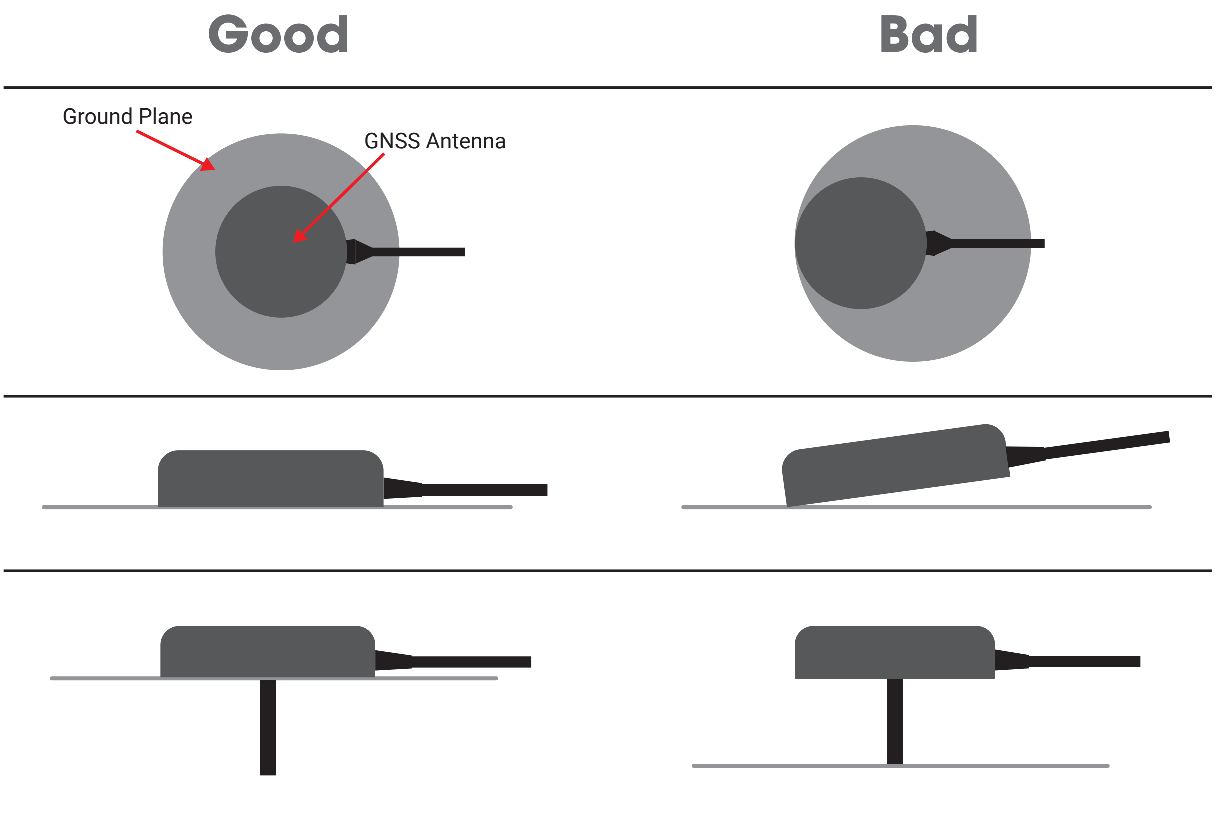



FIGURE 2.1

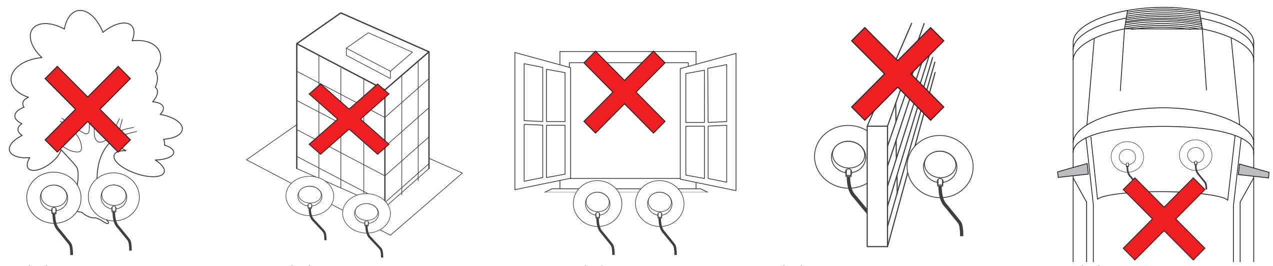
For optimal performance of the VN-310, there are a few additional recommendations that should be considered when installing the GNSS antennas:

- Both antennas should be mounted in the **same orientation** as the RF phase center of an antenna is not always located at the center of the antenna. The RF phase center of an antenna is the point where the antenna can receive signals from the GNSS satellites, so aligning the two antennas in the same orientation ensures an accurate compass baseline measurement.
- The antennas should be placed as **flat and level** as possible, ideally with the pitch and roll of the antenna minimized to less than 10°. Significant pitch and roll of the antenna can lead to increased multipath interference and performance degradation of the sensor.

- Any objects or structures near the antennas can also cause multipath interference. The antennas should be mounted at the **highest point** on the platform, away from other objects or structures.
- It is important to mount the antennas well away from any potential sources of **RF interference** near the GPS frequencies of 1575 MHz and 1227 MHz. RF interference can severely degrade the GNSS measurements and lead to degradation in the performance of the sensor.
- All cabling connected to the antennas should be **properly secured** to avoid stress on the antennas as well as on the VN-310. Great care should be taken when connecting the GNSS antennas to the VN-310 as the connectors can sustain limited side loads and connecting cycles.

Following each of the guidelines listed above and avoiding the poor GNSS conditions shown in Figure 2.2 will ensure the best performance is achieved from the VN-310.

**Poor GNSS Antenna Configurations**



(a) Beneath Foliage

(b) Next to a Building

(c) On a Windowsill

(d) Objects Between the Antennas

(e) On Vehicle Dashboard

**FIGURE 2.2**

## 2.3 VN-310 BASIC CONFIGURATION

During the initial setup of the VN-310, the Antenna A Offset and GNSS Compass Baseline must be properly configured to derive an accurate navigation solution. Beyond the antenna offsets, there is no further configuration required for operation, though the user may wish to modify a few additional register settings such as the baud rate or output messages. The following sections describe the most commonly modified settings on the VN-310—for the full list of configuration registers available, refer to the VN-310 Interface Control Document.

### 2.3.1 Saving User-Configured Settings

The user's desired settings are configured onto the VN-310 using the corresponding Write Register command. However, the Write Register command only saves the settings to the volatile memory of the sensor which will cause the configuration to be erased after a power cycle or reset of the device. To save the user-configured settings to the sensor's non-volatile memory, allowing them to persist through a power cycle or reset, a Write Settings command must be sent to the sensor after the desired Write Register commands have been applied. More information on the Write Settings command can be found in the VN-310 Interface Control Document.

### 2.3.2 Applying a Reference Frame Rotation

Under default settings, the VN-310 assumes that its sensor-frame (Section 1.10.1) is coincident with the desired body-frame (Section 1.10.2) of the platform to which it is rigidly mounted. However, this is not a mounting requirement and many applications may desire the sensor output values in an arbitrary reference frame instead, whether due to mechanical offsets, a mounting misalignment, or system-level integration. Common examples of such cases include a mounting platform frame (i.e. vehicle, aircraft, etc.) or an external sensor-frame (i.e. camera, LiDAR, etc.) that differs from the VectorNav sensor-frame.

A reference frame rotation (RFR) can be applied to the sensor via the Reference Frame Rotation register (Register 26) to rotate the sensor outputs to the desired body-frame. Because the RFR gets applied at a low level and affects all measurements that are used in the filter, these settings must be saved to the non-volatile memory of the sensor through a Write Settings command and then the sensor must be reset or power cycled before the RFR takes effect. For a more detailed analysis and discussion of how to calculate a reference frame rotation, refer to TN004: Reference Frame Rotation.

### 2.3.3 Configuring the INS Reference Point Offset

The INS filter provides its navigation solution (i.e. position, velocity) relative to the INS Reference Point. By default, the INS Reference Point is colocated with the inertial sensor center. If the estimated position and velocity is desired at a point other than the sensor's mounting location, the INS Reference Point Offset should be applied, thus moving the output location of the INS position and velocity data. This offset only translates the INS navigation solution and does not impact the inertial data output (e.g. acceleration). If the acceleration measurements are required in a particular application, the VN-310 should be mounted as close to the location of importance as possible.

The INS Reference Point Offset is the distance from the physical installation location of the VN-310 to the desired location of the INS solution, measured in the body-frame as defined by the Reference Frame Rotation (RFR). More information on applying an RFR onto the VN-310 can be found in Section 2.3.2. This offset can be configured through the INS Reference Point Offset register (Register 105), which contains six inputs — the first three inputs define the position of the INS Reference Point with respect to the physical location of the VN-310, while the three remaining inputs specify the uncertainty of these position measurements.

In a majority of applications, the INS Reference Point is left at the factory default settings; however, if configured, any changes made will not take effect in real time as the values in this register are cached at the startup of the sensor. Because of this, after configuring the INS Reference Point Offset register, a Write Settings command should be issued to the VN-310 followed by a reset or power cycle of the sensor. More information on this register can be found in the VN-310 Interface Control Document.

### 2.3.4 Configuring the GNSS Internal A Antenna Offset

Measurements from a GNSS receiver are reported with respect to the phase center of the corresponding GNSS antenna. To fuse GNSS measurements with inertial sensor data, the distance between the GNSS antenna and the INS Reference Point must be accounted for. The GNSS Internal A Antenna Offset is defined as the position of the GnssA antenna relative to the INS Reference Point (i.e. distance from the INS Reference Point to the GnssA antenna). This distance is measured in the body-frame as defined by the Reference Frame Rotation (RFR). More information on applying an RFR or configuring the INS Reference Point Offset on the VN-310 can be found in Sections 2.3.2 and 2.3.3.

By default, the VN-310 assumes that the GnssA antenna is colocated (within 10 cm) with the INS Reference Point, which is coincident with the sensor in the factory default settings. However, this is not a mounting requirement. The GnssA antenna can be mounted further than 10 cm away from the INS Reference Point as long as this distance is measured and properly configured into the GNSS Internal A Antenna Offset register (Register 57). In the example shown in Figure 2.3, the GNSS Internal A Antenna Offset would be configured as: +0.75 m X, −0.50 m Y, 0.00 m Z. Errors in the measured GNSS Internal A Antenna Offset have a less significant impact on the overall heading accuracy compared to the GNSS Compass Baseline measurement; however, this offset should still be measured as accurately as possible to obtain optimal performance. More information on the GNSS Internal A Antenna Offset register can be found in the VN-310 Interface Control Document.

### 2.3.5 Configuring the GNSS Compass Baseline

In order for the GNSS compass to properly initialize, the sensor must have knowledge of the distance between the two GNSS antennas. This distance is referred to as the GNSS Compass Baseline and is defined as the distance from a point on the GnssA antenna to the same point on the GnssB antenna, specified in the body-frame as defined by the Reference Frame Rotation (RFR). More information on applying an RFR onto the VN-310 can be found in Section 2.3.2.

The compass baseline can be configured onto the sensor through the GNSS Compass Antenna Baseline register (Register 93). This register contains six inputs — the first three inputs define the position of the GnssB antenna with respect to the GnssA antenna, while the three remaining inputs specify the uncertainty of these position measurements. For the sensor to consistently converge on an accurate GNSS compass heading estimate, it is important that the baseline be measured as accurately as possible and the uncertainty values be greater than or equal to the largest expected measurement error. A general rule of thumb for the uncertainty values is to configure them as 2.5% of the largest baseline measurement. Uncertainties below 1 cm are not recommended.

By default, the VN-310 specifies a compass baseline of the GnssB antenna positioned 1 m in front of the GnssA antenna along the x-axis of the platform frame with a 2.5 cm spherical uncertainty. However, this default configuration is not a mounting requirement. The two GNSS antennas can be mounted in any desired configuration, as long as the compass baseline distance is within the range of 25 cm to 2 m and the baseline is properly measured and configured into Register 93. Baseline distances less than 25 cm can begin to cause the GNSS antennas to interfere with each other, while flexing of the structure violates the rigidity requirements in most applications attempting baselines

**GNSS Antenna Offsets**

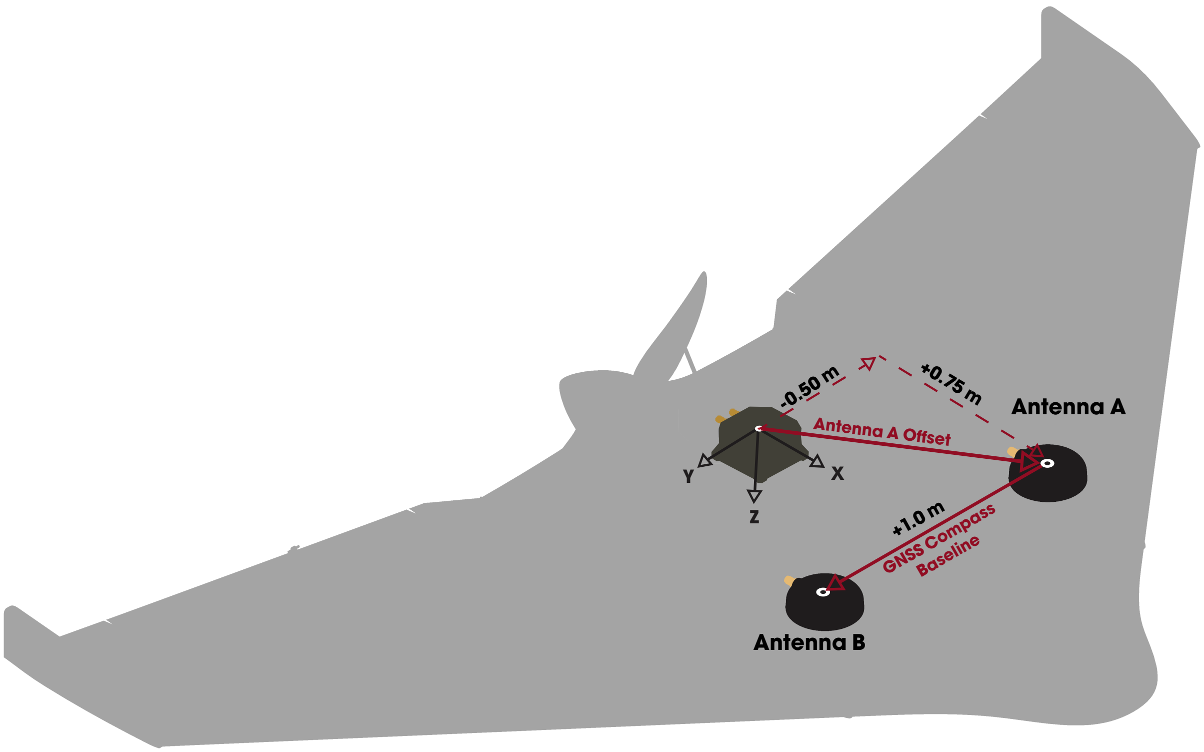



FIGURE 2.3

longer than 2 m. For baseline distances outside the range of 25 cm to 2 m, please reach out to VectorNav Support for further assistance. In the example shown in Figure 2.3, the GNSS compass baseline would be configured as: 0.00 m X, +1.00 m Y, 0.00 m Z with the uncertainty values set to +0.025 m in each axis.

When deciding on the length for the compass baseline, a trade-off must be made between the heading accuracy and the startup time of the GNSS compass. The RMS error of the GNSS compass heading measurement is inversely proportional to the baseline distance between the two antennas such that longer distances will provide higher accuracy GNSS heading estimates. However, longer baseline distances also generally lead to longer startup times of the GNSS compass as shown in Figure 2.4. More information on the GNSS Compass Antenna Baseline register (Register 93) can be found in the VN-310 Interface Control Document.

### 2.3.6 Configuring the Desired Baud Rate

The VN-310 provides the ability to modify the baud rate of each serial port independently through the Baud Rate register (Register 5). The baud rate can be configured at specified rates from 9600 bps up to a maximum of 921600 bps. This allows the user to customize how fast the data is transmitted across the serial line for their specific system requirements.

### 2.3.7 Configuring the Desired Output Messages

The VN-310 provides two different means of obtaining measurements—using either human-readable ASCII messages or user-configurable custom binary output messages.

#### Human-Readable ASCII Messages

The VN-310 provides a variety of proprietary measurement output combinations which can be selected using the Async Data Output Type register (Register 6). The rate of the output can be adjusted from 1 to 200 messages per second using the Async Data Output Freq register (Register 7). Each different proprietary ASCII output message type has its own unique five-character header string so that it can easily be distinguished in the data stream.

In addition to the proprietary output messages, the VN-310 also provides various standard NMEA 0183 output messages which can be selected using the NMEA Output registers (Registers 101 & 102). Many of the messages can source their outputs from either the GNSS data or the INS data and are available at various user-configurable output rates.

GNSS Compass Heading Accuracy and Startup Time

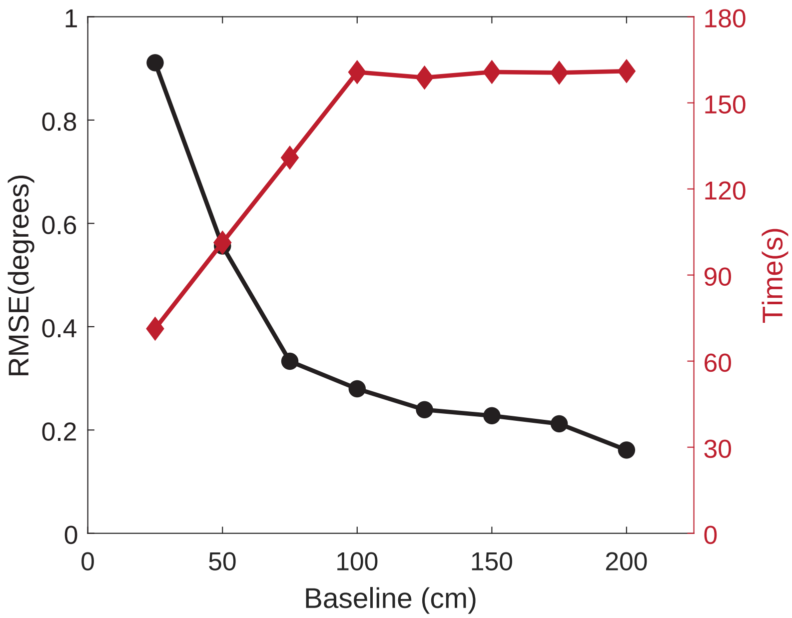



FIGURE 2.4

### User-Configurable Binary Output Messages

Alternatively, for higher rate data or custom message outputs, the VN-310 also supports the ability to construct user-defined binary output messages through the Binary Output Message Configuration registers (Registers 75-77). This option allows the user to select a subset of the available measurements that the VN-310 offers and have it packaged into a single compact binary packet provided at any rate up to the IMU Rate of the sensor. Up to three different custom messages can be created, each with its own separate output rate, and configured to output over one or both of the serial ports.

## 2.3.8 Configuring the User Low-Pass Filter

The VN-310 provides the ability to apply a user-defined, moving window low-pass filter to the output IMU measurements through the IMU Filtering Configuration register (Register 85). This low-pass filter can be used to downsample the inertial sensor data (i.e. acceleration, angular rate, magnetic data, temperature, and pressure) and prevent aliasing when these measurements are output at rates lower than the IMU Rate. The *WindowSize* fields in this register allow the user to adjust the number of samples that are averaged for each output inertial sensor measurement while the *FilterMode* fields select which output quantities to apply the filtering to — uncompensated data, compensated data, or both. When configuring the desired window size, keep in mind that this filtering will also introduce increased latencies in the response of the output sensor measurements and decreased bandwidth available. More information on the IMU Filtering Configuration register can be found in the VN-310 Interface Control Document.

> **i** This low-pass filter is only applied to the measurements output to the user and does not affect the data used in the onboard filter.

# 3 SOFTWARE ARCHITECTURE

The VN-310 software architecture consists of five subsystems: IMU, GNSS, NavState, Vector Processing Engine (VPE), and Communication Interface. The high-level functions performed by these subsystems are outlined in Figure 3.1. This section describes the functions performed by, and outputs of, each of these subsystems.

## 3.1 IMU SUBSYSTEM

The IMU subsystem runs at the highest system rate (default 800 Hz), referred to as the IMU Rate. It is primarily responsible for handling the raw IMU measurements and maintaining consistent system timing. After sampling the IMU components, this subsystem applies a factory calibration, a user-defined calibration, and a user-defined reference frame rotation. The resultant calibrated, body-frame IMU measurements are then passed to the NavState subsystem to be used for propagation. The IMU subsystem produces three different types of outputs: uncompensated outputs, compensated outputs that have the real-time bias compensation values applied, and delta outputs from the coning and sculling integration. The IMU subsystem is responsible for timestamping the IMU measurements to internal system time and relative to both the SyncIn and the GPS PPS signals. These processes are described in more detail in this section.

| FACTORY CALIBRATED | BIAS COMPENSATED | INTEGRALS |
|---|---|---|
| ▪ Acceleration | ▪ Acceleration | ▪ Delta Theta |
| ▪ Angular Rate | ▪ Angular Rate | ▪ Delta Velocity |
| ▪ Magnetic | ▪ Magnetic | ▪ Delta Time |

### 3.1.1 Raw IMU Measurement

The raw IMU measurement stage consists of two parts: the IMU sampling and the factory calibration. First, the internal MEMS are sampled at the highest rate available for each individual sensor, downsampling the gyroscope and accelerometer to the IMU Rate. Second, the factory calibration parameters discussed in Section 1.3 are applied to each sample. These factory calibration parameters are permanently stored on the sensor, and cannot be altered or removed. Once the factory calibration parameters are applied to an IMU sample, it is referred to as a raw IMU measurement.

### 3.1.2 User Calibration

The user calibration stage provides the user with the ability to apply an additional user-defined IMU calibration to remove additional bias, scale factor, and axis misalignment errors. The user calibration is most often used to account for errors that are induced through the lifespan of the part but is optional and, in most cases, not required for normal operation. The magnetometer, accelerometer, and gyroscope calibration parameters can be configured in Register 23, Register 25, and Register 84, respectively.

### 3.1.3 User Reference Frame Rotation

The user reference frame rotation stage provides the user with the ability to redefine the body-frame (discussed in Section 1.10.2) by a rigid-body rotation, which consequently rotates each of the IMU outputs. Because body-frame IMU measurements are used in the attitude estimation algorithms this setting will impact all body-frame outputs including all attitude estimation calculations. The reference frames used by the sensor are discussed in Section 1.10 and can be configured in Register 26. The output of this stage is referred to as a body-frame IMU measurement.

### 3.1.4 Measurement Compensation

The measurement compensation stage compensates each IMU measurement by the real-time calculated bias. Using the VPE state outputs, it subtracts the real-time gyroscope biases, accelerometer biases, and, if enabled, the

## VN-310 Software Architecture

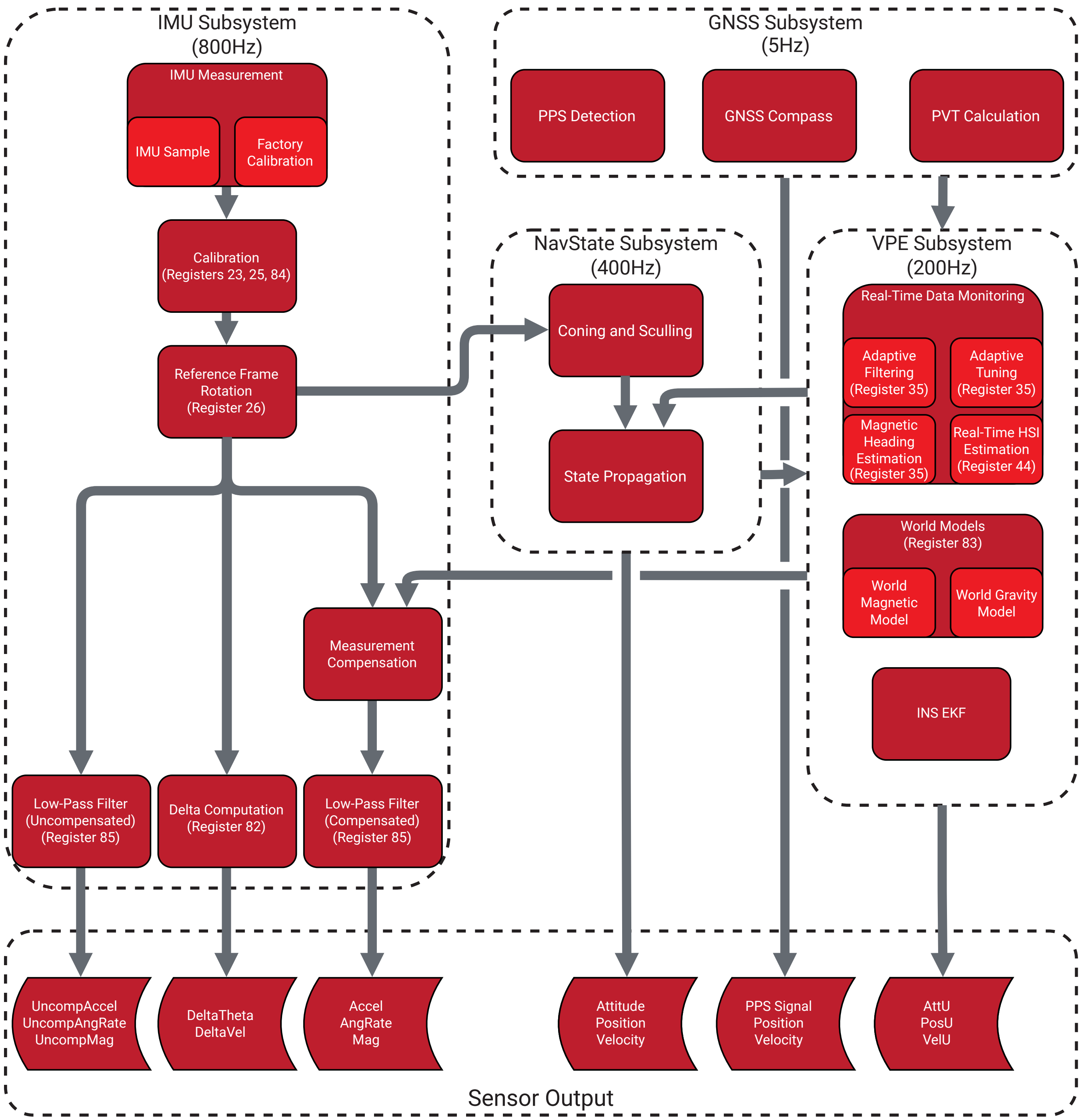



FIGURE 3.1

real-time HSI magnetic disturbances from the body-frame IMU measurements.

### 3.1.5 User Low-Pass Filter

The user low-pass filter stage allows the user with the ability to apply a user-defined, low-pass filter to the output IMU measurements. This can be used to downsample the output IMU measurements to ensure that information is not lost when the IMU measurements are output at a rate lower than the IMU Rate. The low-pass filter can be configured independently for each of the uncompensated and compensated magnetometer, accelerometer, and gyroscope measurements through the IMU Filtering Configuration register (Register 85). This filtering only impacts the IMU measurement outputs; no onboard estimation algorithms will be affected by this setting. The outputs of this stage are directly available to the user.

### 3.1.6 Delta Computation

The delta computation stage is responsible for calculating and outputting the delta theta, delta velocity, and delta time outputs. These outputs represent the change in 3-axis angle, 3-axis velocity, and time between the current delta output and prior delta output. To calculate the delta values, the IMU subsystem computes and accumulates the coning and sculling integrals, resetting them each time the deltas are output—whether by ASCII message, binary message, or polling the Delta Theta and Delta Velocity register (Register 80) directly. Regardless of the delta output rate, the coning and sculling integrals are performed at the IMU Rate. Based on the selected configuration, the delta computation stage can optionally utilize gravity- or bias-compensated IMU measurements, output in the NED reference frame, or compensate for Earth's angular rate. For this functionality, this stage will receive data from, and be dependent upon, the NavState and VPE subsystems. The outputs of this stage are directly available to the user.

### 3.1.7 Timestamping

All onboard IMU measurements are timestamped relative to three internal timing events: the monotonically increasing system time (*TimeStartup*), the time since the last SyncIn Event (*TimeSyncIn*), and the time since the last GPS PPS pulse (*TimeGpsPps*). These timestamps are recorded with nanosecond resolution and approximately 20 µs accuracy relative to the onboard temperature-compensated crystal oscillator. The onboard oscillator has a timing accuracy of approximately 20 ppm over the sensor's operating temperature range. More information on the timing events and processing steps of the VN-310 can be found in TN001: Time Synchronization.

## 3.2 GNSS SUBSYSTEM

The GNSS subsystem runs at the GNSS receiver rate, nominally 5 Hz. It is primarily responsible for supplying GNSS position, velocity, and time (PVT) measurements and a GNSS compass–derived yaw to the VPE subsystem. In addition, this subsystem identifies and outputs a GPS pulse-per-second (PPS) to the VPE subsystem which is critical to time-align the PVT measurements to the INS. By default, the GNSS subsystem uses the internal receiver, but can be configured to interface with any available external GNSS receiver. For more information on interfacing the VN-310 with an external GNSS receiver, reach out to VectorNav Support.

| ESTIMATES | RAW MEASUREMENTS | UNCERTAINTIES |
|---|---|---|
| ▪ Position | ▪ Pseudoranges | ▪ Position |
| ▪ Velocity | ▪ Carrier Phase | ▪ Velocity |
| ▪ Time | ▪ Signal to Noise Ratio (CN0) | ▪ Time |

## 3.3 NAVSTATE SUBSYSTEM

The NavState subsystem runs at a rate fixed to the IMU Rate, referred to as the NavState Rate (default 400 Hz). It is primarily responsible for generating a continuous, reliable stream of low-latency, low-jitter state outputs at a rate higher than the VPE Rate. To accomplish this, the NavState propagates forward the latest VPE states using the IMU measurements, decoupling the rate at which the state outputs are estimated by the onboard Kalman filters from the rate at which they are made available to the user. This process not only effectively upsamples the VPE state outputs, but also guarantees the VN-310 state output timing is unaffected by system load and input measurement availability. Consequently, the NavState is important for many applications which depend on low-latency, low-jitter estimates as inputs to their control loops. The NavState subsystem runs immediately after, and in sync with, the IMU subsystem.

| ATTITUDE | POSITION | VELOCITY |
| --- | --- | --- |
| ▪ Yaw-Pitch-Roll<br>▪ Quaternion<br>▪ Direction Cosine Matrix (DCM) | ▪ Latitude, Longitude, Altitude (LLA)<br>▪ Earth-Centered-Earth-Fixed (ECEF) Frame | ▪ North-East-Down (NED) Frame<br>▪ Earth-Centered-Earth-Fixed (ECEF) Frame<br>▪ Body-Frame |

## 3.4 VPE SUBSYSTEM

The Vector Processing Engine (VPE) subsystem runs at the VPE Rate (default nominally 200 Hz) and is primarily responsible for calculating the fused inertial state outputs through the INS Kalman filter. Because the VPE is dependent upon measurement availability and runs at a relatively low rate, some VPE states are passed to the NavState subsystem to be output at a higher rate. Others are output to the user directly from the VPE subsystem and as such are only updated at the VPE Rate.

In addition to the Kalman filter, the VPE subsystem also includes a collection of sophisticated algorithms which provides real-time monitoring and simultaneous estimation of the attitude as well as the uncertainty of the input measurements used by the attitude estimation algorithm. By estimating its own input measurement uncertainty the VPE is capable of providing significantly improved performance when compared to traditional statically tuned Kalman filters. The estimated measurement uncertainty is used to, in real-time, adaptively tune the onboard Kalman filters. In most cases this adaptive tuning eliminates the need for the user to perform any custom filter tuning for different applications. It also provides robust disturbance rejection capabilities, enabling the VN-310 in most cases to reliably estimate attitude even in the presence of vibration, short-term accelerations, and some forms of magnetic disturbances.

| UNCERTAINTIES | INERTIAL BIASES | WORLD MODELS |
| --- | --- | --- |
| ▪ Attitude<br>▪ Position<br>▪ Velocity | ▪ Accelerometer<br>▪ Gyroscope | ▪ Gravity (EGM96)<br>▪ World Magnetic Model (WMM) |

### 3.4.1 INS Kalman Filter

The INS Kalman filter is an extended Kalman filter which nominally runs at the VPE Rate. The INS Kalman filter uses the accelerometer, gyroscope, GNSS, and—at startup—the magnetometer to simultaneously estimate the full quaternion-based attitude solution, position and velocity, and time-varying gyroscope and accelerometer sensor biases. The state outputs of the INS Kalman filter are passed to the NavState allowing for the attitude, position, and velocity to be made available at the higher rate of the NavState subsystem. The INS Kalman filter provides superior attitude estimation performance compared to the AHRS Kalman filter due to its inherent ability to account for accelerations through its use of the GNSS measurements. As such, when GNSS is available the VN-310 will default to utilize the INS Kalman filter for attitude estimation.

### 3.4.2 AHRS Kalman Filter

Since the INS Kalman filter relies upon a continuous stream of GNSS measurements to operate, the VN-310 supports automatic transition from INS to AHRS attitude estimation modes. In situations when GNSS measurements are not available, the VN-310 will automatically use the magnetometer and the accelerometer to estimate attitude. This transition is handled in a seamless fashion, thus eliminating any potential jump discontinuities from appearing in the attitude or angular rate outputs when transitioning to and from the AHRS. Optionally, the user can manually select between using the INS or AHRS attitude estimation modes using the INS Basic Configuration register (Register 67).

### 3.4.3 Adaptive Filtering

The VPE employs adaptive filtering techniques to significantly reduce the effect of high-frequency magnetic and acceleration disturbances. Prior to entering the INS filter, the magnetic and acceleration measurements are digitally filtered to reduce high-frequency components typically caused by electromagnetic interference and vibration. The level of filtering applied to the inputs is dynamically altered by the VPE in real time. The VPE calculates the minimal amount of digital filtering required in order to achieve specified orientation accuracy and stability requirements. By applying only the minimal amount of filtering necessary, the VPE reduces the amount of delay added to the input signals. For applications that have very strict latency requirements, the VPE provides the ability to limit the amount of adaptive filtering performed on each of the input signals or to disable it entirely.

### 3.4.4 Adaptive Tuning

Kalman filters employ coefficients that specify the uncertainty in the input measurements which are typically used as tuning parameters to adjust the behavior of the filter. Normally these tuning parameters have to be adjusted by the engineer to provide adequate performance for a given application. This tuning process can be ad-hoc, time-consuming, and application-dependent. The VPE employs adaptive tuning logic which provides online estimation of the uncertainty of each of the input signals during operation. This uncertainty is then applied directly to the onboard INS filter to correctly account for the uncertainty of the inputs. The adaptive tuning reduces the need for manual filter tuning.

### 3.4.5 Adaptive Filtering and Tuning Settings

The VPE actively employs both adaptive filtering and adaptive tuning techniques to enhance performance in conditions of dynamic motion and magnetic and acceleration disturbances. The VPE provides the ability to modify the amount of adaptive filtering and tuning applied on both the magnetometer and the accelerometer through the VPE Magnetometer Basic Tuning register (Register 36) and the VPE Accelerometer Basic Tuning register (Register 38). In most cases the VPE can be used in the default configuration without any need to adjust these settings. For some applications, higher performance can be obtained by adjusting the amount of adaptive filtering and tuning performed on the inputs. The following settings are provided for both the magnetometer and accelerometer.

#### Static Measurement Uncertainty

The static gain adjusts the level of uncertainty associated with either the magnetic or acceleration measurement when no disturbances are present. The level of uncertainty associated with the measurement will directly influence the accuracy of the estimated attitude solution. The level of uncertainty in the measurement will also determine how quickly the attitude filter will correct for errors in the attitude when they are observed. The lower the uncertainty, the quicker it will correct for observed errors.

- This parameter can be adjusted from 0 to 10.
- Zero places no confidence (or infinite uncertainty) in the sensor, thus eliminating its effect on the attitude solution.
- Ten places full confidence (minimal uncertainty) in the sensor and assumes that its measurements are always 100% correct.

#### Adaptive Tuning Gain

The adaptive tuning stage of the VPE monitors both the magnetic and acceleration measurements over an extended period of time to estimate the time-varying level of uncertainty in the measurement. The adaptive tuning gain directly scales either up or down this calculated uncertainty.

- This parameter can be adjusted from 0 to 10.
- The minimum value of zero turns off all adaptive tuning.
- The maximum value of 10 applies several times the estimated level of uncertainty.

#### Adaptive Filtering Gain

The adaptive filtering stage of the VPE monitors both the magnetic and acceleration measurements to determine if large-amplitude, high-frequency disturbances are present. If so, then a variable level of filtering is applied to the inputs in order to reduce the amplitude of the disturbance down to acceptable levels prior to inputting the measurement into the attitude filter. The advantage of adaptive filtering is that it can improve accuracy and eliminate jitter in the output attitude when large-amplitude AC disturbances are present. The disadvantage to filtering is that it will inherently add some delay to the input measurement. The adaptive filtering gain adjusts the maximum allowed AC disturbance amplitude for the measurement prior to entering the attitude filter. The larger the allowed disturbance, the less filtering that will be applied. The smaller the allowed disturbance, the more filtering will be applied.

- This parameter can be adjusted from 0 to 10.
- The minimum value of zero turns off all adaptive filtering.
- The maximum value of 10 applies maximum filtering.

Keep in mind that regardless of this setting, the adaptive filtering stage will apply only the minimal amount of filtering necessary. As such, this parameter provides the ability to set the maximum amount of delay that is acceptable in the input measurement.

### 3.4.6 Heading Modes

As part of its collection of algorithms, the VPE includes three independent heading modes: Absolute Mode, Relative Mode, and Indoor Mode. These heading modes control how the VPE interprets the magnetic measurements in estimating magnetic-based heading and are described in detail in the following sections. The particular heading mode of the VN-310 can be configured using the *HeadingMode* field in the VPE Basic Control register (Register 35).

While each mode is unique in how it handles magnetic measurements, all three modes are capable of handling high-frequency external magnetic disturbances greater than 1 Hz as well as constant external magnetic disturbances lasting less than a few seconds. The distinction between the various modes becomes crucial for external magnetic disturbances lasting longer than a few seconds.

The different heading modes were designed as a way to handle external magnetic disturbances the VN-310 may encounter in its environment and are not intended to account for any internal magnetic disturbances which are rigidly mounted with respect to the sensor. A hard and soft iron (HSI) calibration should be performed on the sensor to handle any internal magnetic disturbances. If a valid HSI calibration is not performed prior to use, the behavior of these heading modes can be impacted and may not operate as expected. More information on performing an HSI calibration can be found in TN002: Hard & Soft Iron (HSI) Calibration.

#### Absolute Mode

In Absolute Mode, the VPE assumes the magnetometer is measuring Earth's magnetic field alone and no external magnetic disturbances are present. As such, only short-term magnetic disturbances greater than 1 Hz are tuned out. Unfortunately, long-term external magnetic disturbances cannot be handled in Absolute Mode as a constant long-term external magnetic disturbance will be indistinguishable from Earth's magnetic field and will, consequently, result in a loss of heading accuracy.

Because of the assumptions placed on the magnetometer measurements, Absolute Mode can also impact the estimation of the real-time gyroscope bias in addition to the heading estimate. When a long-term external magnetic disturbance is encountered, the magnetometer will measure more than just Earth's magnetic field, causing the magnetic-based yaw to slew over to an erroneous heading estimate. Because this transition in the heading is not due a physical rotation of the sensor, a disagreement between the magnetometer and gyroscope measurements will arise. In order to resolve this mismatch between the two sensors, the real-time gyroscope bias estimate must be updated, often resulting in degradation of this estimate.

Absolute Mode is ideal for applications that do not encounter any external magnetic disturbances lasting more than a few seconds, such as an aircraft in flight or a marine vessel in open water. Additionally, this heading mode maintains absolute tracking of the heading relative to the fixed Earth, making it perfect for applications requiring a stable and repeatable heading. However, it is important to note that in order to track an absolute heading, any internal magnetic distortions need to be well characterized by performing a hard and soft iron (HSI) calibration on the VN-310. Hard and soft iron distortions that are not properly accounted for will induce heading errors proportional to the magnitude of the distortion.

> If a magnetic disturbance occurs due to an event controlled by the user, such as the switching on/off of an electric motor, an absolute heading can still be maintained if the VN-310 is notified of the presence of the disturbance using the Known Magnetic Disturbance command.

#### Relative Mode

In Relative Mode, the VPE places no assumptions on the magnetometer measurements and instead recognizes that the magnetometer is likely impacted by external magnetic disturbances in the surrounding environment in addition to measuring Earth's magnetic field. To minimize the impact of external magnetic disturbances on the derived heading, Relative Mode estimates the external magnetic field in real time using a comparison between the magnetometer and gyroscope measurements. This estimation process allows Relative Mode to ignore magnetic disturbances in the heading calculation when they are encountered in the environment.

While the heading estimate in Relative Mode will often remain stable in the presence of external magnetic disturbances, the estimation process used to track the external magnetic field is not perfect. The magnetic measurements themselves are often noisy and the integration of the angular rate measurements will drift over time due to the inherent noise and bias properties of the gyroscope. As a result, drift can accumulate in the heading solution, such that Relative Mode can only provide a relative heading and cannot always ensure the magnetic-based heading is referenced to Magnetic North. The amount of drift accrued depends on how many magnetic disturbances are encountered, how often they are encountered, and the magnetic strength of each disturbance. Additionally, if an HSI calibration has not been performed on the VN-310 to account for internal, time-invariant magnetic disturbances, drift will accumulate fairly rapidly as the sensor will continually encounter these disturbances.

Relative Mode is designed for use in situations where maintaining a stable attitude solution is the most important requirement. In general, Relative Mode will provide the most accurate heading of the three heading modes, particularly over the short term, even with some drift in the estimation process. Because Relative Mode provides a stable heading, it is also able to produce an accurate estimate of the gyroscope bias.

#### Indoor Mode

In any environment, the measured magnetic field is generally a blend of Earth's magnetic field and other local magnetic fields created by objects near the VN-310. For indoor environments in particular, this becomes problematic due to the potential proximity to objects such as metal desks and chairs, speakers, rebar in the concrete floor, and other items which either distort or produce their own magnetic field. The strength of these local magnetic fields is position-dependent; if the strength is on the same order of magnitude as that of Earth's magnetic field, directly trusting the magnetic measurements to determine heading can lead to inaccurate heading estimates.

Indoor Mode is ideal for applications in which the external magnetic disturbances are constantly changing and works best in cases where disturbances are short-lived and zero-mean, such as a sensor that is constantly in motion. When used in Indoor Mode, the VN-310 should be in proximity to magnetic disturbances for no more than a few seconds at a time. Unfortunately, a majority of applications will not experience such an environment and Indoor Mode may provide worse magnetic disturbance rejection than Relative Mode or Absolute Mode.

### 3.4.7 Real-Time Hard and Soft Iron Estimator

The VPE subsystem also includes a separate EKF which provides real-time estimation of the local magnetic hard and soft iron (HSI) distortions. Local HSI distortions are magnetic fields generated by electrical currents or ferrous materials which are constant relative to the position and orientation of the sensor. These distort the direction and magnitude of the measurement of Earth's magnetic field, thus negatively impacting the ability of the filter to reliably and accurately estimate its magnetometer-based heading. To remove the unwanted effect of these disturbances, an HSI calibration must be performed. This requires rotating the sensor around in multiple circles while collecting magnetic data for offline calculation of the magnetic hard and soft iron calibration coefficients. This calibration can be time-consuming and may not be possible for some applications. The Real-Time Hard and Soft Iron Estimator runs on the VN-310 in the background without requiring any user intervention. For many applications this simplifies the process for the end user and allows for operation in environments where HSI disturbances may change slowly over time. On the VN-310, the Real-Time Hard and Soft Iron Estimator is turned off by default, but can be enabled and configured by the Real-Time HSI Control register (Register 44). More information on the Real-Time Hard and Soft Iron Estimator can be found in TN002: Hard & Soft Iron (HSI) Calibration.

### 3.4.8 World Magnetic Model

The World Magnetic Model (WMM) is a large spatial-scale representation of Earth's magnetic field. The model used in the VN-310 consists of a spherical-harmonic expansion of the magnetic potential of the geomagnetic field generated in Earth's core. By default, the World Magnetic Model on the VN-310 is enabled and automatically uses the estimated position from the INS to directly set the reference magnetic field strength. Alternatively the World Magnetic Model can be manually used to calculate the magnetic field strength for a given latitude, longitude, altitude, and date to be subsequently used as the fixed magnetic field reference strength. The Reference Model Configuration register (Register 83) can be used to control the World Magnetic Model.

### 3.4.9 World Gravity Model

The World Gravity Model (WGM) is a large spatial-scale representation of Earth's gravitational potential as a function of position on Earth. The internal model used on the VN-310 is consistent with the Earth Gravity Model (EGM96), which consists of a spherical-harmonic expansion of Earth's geopotential. By default, the World Gravity Model on the VN-310 is enabled, and automatically is set based on the INS-estimated position. As with the World Magnetic Model, the World Gravity Model can be used to calculate the gravitational potential for a given latitude, longitude, and altitude to be subsequently used as the fixed reference gravitational potential. The Reference Model Configuration register (Register 83) can be used to control the World Gravity Model.

## 3.5 COMMUNICATION INTERFACE

The VN-310 communication interface consists of two physically independent bidirectional UART serial ports. Each UART supports baud rates from 9600 bps up to a maximum of 921600 bps. The ruggedized version of the VN-310 offers both UARTs with RS-422 differential logic level input and output voltages. A variant of the VN-310 (VN-310-A) also exists that offers the primary UART (UART-1) with RS-232 logic level voltages, while the auxiliary serial port (UART-2) remains at RS-422 differential logic levels. The embedded version of the VN-310 (VN-310E) offers both UARTs with 3 V TTL logic level input and output voltages. More information on the VN-310 serial interface can be found in the VN-310 Interface Control Document.

> ! The ability to update the firmware using the onboard bootloader is only supported on the primary serial port (UART-1). It is highly recommended that if the primary serial port is not used for normal operation, a means of accessing it is designed into the product to support future firmware updates.

# 4 OPERATION

Understanding the operation of the VN-310 is critical to ensuring the sensor is integrated successfully and operating nominally. The following sections detail the recommended outputs to use in monitoring the status of the sensor, walk through the startup sequence of the VN-310, and provide guidance for using the sensor in the most challenging conditions.

## 4.1 SENSOR STATUS

During operation of the VN-310, it is important to monitor the status of the sensor to ensure the quality of the overall solution. The following outputs provide an indication of the overall health of many of the different subsystems on the sensor and should be the first place to check if any problems arise when using the VN-310.

### 4.1.1 INS Status Output

The *InsStatus* output is a bitfield output containing various status information for the INS filter. This output can be configured as part of a binary output message from the Common or INS binary output groups, parsed from the VNINS or VNINE ASCII output messages, read directly from Registers 63 and 64, or appended to the end of an ASCII output message using the Communication Protocol Control register (Register 30). Monitoring this output, particularly during the startup process of the sensor, allows the user to ensure the INS filter and GNSS compass initialize properly and are operating nominally.

The *InsStatus* output can be broken down into the following bitfield values:

- *Mode*: This bitfield value indicates the current status of the INS Filter and can be broken down into four different states:
  - *NotTracking* (0): The INS filter has not initialized and its outputs are invalid.
  - *Aligning* (1): The INS filter has initialized and the INS position and velocity measurements are now valid, but the attitude outputs are not.
  - *Tracking* (2): The INS filter is tracking and all of its outputs are now valid (i.e. position, velocity, attitude).
  - *GnssLost* (3): An extended GNSS outage has occurred and the INS position and velocity outputs are no longer valid, though the attitude outputs remain valid.
- *GnssFix*: This flag indicates the sensor currently has a valid 3D GNSS fix.
- *ImuErr*: This flag indicates whether an IMU subsystem error is detected by the sensor.
- *MagPresErr*: This flag indicates whether a magnetometer or barometer error is detected by the sensor.
- *GnssErr*: This flag indicates whether a GNSS communication error is detected by the sensor.
- *GnssHeadingIns*: This flag indicates the GNSS compass is aiding the INS filter heading solution.
- *GnssCompass*: This flag indicates whether the GNSS compass is tracking the carrier phase measurements on both Antenna A & B and calculating potential heading solutions.

For more information on extracting each of these values from the *InsStatus* output, please refer to the VN-310 Interface Control Document.

### 4.1.2 IMU Status Output

The *ImuStatus* output is a bitfield output that provides real-time monitoring of the onboard sensors (gyroscope, accelerometer, magnetometer, barometer, and temperature sensor) to ensure that each is operating as expected. This output can be configured as part of a binary output message from the IMU binary output group or appended to an ASCII output message through the Communication Protocol Control register (Register 30).

Each bitfield value in the *ImuStatus* output (*GyroStatus*, *AccelStatus*, *MagStatus*, *PresTempStatus*) can be broken down into four different states:

- *NominalUpdated*: The sensor is operating as expected and the current output is a new measurement.
- *NominalNotUpdated*: The sensor is operating as expected, but the current output is not a new measurement. This can occur when the sampling rate of the sensor is lower than the IMU Rate.
- *Saturated*: The sensor is saturated and its current output measurement has been set to the maximum value measurable by the sensor.
- *Failed*: The sensor is experiencing a failure and its output should not be trusted.

For more information on extracting each of these bitfield values from the *ImuStatus* output, please refer to the VN-310 Interface Control Document.

### 4.1.3 Uncertainty Outputs

The VN-310 offers a variety of different uncertainty outputs that the user can monitor for insight into the current status of the sensor. GNSS position and velocity uncertainty values can be used to help assess the current GNSS conditions. Similarly, the INS position and velocity uncertainty values can be monitored for the status of the onboard filter. An attitude uncertainty output is also available, which provides an indication of the quality of the current attitude solution.

> The INS uncertainty outputs and the attitude uncertainty outputs are only valid after the sensor has transitioned into the *Aligning* mode in the *InsStatus* output.

## 4.2 STARTUP SEQUENCE

Understanding the startup process of the VN-310 is vital for ensuring optimal operation of the sensor. In this section, the typical startup sequence of the sensor as well as methods for expediting this startup process will be discussed.

### 4.2.1 Typical Startup Sequence

During the startup of the VN-310, the sensor will progress through a number of different events marked by changes in the *InsStatus* output flags, as shown in Figure 4.1. It is important to monitor the sensor throughout each of these events to ensure the sensor has been properly setup and initializes as expected.

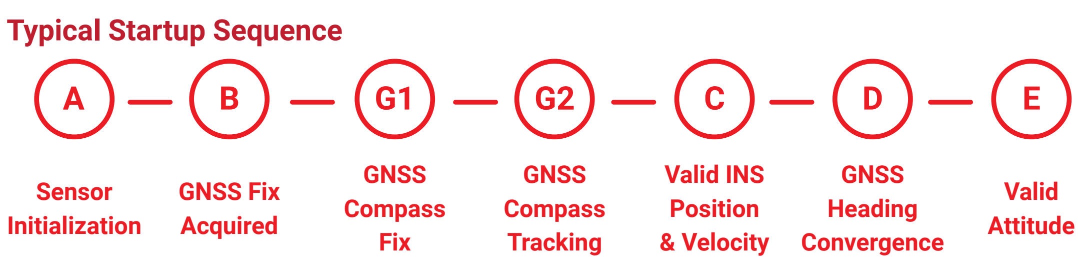



FIGURE 4.1

- **Event A: Sensor Initialization** Upon powering on or resetting the sensor, all flags in the *InsStatus* output will be low and the sensor will be in the *NotTracking* mode, illustrated in Figure 4.2 and 4.3. At this point the INS filter has not been initialized and is currently invalid. Consequently, the INS position, velocity, and uncertainty estimates will be reported as zeros. Because the sensor initially does not have a GNSS fix, the GPS time will be populated with the time since the startup of the unit until a GNSS fix is acquired. If *AhrsAiding* is enabled in Register 67, the heading will be derived from the onboard magnetometer and the sensor will operate similar to that of an attitude & heading reference system (AHRS). This is not guaranteed to be an accurate heading solution and is only used as a coarse heading for a smooth initialization.

- **Event B: GNSS Fix Acquired** With clear sky visibility, the sensor will typically acquire a GNSS fix within 30 to 45 seconds after startup. Once acquired, the *GnssFix* flag in the *InsStatus* output will go high as seen in Figure 4.2 and 4.3. The GPS time outputs (i.e. GPS TOW, GPS Week, etc.) will switch from the time since sensor startup to the current GPS time, and the GNSS outputs will be valid. The current GNSS position will be used to calculate and apply the local magnetic reference vector and declination angle. Subsequently, the coarse heading solution may transition to a new value as this reference vector and declination angle takes effect. The sensor will also output a large attitude uncertainty value to reflect that the current heading is a coarse magnetic-based heading.
- **Event G1: GNSS Compass Fix** In a clear sky environment, the sensor should begin tracking the carrier phase measurements within 60 seconds of acquiring a GNSS fix. The GNSS compass will then begin calculating potential heading solutions based on the carrier phase measurements and antenna inputs from the user. Once this occurs, the *GnssCompass* flag in the *InsStatus* output will go high as displayed in Figure 4.2. The sensor will continue to be in *NotTracking* mode and will report a coarse magnetic heading. If the *GnssCompass* flag fails to go high, this indicates that the sensor may be operating in a degraded GNSS environment. Under dynamic conditions, this event may be bypassed in the startup sequence, such that the VN-310 transitions directly from Event B to Event C.
- **Event G2: GNSS Compass Tracking** The GNSS compass takes roughly 3 minutes to explore the available search space and track a heading solution in ideal conditions; however, it can take upwards of 10 minutes as the GNSS compass is highly dependent on the compass baseline distance and the current GNSS environment conditions. Carrier phase measurements used in the GNSS compass can be difficult to track, particularly in the presence of multipath. Additionally, as shown in Figure 2.4, shorter compass baseline distances will provide a faster startup time as there is a smaller search space for the GNSS compass to explore for potential solutions. Shorter baseline distances will also typically observe similar multipath conditions between antennas, if any are present, allowing the GNSS compass to more easily reject those carrier phase measurements in its calculation. As observed in Figure 4.2, the attitude uncertainty may temporarily spike. Under dynamic conditions, this event may be bypassed in the startup sequence, such that the VN-310 transitions directly from Event B or Event G1 to Event C.
- **Event C: Valid INS Position & Velocity** The INS filter has been initialized and the INS position, velocity, and corresponding uncertainty measurements are now valid. This event is indicated by the sensor transitioning into the *Aligning* mode in the *InsStatus* output as seen in Figure 4.2 and 4.3.
- **Event D: GNSS Heading Convergence** This event signifies that the GNSS compass or dynamic alignment process has converged on a GNSS-derived heading solution.

  In order for the GNSS compass to converge on a heading solution, the VN-310 must have progressed through Event G1 and Event G2.

  Dynamic alignment will begin once the VN-310 has exceeded the velocity threshold of 5 m/s for at least one second. During this process, the horizontal accelerations measured independently by the accelerometer and GNSS are correlated to derive a high-accuracy heading estimate. There is no specific motion required to achieve dynamic alignment, all that is needed is horizontal acceleration of any type. Generally, a car getting up to speed or an aircraft accelerating down a runway at takeoff is enough to trigger this process.

  Upon reaching this event, the heading will smoothly transition from the magnetometer-based heading solution to the GNSS-derived heading solution. The duration for this transition differs from application to application and is dependent on the difference between the magnetometer and GNSS heading solutions.
- **Event E: Valid Attitude** Once this event is reached, the sensor will transition into the *Tracking* mode in the *InsStatus* output, indicating that the INS heading agrees with the GNSS-derived heading and there is confirmed consistency between the INS and GNSS measurements, as shown in Figure 4.2 and 4.3. When this occurs, the attitude is performing within specification.

### 4.2.2 Quick Startup Methods

As detailed in Section 4.2.1, the VN-310 can take some time to achieve a valid attitude solution. This startup time is crucial in some applications requiring faster initialization. The following methods can be utilized to expedite the startup sequence of the sensor.

#### Set Initial Heading

If the initial heading of the sensor is known at startup to within 5° of the true heading relative to True North, the Set Initial Heading command can be used to quicken the startup process. Once the VN-310 has received this command,

## Static Startup

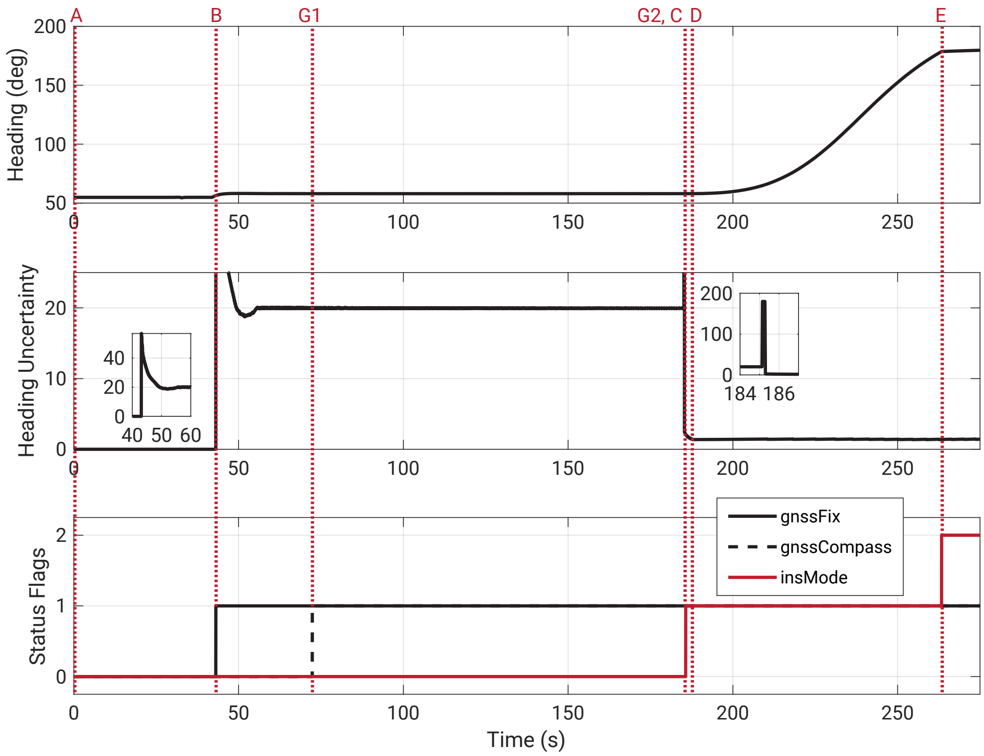



FIGURE 4.2

## Dynamic Startup

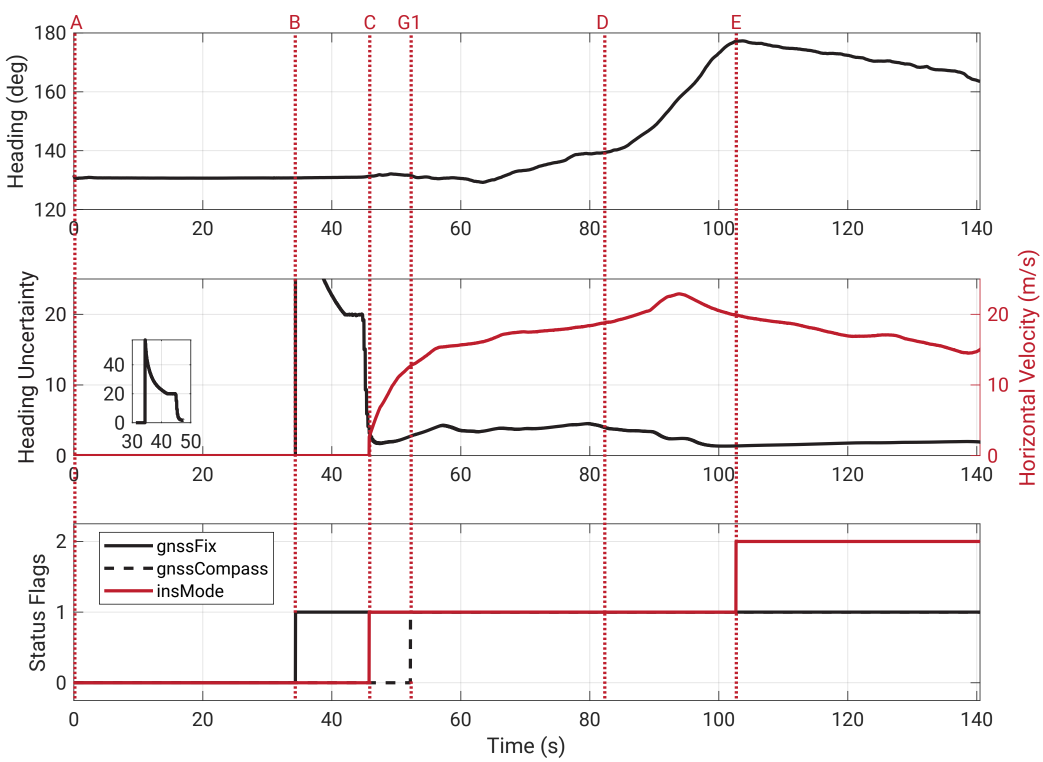



FIGURE 4.3

the heading will instantly update to the initial heading value input by the user. After Event G1 has been reached in the startup sequence, the sensor immediately transitions to Event G2, bypassing the typical several minute convergence period of the GNSS compass. More information on the Set Initial Heading command can be found in the VN-310 Interface Control Document.

> It is important that the initial heading provided to the VN-310 be accurate to within 5° of the true heading of the sensor relative to True North. If the initial heading provided is not within this accuracy window, then the INS may lose tracking and possibly reset.

#### Disable AHRS Aiding

The AHRS aiding feature on the VN-310 enables the ability to switch to using the AHRS to stabilize the attitude during times when the INS filter is unavailable, such as at startup. While disabling this feature will remove the ability to fall back on the AHRS, it will also tune out the magnetometer measurements when used in the INS filter. Consequently, when Event D is reached in the startup sequence, rather than smoothly transitioning from the coarse magnetic heading to the GNSS-derived heading, the VN-310 will immediately jump to the GNSS-based heading solution. Though this causes a discontinuous jump in the heading output, this method can significantly decrease the time required to transition from Event D to Event E. The AHRS aiding feature can be disabled on the VN-310 by configuring the *AhrsAiding* field in the INS Basic Configuration register (Register 67) to *Disable*.

#### Improve Coarse Magnetic Heading

With the AHRS aiding feature enabled, the heading will smoothly transition from the magnetometer based heading solution to the GNSS-derived heading solution. The duration for this transition differs from application to application and is dependent on the difference between the magnetometer and GNSS heading solutions. Having an accurate magnetic heading will shorten the time required to progress from Event D to Event E, thus providing a faster startup of the VN-310. To improve the coarse magnetic heading estimate, a hard & soft iron (HSI) calibration can be performed on the sensor, which will account for the magnetic signature of the platform that the VN-310 is rigidly attached to. More information on performing an HSI calibration on the VN-310 can be found in TN002: Hard & Soft Iron (HSI) Calibration.

## 4.3 GNSS COMPASS BASELINE CALIBRATION

The VN-310 has a built-in feature allowing the sensor to calibrate the GNSS compass baseline measurement with tighter uncertainties. In most applications, it is recommended during initial use that larger uncertainty values be input into the GNSS Compass Antenna Baseline register (Register 93) to ensure that the GNSS compass properly initializes. A general rule of thumb for the initial value of the uncertainties is 2.5% of the largest baseline measurement. In subsequent operation, the onboard calibration can be used to minimize these uncertainties.

Once a platform is in motion and has dynamically aligned, the sensor will use the heading derived via dynamic alignment to improve the estimate of the compass baseline and lower the uncertainty of these measurements. Typically, this calibration process takes about thirty minutes to an hour of motion to converge on a baseline solution. After the calibration has converged, the calibrated baseline measurements will populate in the GNSS Compass Estimated Baseline register (Register 97). This register also includes a status flag called *EstBaselineComplete* to indicate that the calibration has converged and is currently being used onboard the sensor. This calibrated measurement will automatically take effect in real time, as long as there is consistency between the initial user input baseline and the calibrated baseline measurements.

> To save these measurements to the VN-310 and have them persist through a reset or power cycle, the measurements should be copied into the GNSS Compass Antenna Baseline register (Register 93) followed by a Write Settings command issued to the sensor.

## 4.4 SINGLE ANTENNA MODE

While designed as a dual-antenna GNSS/INS, the VN-310 can operate instead as a single-antenna GNSS/INS. In some applications, it may not be feasible or desirable to mount two separate GNSS antennas due to size or weight constraints. Other systems may have two GNSS antennas connected, but want to operate the sensor as a single-antenna GNSS/INS for various reasons. When operated as a single-antenna GNSS/INS, the GNSS compass will not be operational and the VN-310 must have sufficient motion for dynamic alignment in order to achieve Event E detailed in Section 4.2.1. For additional information on using the VN-310 with a single antenna, reach out to the VectorNav Support team.

## 4.5 REAL-TIME KINEMATIC (RTK) POSITIONING

For systems requiring precise positioning in real time, a technique known as real-time kinematic (RTK) positioning is often used in which correction data from a static base station is sent to a rover receiver, allowing the receiver to achieve centimeter-level positioning. The VN-310 is able to accept RTCM (Radio Technical Commission for Maritime Services) version v3 messages from a static base station as correction data for RTK positioning. These correction messages can be sent to the sensor on either serial port (UART-1 or UART-2). There are no requirements from the user to configure any settings prior to sending RTCM messages to the VN-310, the sensor will automatically detect the RTCM messages and apply the corrections. It is generally recommended that the RTCM 1005, GPS MSM4 or MSM7 (1074 or 1077), and Galileo MSM4 or MSM7 (1094 or 1097) correction messages be sent to the VN-310. Additionally, it is recommended that the real-time link used to transmit the data be capable of transferring the correction messages at an update rate of 1 Hz with minimal latency.

## 4.6 POST-PROCESSED KINEMATIC (PPK) POSITIONING

Applications in which a real-time solution is not critical often utilize an offline technique known as post-processed kinematic (PPK) positioning to achieve a centimeter-level positioning solution. In such an approach, raw GNSS measurements from a base station and a rover receiver are logged during a mission then compared in post to improve the navigation solution. The VN-310 can be utilized as the rover receiver by logging the GnssRawMeas binary output type found in the Gnss binary output group at 5 Hz to a raw binary file. Once the mission is complete, the raw GNSS data logged from the VN-310 should be exported into a RINEX file using the Log Explorer tool found in VectorNav's Control Center software suite. This RINEX file along with stored data (i.e. ephemeris and RINEX files) from a nearby base station can then be post-processed using third-party software to obtain high accuracy position data. IMU data from the VN-310 can optionally be logged as well for use in third-party software supporting a full GNSS/INS post-processing solution. Reach out to VectorNav Support for additional information on post-processing data from the VN-310.

## 4.7 OPERATIONAL CHALLENGES

While the VN-310 has been designed to operate in a wide variety of applications and use cases, there are some operations that can pose more of a challenge for the sensor. This section details challenges that may arise during operation of the VN-310 as well as troubleshooting tips for the most commonly encountered issues.

### 4.7.1 GNSS-Challenged/Denied Operations

In applications that experience GNSS-challenged or GNSS-denied conditions, the VN-310 will continue to propagate the navigation solution using the onboard inertial sensors, though the accuracy of the solution will degrade quite rapidly. If the conditions persist over an extended period of time, the INS filter will reset resulting in the VN-310 operating as an attitude and heading reference system (AHRS) until a valid GNSS fix has been reacquired.

#### Challenge

The VN-310 requires regular GNSS updates to maintain an accurate navigation solution. During operation, there may be instances in which the sensor is used in poor GNSS conditions such that the GNSS measurements are degraded or even lost altogether. Poor conditions are often caused by a signal blockage that prevents the signal from reaching the GNSS receiver or from a signal interference which causes a disturbance on the signal transmitted by the GNSS satellites. A hardware malfunction along the RF path, such as a bad GNSS antenna, could also lead to degraded GNSS conditions. If the VN-310 has initialized the INS filter prior to loss of GNSS, the filter will continue to propagate the position, velocity, and attitude estimates using the onboard inertial sensor measurements. The VN-310 can maintain an accurate navigation solution through short outages lasting up to tens of seconds without access to GNSS. However, over extended periods the navigation solution will degrade quite rapidly.

Because the accuracy of the navigation solution will swiftly degrade and result in large unbounded errors when operating in GNSS-denied conditions, a reset of the INS filter is often necessary. A reset of the filter can happen at any time and will occur either if a divergence of the filter is detected or no longer than 75 seconds after the loss of GNSS occurred. A GNSS outage is often preceded by degraded GNSS conditions, which can hasten the divergence detection and, consequently, a reset of the filter.

If the *InsStatus* reaches *Tracking* mode prior to loss of GNSS, the behavior of the VN-310 will depend on how quickly the attitude degrades. If attitude remains valid 45 seconds after the GNSS outage occurs, the VN-310 will progress into the *GnssLost* mode in the *InsStatus* output, indicating the attitude is still valid though the position and velocity estimates are no longer valid and have locked onto their last estimated value. However, if the attitude uncertainty increases beyond 2°, the VN-310 will drop into *Aligning* mode and remain there for no longer than 45 seconds after the GNSS loss.

Once a reset of the INS filter has occurred, the *InsStatus* will shift into *NotTracking* mode and the VN-310 will operate as an AHRS if the AHRS aiding feature is enabled in the INS Basic Configuration register (Register 67). Unfortunately, the position and velocity will not be available until a valid GNSS fix has been reacquired. During this time that the filter is operating as an AHRS, the attitude is estimated predominantly from the onboard magnetometer and accelerometer. While seemingly straightforward, obtaining accurate attitude from an AHRS can prove to be quite challenging. In many real-world applications, the magnetometer is often measuring magnetic disturbances created by nearby objects in addition to Earth's magnetic field, leading to errors in the estimated magnetic-based heading. In addition, sustained dynamic accelerations can cause degraded pitch and roll estimates if this acceleration due to motion is not accounted for.

#### Mitigation

Applications requiring a precise navigation solution when operating in GNSS-challenged or GNSS-denied environments can increase the performance of the VN-310 through its extended capabilities.Pairing an external GNSS receiver utilizing anti-jamming or anti-spoofing capabilities, such as a SAASM or M-code receiver, with the VN-310 can allow the sensor to continue to receive GNSS measurements in GNSS-challenged conditions. Additionally, incorporating an external IMU with higher-end inertial technology into the VN-310 can help increase the performance of the navigation solution during GNSS-denied operation. For more information on interfacing the VN-310 with an external IMU or an external GNSS receiver, reach out to VectorNav Support.

In such cases that a loss of GNSS is experienced, it is recommended that the velocity aiding feature be used, particularly if the sensor will be subjected to sustained linear accelerations and an accurate attitude is required. Additionally, a hard and soft iron (HSI) calibration should be performed on the sensor to account for the magnetic signature of the platform that the VN-310 is rigidly attached to. Additional details on the velocity aiding feature can be found in TN005: Velocity Aiding. More information on performing an HSI calibration on the VN-310 can be found in TN002: Hard & Soft Iron (HSI) Calibration.

### 4.7.2 Troubleshooting

If any issues are encountered during the setup, initialization, or operation of the VN-310, some additional troubleshooting may be required. Below are a few of the most commonly encountered issues when using the VN-310. If the behavior persists after reviewing these troubleshooting tips, please reach out to VectorNav Support for additional assistance.

#### GNSS Compass Issues

There are three common issues typically encountered while using the sensor: no GNSS compass fix, slow GNSS compass startup, and failure to transition to *Tracking* mode. These issues are usually caused by the same setup problems, so if any of these issues arise it is recommended to:

- Check for clear sky visibility and be sure there are no obstructions blocking the antennas — move away from buildings, large structures, and terrain.
- Ensure ground planes are installed beneath the antennas.
- Monitor the number of common RTK satellites in the GNSS Compass Signal Health Status register (Register 86)— a minimum of 6 common satellites are required for the GNSS compass to operate.
- Check the GNSS compass baseline measurements are correctly configured in Register 93 — be sure to check that both the measurement values are correct and the correct axes are used. Additionally, ensure that the uncertainty values used in Register 93 are scaled to 2.5% of the largest baseline measurement.
- Monitor the startup progress of the GNSS compass in the GNSS Compass Startup Status register (Register 98).
- Check for potential sources of interference near the GPS frequency of 1575 MHz.

#### Heading Drift While Stationary

If the sensor is in *Tracking* mode in the *InsStatus* output, indicating that the attitude is valid, but the heading output is drifting while the sensor is stationary, this can indicate the antennas are operating in poor GNSS conditions. To troubleshoot this behavior:

- Check that the GNSS antennas have a clear view of the sky.

- Ensure ground planes are placed directly beneath each of the antennas.
- Ensure the antennas are in an open area away from anything that could cause multipath interference, including large structures and terrain.
- Check for improper GNSS compass baseline measurements configured in Register 93 — be sure to check the measurements are correct and the uncertainty values are scaled to 2.5% of the largest baseline measurement.
- Ensure that the antennas are mounted as flat and level as possible.
- Be sure there are no potential sources of interference near the GPS frequency of 1575 MHz.

### Drops Out of Tracking Mode After Motion

If the sensor is in *Tracking* mode in the *InsStatus* output when stationary, but drops into *Aligning* mode after the platform begins moving, this indicates that there is a mismatch between the GNSS compass and dynamic alignment heading solutions. It is recommended to:

- Ensure that the GnssA and GnssB antennas are connected to the correct ports on the sensor.
- Check that the GNSS Internal A Antenna offset is correctly configured in Register 57.
- If a reference frame rotation is configured on the sensor in Register 26, ensure it has been correctly applied.

### Heading Solution Off 180°

This indicates that the GNSS compass baseline configuration settings do not match the actual installation. Ensure the GnssA and GnssB antennas are not switched compared to the GNSS compass baseline inputs in Register 93.

### User-Configured Settings Erased After Power Cycle or Reset

In order for the user-configured settings to be saved to the non-volatile memory of the VN-310 and persist through a reset or power cycle of the sensor, a Write Settings command must be sent to the sensor after all desired settings have been configured.

# A ADDITIONAL RESOURCES

## A.1 OPTIONAL CONFIGURATION

While the following register settings are typically not needed during nominal operation of the VN-310, there may be instances in which their use is required. For help in determining whether the following settings should be modified in a particular application, please reach out to the VectorNav Support team for additional assistance.

### A.1.1 Hard and Soft Iron Calibration

A hard and soft iron (HSI) calibration is typically not required for the VN-310 if the GNSS compass is active, but should be performed for robustness if GNSS outages are expected, during which the magnetometer must be relied upon for heading. Using a magnetometer to accurately estimate the heading can prove to be quite challenging as Earth's magnetic field is relatively weak and there often exist magnetic fields created by objects near the VN-310, known as magnetic disturbances. These magnetic disturbances bias and distort Earth's background magnetic field leading to errors in the estimated heading. An HSI calibration can be used to account for any time-invariant magnetic disturbances that are rigidly attached to the VN-310. More information on performing an HSI calibration on the VN-310 can be found in TN002: Hard & Soft Iron (HSI) Calibration.

### A.1.2 Configuring the VPE Heading Mode

As part of its collection of algorithms, the Vector Processing Engine (VPE) includes three distinct heading modes known as Absolute Mode, Relative Mode, and Indoor Mode. These heading modes control how the magnetic measurements are interpreted in the magnetic-based heading estimation and were designed as a way to handle any external magnetic disturbances the sensor may encounter in its environment. More details on how each heading mode handles magnetic disturbances as well as the recommended use case for each mode can be found in Section 3.4.6. The desired heading mode can be configured on the VN-310 using the *HeadingMode* field in the VPE Basic Control register (Register 35).

> Configuration of the heading mode is generally not required on the VN-310 if the GNSS Compass is active, though the desired heading mode can be set using the *HeadingMode* field in the VPE Basic Control register (Register 35) for robustness if GNSS outages are expected.

> The heading modes are not intended to account for any internal magnetic disturbances, which are characterized as magnetic disturbances that are rigidly mounted to the VN-310. To account for any internal magnetic disturbances, an HSI calibration should be performed on the VN-310 as discussed in Section A.1.1.

### A.1.3 Configuring the VPE Adaptive Tuning & Filtering

The Vector Processing Engine (VPE) provides the ability to adaptively tune and filter the accelerometer and magnetometer measurements prior to entering the onboard Kalman filters allowing for improved performance in the presence of vibration, short-term accelerations, and some forms of magnetic disturbances. The amount of tuning and filtering applied to these measurements can be adjusted in the VPE Magnetometer Basic Tuning register (Register 36) and the VPE Accelerometer Basic Tuning register (Register 38). The *BaseTuning* fields within these registers control how much trust the filter will place in the magnetometer and accelerometer readings when estimating the attitude. The *AdaptiveTuning* and *AdaptiveFiltering* fields adjust the amount of adaptive tuning and adaptive filtering employed by the VPE algorithms. More information on these adaptive tuning and filtering settings can be found in Section 3.4.5.

In a majority of applications, the VN-310 can be used with the default tuning and filtering values for best performance. If desired, the *BaseTuning* fields can be adjusted by the user to control how much trust is placed in the magnetometer and accelerometer, though generally modifying the *AdaptiveTuning* and *AdaptiveFiltering* fields is not recommended.

### A.1.4 Applying the Declination Angle

By default, the VN-310 references its magnetic-based heading to Magnetic North at startup. To instead reference the magnetic-based heading to True North at startup, the declination angle ($\delta$) can be applied through either the Magnetic and Gravity Reference Vectors register (Register 21) or the Reference Model Configuration register (Register 83).

The Magnetic and Gravity Reference Vectors register (Register 21) allows the user to manually apply the magnetic reference vector onto the sensor. By default, this register is set to a 0° declination angle, meaning the yaw angle will be referenced to Magnetic North. The local magnetic reference vector can be obtained directly from the World Magnetic Model or calculated from the declination angle using the following:

$$MagRefX = cos(\delta) \tag{A.1}$$

$$MagRefY = sin(\delta) \tag{A.2}$$

These parameters should then be configured into the corresponding fields in Register 21. Once configured, the onboard filter will use this local magnetic reference vector to account for the declination angle in the magnetic-based heading.

The Reference Model Configuration register (Register 83) can alternatively be used to apply the declination angle by enabling the onboard World Magnetic Model (WMM). To utilize the WMM, the *EnableMagModel* field should be set to $1$ and the current location of the sensor and decimal year must be input into the *Year*, *Latitude*, *Longitude*, and *Altitude* fields. Once configured, this register will apply the local magnetic reference vector and declination angle, improving the accuracy of the heading. If the WMM is disabled by setting the *EnableMagModel* to $0$, the user-configured reference vector in the Magnetic and Gravity Reference Vectors register (Register 21) will be used instead.

The VN-310 automatically applies the WMM after acquiring a GNSS fix, so no additional configuration to this register is needed by the user unless the magnetic-based heading referenced to True North is needed prior to acquiring a GNSS fix.

The WMM onboard the VN-310 can be updated every five years similarly to a firmware update. To obtain the latest WMM for your sensor, please reach out to the VectorNav Support team.

This page intentionally left blank.

This page intentionally left blank.

This page intentionally left blank.

VectorNav Technologies, LLC
10501 Markison Rd
Dallas, TX 75238, USA

Tel: +1.512.772.3615
Email: sales@vectornav.com
Web: vectornav.com


Version 10-3100-R2