Embedded Navigation Solutions

VN-200 User Manual

Firmware v1.0.0.0

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VectorNav Technologies
10501 Markison Road
Dallas, Texas 75238
United States of America

Contact Info
Phone +1 512 772 3615
Email support@vectornav.com
Website www.vectornav.com

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VectorNav Technical Documentation

In addition to our product-specific technical data sheets, the following manuals are available to assist VectorNav customers in product design and development.

- **VN-200 User Manual:** The user manual provides a high-level overview of product specific information for each of our inertial sensors. Further detailed information regarding hardware integration and application specific use can be found in the separate documentation listed below.
- **Hardware Integration Manual:** This manual provides hardware design instructions and recommendations on how to integrate our inertial sensors into your product.
- **Application Notes:** This set of documents provides a more detailed overview of how to utilize many different features and capabilities offered by our products, designed to enhance performance and usability in a wide range of application-specific scenarios.

Document Symbols

The following symbols are used to highlight important information within the manual:

The information symbol points to important information within the manual.

The warning symbol points to crucial information or actions that should be followed to avoid reduced performance or damage to the navigation module.

Technical Support

Our website provides a large repository of technical information regarding our navigation sensors. A list of the available documents can be found at the following address:

http://www.vectornav.com/support

If you have technical problems or cannot find the information that you need in the provided documents, please contact our support team by email or phone. Our engineering team is committed to providing the required support necessary to ensure that you are successful with the design, integration, and operation of our embedded navigation sensors.

Technical Support Contact Info

Email: support@vectornav.com **Phone:** +1.512.772.3615

Table of Contents

1 Introduction

1.1 Product Description

The VN-200 is a miniature, surface-mount, high-performance GPS-Aided Inertial Navigation System (GPS/INS). Incorporating the latest solid-state MEMS sensor technology, the VN-200 combines a set of 3-axis accelerometers, 3-axis gyros, 3-axis magnetometer, a barometric pressure sensor, a 50-channel L1 GPS receiver, as well as a 32-bit processor into a miniature surface-mount module. The VN-200 couples measurements from the onboard GPS module with measurements from the onboard inertial sensors to provide position, velocity, and attitude estimates of higher accuracies and with better dynamic performance than a standalone GPS module or Attitude Heading Reference System (AHRS).

1.2 Factory Calibration

MEMS inertial sensors are subject to several common sources of error: bias, scale factor, misalignments, temperature dependencies, and gyro g-sensitivity. All VN-200 sensors undergo a rigorous calibration process at the VectorNav factory to minimize these error sources. Compensation parameters calculated during these calibrations are stored on each individual sensor and digitally applied to the real-time measurements. VN-200 sensors are available with two calibration options:

- Standard Calibration – single temperature point calibration at 25C, which typically holds performance specifications when operating in an environment with a range of 15C to 35C.
- Thermal Calibration – this option extends the calibration process over multiple temperatures to ensure performance specifications are met over the full operating temperature range of -40C to +85C.

1.3 Operation Overview

The VN-200 has a built-in microprocessor that runs a robust INS Kalman Filter that estimates the position, velocity, and attitude of the sensor. The VN-200 INS filter couples position and velocity measurements from the onboard GPS module with inertial sensor measurements from the onboard accelerometers, gyroscopes, magnetometers, as well as the barometric pressure sensor. 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-200 is in motion, the VN-200 INS filter determines the attitude by comparing the position and velocity measurements to the onboard accelerometer measurements, and the magnetometer measurements are ignored by the INS filter. Compared to an AHRS, the heading accuracy is improved since the INS filter does not rely on measurements of Earth's background magnetic field and magnetic disturbances no not have an effect on the attitude solution. In addition, the VN-200 pitch and roll estimates are robust to induced accelerations caused by dynamic motion of the sensor. Under static conditions, the heading angle is no longer observable and the VN-200 INS filter reverts back to relying on magnetometer measurements operating in an AHRS mode. The VN-200 includes a feature that automatically transitions between INS and AHRS modes depending on the motion of the sensor and GPS availability in order to provide optimal performance under both static and dynamic conditions.

Outputs from the VN-200 include:

- Position Estimates in the following reference frames:
  - Latitude, Longitude, and Altitude
  - X, Y, Z position in Earth Centered Earth Fixed frame
  - X, Y, Z position in North, East, Down frame
- Velocity Estimates in the following reference frames:
  - X, Y, Z velocities in Earth Centered Earth Fixed frame
  - X, Y, Z velocities in the North, East, Down frame
- Attitude Estimates:
  - Yaw, Pitch, Roll
  - Quaternions
  - Rotation Matrix
- INS Filter Uncertainties
  - Position, Velocity, & Attitude
- GPS Time
  - GPS Time of Week
  - UTC Time
- Angular Rate Measurements:
  - Bias compensated angular rates
  - Calibrated gyro measurements
- Acceleration Measurements:
  - Bias compensated acceleration
  - Calibrated acceleration measurements
  - Gravity vector
- Magnetic Measurements
- Pressure Measurements / Altitude

1.4 Packaging Options

The VN-200 is available in two different configurations; a 30-pin surface mount package (VN-200 SMD) and an aluminum encased module (VN-200 Rugged). The VN-200 surface mount package is well suited for customers looking to integrate the VN-200 sensor at the electronics level while the VN-200 Rugged provides a precision enclosure with mounting tabs and alignment holes for a more off-the-shelf solution.

1.4.1 Surface-Mount Package

For embedded applications, the VN-200 is available in a miniature surface-mount package.

Features

- Small Size: 22 x 24 x 3 mm
- Single Power Supply: 3.2 to 5.5 V
- Communication Interface: Serial TTL & SPI
- Low Power Requirement: < 105 mA @ 3.3V

1.4.2 Rugged Package

The VN-200 Rugged consists of the VN-200 sensor installed and calibrated in a robust precision aluminum enclosure.

Features

- Precision aluminum enclosure
- Locking 10-pin connector
- Mounting tabs with alignment holes
- Compact Size: 36 x 33 x 9.5 mm
- Single Power Supply: 3.3 to 17 V
- Communication Interface: Serial RS-232 & TTL

1.4.3 Surface Mount Development Kit

The VN-200 Development Kit provides the VN-200 surface-mount sensor installed onto a small PCB, providing easy access to all of the features and pins on the VN-200. Communication with the VN-200 is provided by USB and RS-232 serial communication ports. A 30-pin header provides easy access to each of the critical pins. The VN-200 Development Kit also includes all of the necessary cabling, documentation, and support software.

Features

- Pre-installed VN-200 Sensor
- Onboard USB->Serial converter
- Onboard TTL->RS-232 converter
- 30-pin 0.1” header for access to VN-200 pins
- Power supply jack – 5V (Can be powered from USB)
- Board Size: 76 x 76 x 14 mm

1.4.4 VN-200 Rugged GPS/INS Development Kit

The VN-200 Rugged Development Kit includes the VN-200 Rugged sensor along with all of the necessary cabling required for operation. Two cables are provided in each Development Kit: one for RS-232 communication and a second custom cable with a built in USB converter. The Development Kit also includes all of the relevant documentation and support software.

Features

- VN-200 Rugged Sensor
- 10 ft RS-232 cable
- 6 ft USB connector cable
- 16 ft Magnetic Mount GPS Antenna
- MCX to SMA Antenna Adapter
- Cable Connection Tool
- CD w/Software Development Kit
- User Manual, Quick Start Guide & Documentation
- Carrying Case

1.5 VN-200 Product Codes

VN-200 Options			
Item Code	**Sensor Packaging**	**Calibration Option**	**Product Type**
VN-200S	Surface Mount Device	Standard at 25C	GPS/INS
VN-200T	Surface Mount Device	Thermal -40C to +85C	GPS/INS
VN-200S-DEV	Surface Mount Development Kit	Standard at 25C	GPS/INS
VN-200T-DEV	Surface Mount Development Kit	Thermal -40C to +85C	GPS/INS
VN-200S-CR	Rugged Module	Standard at 25C	GPS/INS
VN-200T-CR	Rugged Module	Thermal -40C to +85C	GPS/INS
VN-200S-CR-DEV	Rugged Development Kit	Standard at 25C	GPS/INS
VN-200T-CR-DEV	Rugged Development Kit	Thermal -40C to +85C	GPS/INS
VN-C200-0310	VN-200 Rugged USB Adapter Cable	N/A	Cable
VN-C200-0410	VN-200 Rugged Serial Adapter Cable	N/A	Cable

2 Specifications

2.1 VN-200 Surface-Mount Sensor (SMD) Electrical

Figure 1 – Pin assignments (top down view)

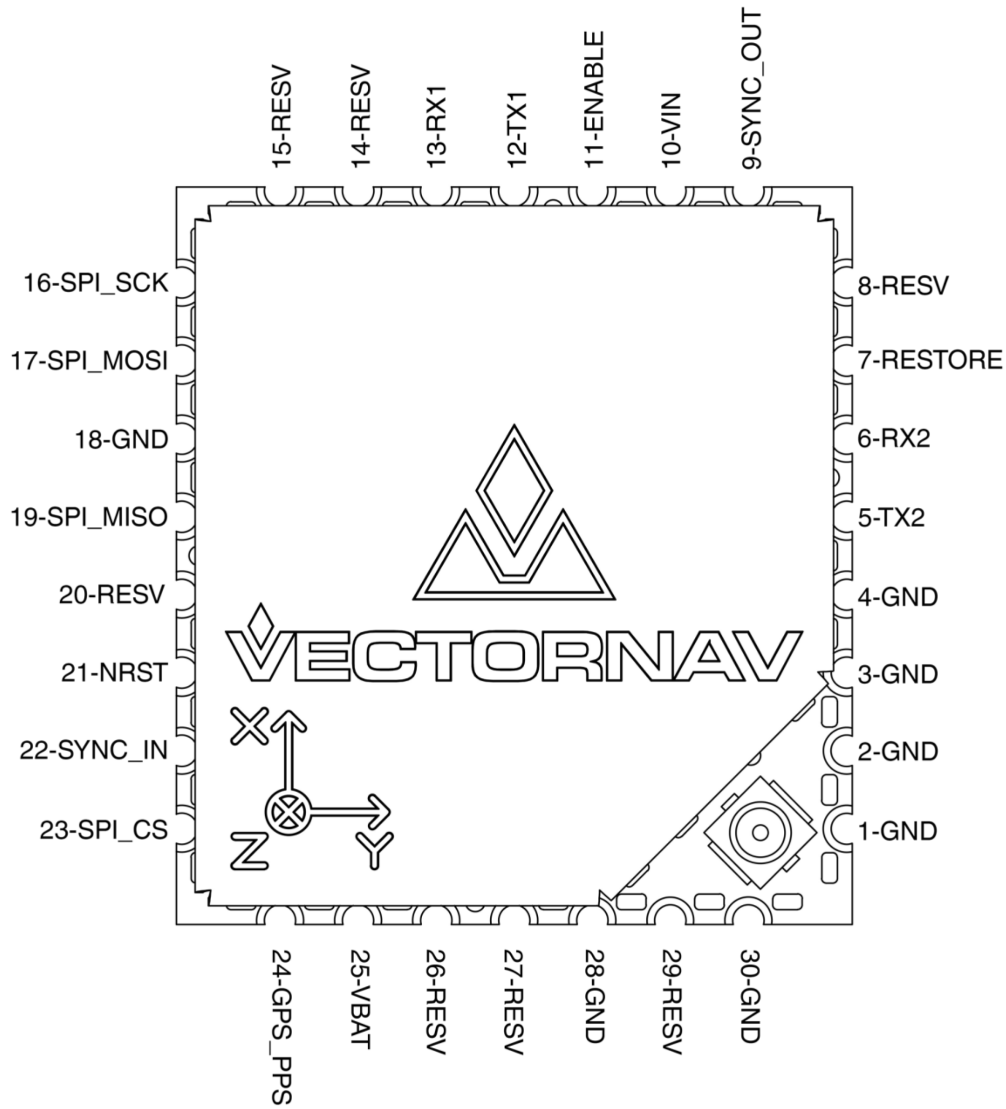


Table 1 – VN-200 SMD Pin Assignments

Pin	Pin Name	Type	Description
1	GND	Supply	Ground.
2	GND	Supply	Ground.
3	GND	Supply	Ground.
4	GND	Supply	Ground.
5	TX2	Output	Serial UART #2 data output. (sensor)
6	RX2	Input	Serial UART #2 data input. (sensor)
7	RESTORE	Input	During power on or device reset, holding this pin high will cause the module to restore the default factory settings. Internally held low with 10k resistor.
8	RESV	N/A	Reserved for internal use. Do not connect.
9	SYNC_OUT	Output	Time synchronization output signal.
10	VIN	Supply	3.2 - 5.5 V input.
11	ENABLE	Input	Leave high for normal operation. Pull low to enter sleep mode. Internally pulled high with pull-up resistor.
12	TX1	Output	Serial UART #1 data output. (sensor)
13	RX1	Input	Serial UART #1 data input. (sensor)
14	RESV	N/A	Reserved for internal use. Do not connect.
15	RESV	N/A	Reserved for internal use. Do not connect.
16	SPI_SCK	Input	SPI clock.
17	SPI_MOSI	Input	SPI input.
18	GND	Supply	Ground.
19	SPI_MISO	Output	SPI output.
20	RESV	N/A	Reserved for internal use. Do not connect.
21	NRST	Input	Microcontroller reset line. Pull low for > 20 μs to reset MCU. Internally pulled high with 10k.
22	SYNC_IN	Input	Time synchronization input signal.
23	SPI_CS	Input	SPI slave select.
24	GPS_PPS	Input	GPS time pulse. One pulse per second, synchronized on rising edge. Pulse width is 100 ms.
25	VBAT	Supply	Optional GPS RTC battery backup. 1.4 V – 3.6 V input.
26	RESV	N/A	Reserved for internal use. Do not connect.
27	RESV	N/A	Reserved for internal use. Do not connect.
28	GND	Supply	Ground.
29	RESV	N/A	Reserved for internal use. Do not connect.
30	GND	Supply	Ground.

2.1.1 VN-200 SMD Power Supply

The minimum operating supply voltage is 3.2 V and the absolute maximum is 5.5 V.

2.1.2 VN-200 SMD Serial (UART) Interface

The serial interface on the VN-200 operates with 3V TTL logic.

Table 2 - Serial I/O Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5 V		0.8 V
Input high level voltage	2 V		5.5 V
Output low voltage	0 V		0.4 V
Output high voltage	2.4 V		3.0 V

2.1.3 VN-200 SMD Serial Peripheral Interface (SPI)

Table 3 - Serial I/O Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5 V		0.8 V
Input high level voltage	2 V		5.5 V
Output low voltage	0 V		0.4 V
Output high voltage	2.4 V		3.0 V
Clock Frequency		8 MHz	16 MHz
Close Rise/Fall Time			8 ns

2.1.4 VN-200 SMD Reset, SyncIn/Out, and Other General I/O Pins

Table 4 - NRST Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5 V		0.8 V
Input high level voltage	2 V		5.5 V
Weak pull-up equivalent resistor	30 kΩ	40 kΩ	50 kΩ
NRST pulse width	20 µs		

Table 5 - SyncIn Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5 V		0.8 V
Input high level voltage	2 V		5.5 V
Pulse Width	100 ns		

Table 6 - SyncOut Specifications

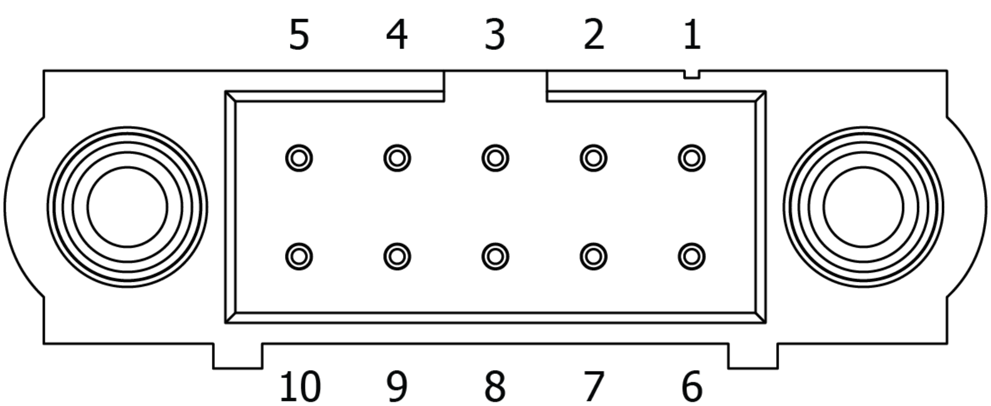
Specification	Min	Typical	Max
Output low voltage	0 V		0.4 V
Output high voltage	2.4 V		3.0 V
Output high to low fall time			125 ns
Output low to high rise time			125 ns
Output Frequency	1 Hz		1 kHz

2.2 VN-200 Rugged Electrical

Table 7 – VN-200 Rugged Pin Assignments

Pin	Pin Name	Description
1	VCC	+3.3V to +17V
2	TX1	RS-232 voltage levels data output from the sensor. (Serial UART #1)
3	RX1	RS-232 voltage levels data input to the sensor. (Serial UART #1)
4	SYNC_OUT	Output signal used for synchronization purposes. Software configurable to pulse when ADC, IMU, or attitude measurements are available.
5	GND	Ground
6	RESTORE	If high at reset, the device will restore to factory default state. Internally held low with 10k resistor.
7	SYNC_IN	Input signal for synchronization purposes. Software configurable to either synchronize the measurements or the output with an external device.
8	TX2_TTL	Serial UART #2 data output from the device at TTL voltage level (3V).
9	RX2_TTL	Serial UART #2 data into the device at TTL voltage level (3V).
10	RESV	This pin should be left unconnected.

Figure 2 - VN-200 Rugged External Connector



2.2.1 VN-200 Rugged Power Supply

The power supply input for the VN-200 Rugged is 3.3 to 17 V DC.

2.2.2 VN-200 Rugged Serial UART Interface

Table 8 - Serial I/O Specifications

Specification	Min	Typical	Max
Input low level voltage	-25 V		
Input high level voltage			25 V
Output low voltage	-5.0 V	-5.4 V	
Output high voltage	5.0 V	5.5 V	
Output resistance	300 Ω	10 MΩ	
Data rate			1 Mbps
Pulse slew		300 ns	

2.2.3 VN-200 Rugged Reset, SyncIn/Out, and Other General I/O Pins

Table 9 - NRST Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5 V		0.8 V
Input high level voltage	2 V		5.5 V
Weak pull-up equivalent resistor	30 kΩ	40 kΩ	50 kΩ
NRST pulse width	20 µs		

Table 10 - SyncIn Specifications

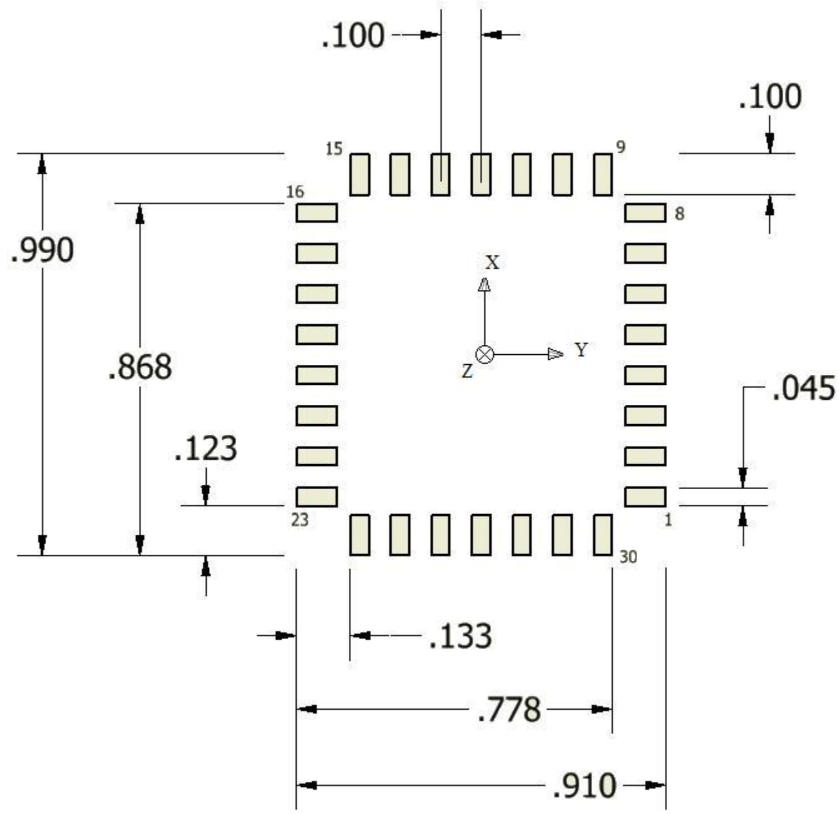
Specification	Min	Typical	Max
Input low level voltage	-0.5V		0.8V
Input high level voltage	2V		5.5V
Pulse Width	100 ns		

Table 11 - SyncOut Specifications

Specification	Min	Typical	Max
Output low voltage	0 V		0.4 V
Output high voltage	2.4 V		3.0 V
Output high to low fall time			125 ns
Output low to high rise time			125 ns
Output Frequency	1 Hz		1 kHz

2.3 VN-200 Surface-Mount Sensor (SMD) Dimensions

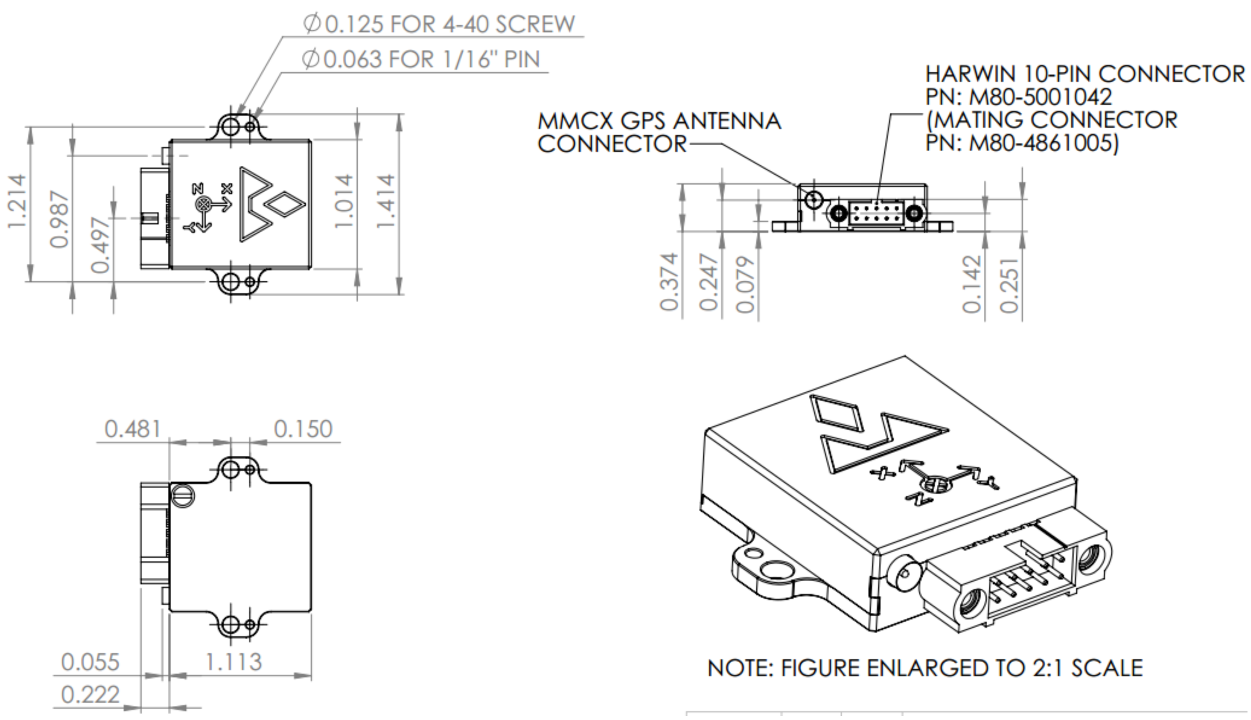
Figure 3 – VN-200 PCB Footprint*



* Measurements are in inches

2.4 VN-200 Rugged Dimensions

Figure 4 - VN-200 Rugged Dimensions



* Measurements are in inches

2.4.1 Rugged Connector Type

The main connector used on the VN-200 Rugged is a 10-pin Harwin M80-5001042. The mating connector used on the cable assemblies provided by VectorNav for use with the VN-200 Rugged is a Harwin M80-4861005. The RF connector used on the VN-200 Rugged is a female MMCX jack.

2.5 Absolute Maximum Ratings

Table 12 – SMD Absolute Maximum Ratings

Specification	Min	Max
Input Voltage	-0.3 V	5.5 V
Operating Temperature	-40 C	85 C
Storage Temperature	-40 C	85 C

Table 13 – Rugged Absolute Maximum Ratings

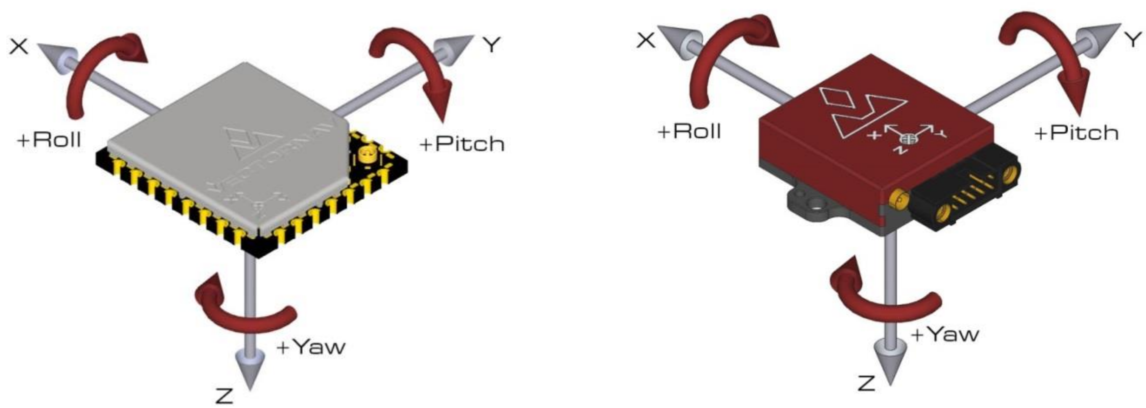
Specification	Min	Max
Input Voltage	-0.3 V	17 V
Operating Temperature	-40 C	85 C
Storage Temperature	-40 C	85 C

2.6 Sensor Coordinate System

2.6.1 Sensor Coordinate Frame

The VN-200 uses a right-handed coordinate system. 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 axes direction with respect to the VN-200 module is shown in Figure 5.

Figure 5 - VN-200 Coordinate System

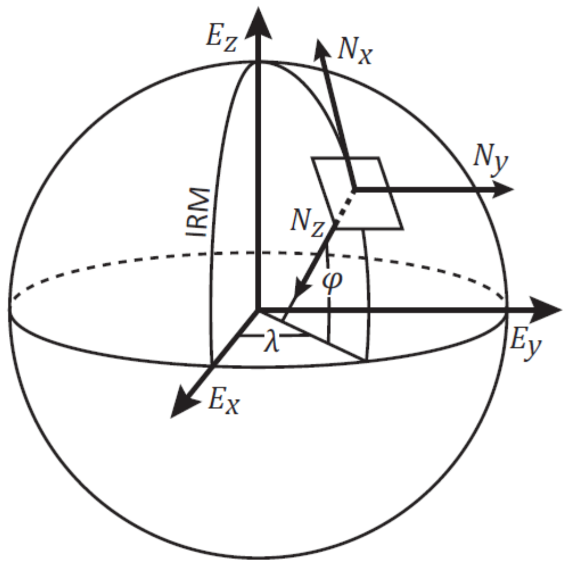


2.6.2 Earth Centered Earth Fixed Frame

The VN-200 position and velocity estimates can be output in the Earth-Centered-Earth-Fixed (ECEF) Frame defined as follows ($\mathbf{E_X}$, $\mathbf{E_Y}$, $\mathbf{E_Z}$):

- Right-handed, Cartesian, non-inertial frame with origin located at the center of Earth;
- Fixed to and rotates with Earth;
- Positive X-axis aligns with the WGS84 X-axis, which aligns with the International Earth Rotation and Reference Systems Service (IERS) Reference Meridian (IRM);
- Positive Z-axis aligns with the WGS84 Z-axis, which aligns with the IERS Reference Pole (IRP) that points towards the North Pole;
- Positive Y-axis aligns with the WGS84 Y-axis, completing the right-handed system.

Figure 6 - ECEF Frame



2.6.3 Latitude, Longitude, Altitude

The VN-200 position estimates can be output in Latitude, Longitude, Altitude coordinates defined as follows (**φ, λ, h**):

- Non-inertial, geodetic frame with origin located at the surface of Earth (WGS84 ellipsoid);
- Latitude is defined as the angle from the equatorial plane to a line normal to the surface of the WGS84 ellipsoid at the location of the VN-200;
- Longitude is defined as the east-west angular displacement measured positive to the east from the IERS Reference Meridian to the location of the VN-200;

Altitude is defined as the distance from the WGS84 ellipsoid to the location of the VN-200 in a direction normal to the ellipsoid.

2.6.4 North-East-Down Frame

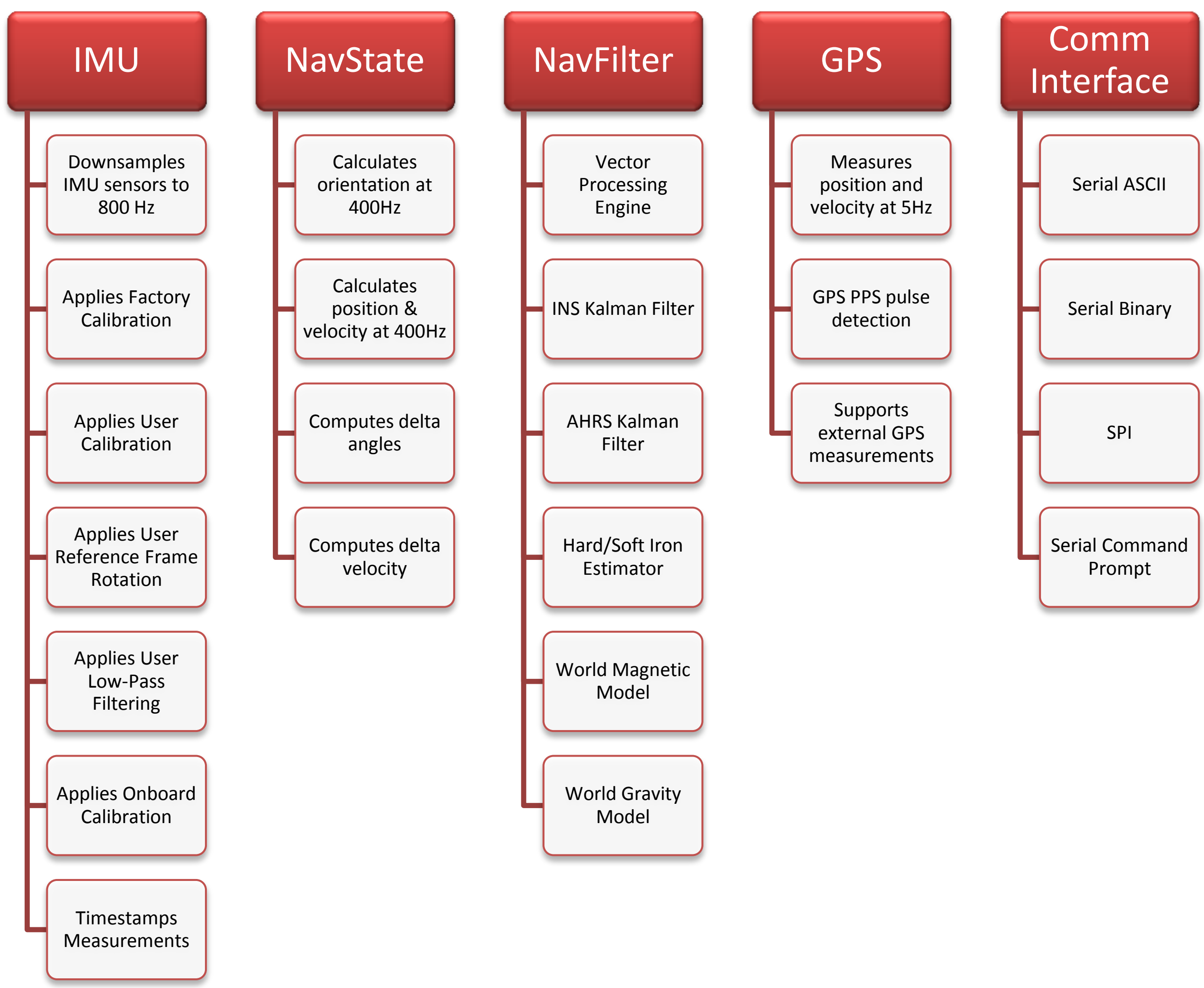
The VN-200 velocity estimates can be output in the North-East-Down (NED) coordinate frame defined as follows ($\mathbf{N_X, N_Y, N_Z}$):

- Right-handed, Cartesian, non-inertial, geodetic frame with origin located at the surface of Earth (WGS84 ellipsoid);
- Positive X-axis points towards North, tangent to WGS84 ellipsoid;
- Positive Y-axis points towards East, tangent to WGS84 ellipsoid;
- Positive Z-axis points down into the ground completing the right-handed system.

3 VN-200 Software Architecture

The software architecture internal to the VN-200 includes five separate subsystems. These subsystems are the IMU, the NavState, the NavFilter, the GPS, and the Communication Interface. The high-level functions performed by these subsystems are outlined below. This chapter describes these functions performed by these subsystems in more detail and describes which of the various measurement outputs originate from each of these corresponding subsystems.

Figure 7 - VN-200 Software Architecture

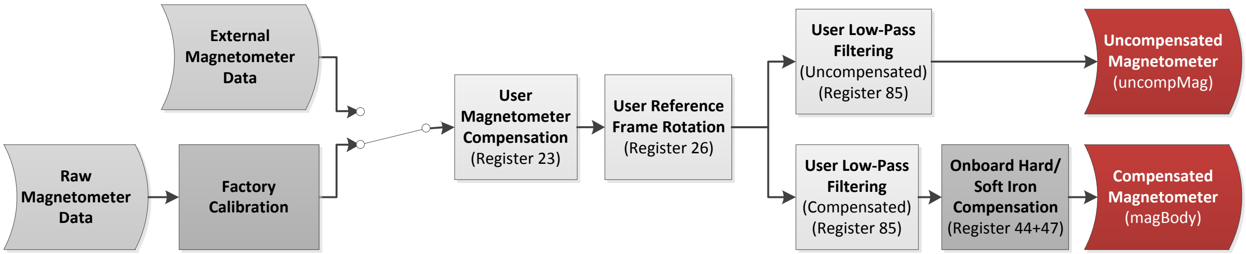


3.1 IMU Subsystem

The IMU subsystem runs at the highest system rate, described from this point forward as the IMU Rate (defaults to 800Hz). It is responsible for collecting the raw IMU measurements, applying a static, user, and dynamic calibration to these measurements, and optionally filtering the individual sensor measurements for output. The coning and sculling integrals also are calculated by the IMU subsystem at the full IMU Rate. The IMU subsystem is also responsible for time stamping the IMU measurements to internal system time, and relative to both the SyncIn and the GPS PPS signal.

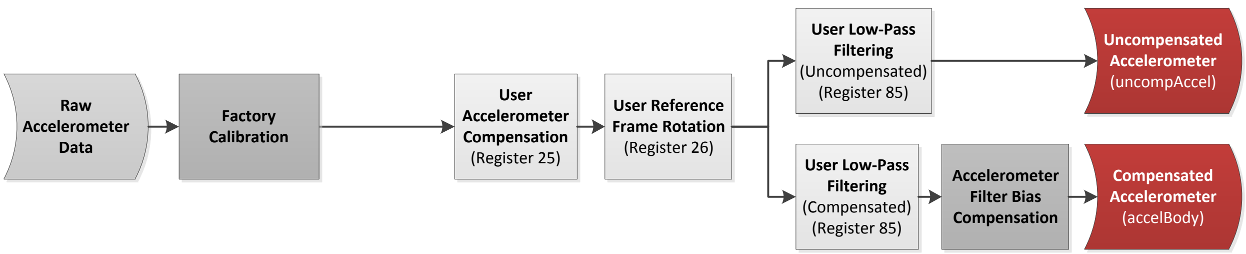
3.1.1 Magnetometer

Figure 8 - Magnetometer IMU Measurements



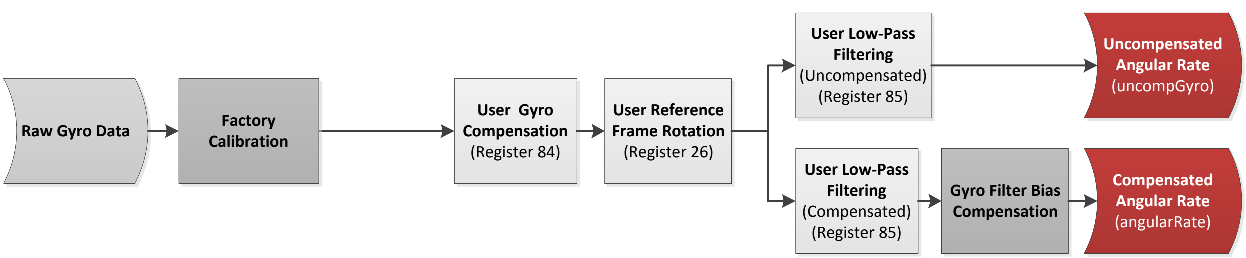
3.1.2 Accelerometer

Figure 9 - Accelerometer IMU Measurements



3.1.3 Gyro

Figure 10 - Gyro IMU Measurements



3.1.4 Raw IMU Measurements

The raw IMU measurements are collected from the internal MEMS at the highest rate available for each individual sensor. For the gyro and accelerometer, the measurements are down-sampled to the IMU Rate.

3.1.5 Factory Calibration

Each VN-200 sensor is tested at the factory at multiple known angular rates, accelerations, and magnetic field strengths to determine each sensor's unique bias, scale factor, axis alignment, and temperature dependence. The calibration coefficients required to remove these unwanted errors are permanently stored in flash memory on each sensor. At the IMU Rate, these calibration coefficients are applied to the raw IMU measurements, to correct for and remove these known measurement errors. For thermally calibrated units the onboard temperature sensor is used to remove the measurement temperature dependence. The output of the factory calibration stage is referred to as the calibrated (but un-compensated) IMU measurements.

3.1.6 User Calibration

The VN-200 provides the user with the ability to apply a separate user calibration to remove additional bias, scale factor, and axis misalignments. The user calibration is applied after the factory calibration, and can be used to optionally fine tune the calibration for each of the individual sensors. The user calibration is optional and in most cases not required for normal operation.

3.1.7 User Reference Frame Rotation

The user reference frame rotation provides the user with the ability to apply a rigid body rotation to each of the sensor outputs. This can be used to transform the coordinate system of the onboard sensors into any other coordinate frame of the user's choice. Since this transformation is applied to the IMU measurements prior to their use in the onboard attitude estimation algorithms, applying a user reference frame rotation will not only change the output coordinates for the IMU measurements, it will also change the IMU body frame for all subsequent attitude estimation calculations.

3.1.8 User Low-Pass Filtering

The VN-200 also provides a means (see Register 85) to apply low-pass filtering to the output compensated IMU measurements. It is important to note that the user low-pass filtering only applies to the output compensated IMU measurements. All onboard Kalman filters in the NavFilter subsystem always use the unfiltered IMU measurements after the User Reference Frame Rotation (Register 26) has been applied. As such the onboard Kalman filtering will not be affected by the user low-pass filter settings. The user low-pass filtering can be used to down-sample the output IMU measurements to ensure that information is not lost when the IMU measurements are sampled by the user at a lower rate than the internal IMU Rate.

3.1.9 Timestamp Measurements

All onboard measurements captured by the IMU subsystem are time stamped relative to several internal timing events. These events include the monotonically increasing system time (time since startup), the time since the last SyncIn event, and the time since the last GPS PPS pulse. These timestamps are recorded with microsecond resolution and ~10 microsecond accuracy relative to the onboard temperature compensated crystal oscillator. The onboard oscillator has a timing accuracy of ~20ppm over the temperature range of -40C to 80C.

3.1.10 Coning & Sculling

The IMU subsystem is also responsible for computing and accumulating the coning and sculling integrals. These integrals track the delta angle and delta velocity accumulated from one time step to another. The coning and sculling integrals are reset each time the delta angle and/or delta velocity are outputted (asynchronously) or polled from the delta theta and velocity register (Register 80). Between output and polling events, the coning and sculling integration are performed by the IMU subsystem at the IMU Rate.

3.2 NavState Subsystem

The NavState subsystem generates a continuous reliable stream of low-latency, low-jitter state outputs at a rate fixed to the IMU sample rate. The state outputs include any output such as attitude, position, and velocity, which is not directly measureable by the IMU and hence must be estimated by the onboard Kalman filters. The NavState runs immediately after, and in sync with the IMU subsystem, at a rate divisible into the IMU Rate. This rate is referred to as the NavState Rate (default 400Hz). The NavState decouples the rate at which the state outputs are made available to the user, from the rate at which they are being estimated by the onboard Kalman filters. This is very important for many applications which depend on low-latency, low-jitter attitude, position, and velocity measurements as inputs to their control loops. The NavState guarantees the output of new updated state information at a rate fixed to the IMU Rate with very low latency and output jitter. The NavState also provides the ability for the VN-200 to output estimated states at rates faster than the rate of the onboard Kalman filters, which may be affected by system load and input measurements availability.

3.2.1 NavState Measurements

The measurements shown below are calculated by the NavState subsystem and are made available at the NavState Rate (default 400 Hz).

NavState Outputs
Attitude (Yaw, Pitch, Roll, Quaternion, DCM)
Position (LLA, ECEF)
Velocity (NED, ECEF, Body)
Delta Angle
Delta Velocity

3.3 NavFilter Subsystem

The NavFilter subsystem consists of the INS Kalman filter, the Vector Processing Engine (VPE), and its collection of other Kalman filters and calculations that run at a lower rates than the NavState. Most high level states such as the estimated attitude, position, and velocity are passed from the NavFilter to the NavState, and as such are made available to the user at the NavState rate. There are a handful of outputs however that will only update at the rate of the NavFilter, some of which are listed below.

NavFilter Outputs
Attitude Uncertainty
Position & Velocity Uncertainty
Gyro & Accel Filter Biases
Mag & Accel Disturbance Estimation
Onboard Magnetic Hard & Soft Iron Estimation
World Magnetic & Gravity Model

3.3.1 INS Kalman Filter

The INS Kalman filter consists of an Extended Kalman filter which nominally runs at the NavFilter rate (default 200 Hz). The INS Kalman filter uses the accelerometer, gyro, GPS, and (at startup) the magnetometer to simultaneously estimate the full quaternion based attitude solution, the position and velocity, as well as the time varying gyro, accelerometer, and barometric pressure sensor biases. The output of the INS Kalman filter is passed to the NavState, allowing for the attitude, position, and velocity to be made available at the higher fixed rate of the NavState. The INS Kalman filter provides superior attitude estimation performance compared to the AHRS Kalman filter due to its inherent ability to account for dynamic motion through its use of the GPS measurements. As such when GPS is available the VN-200 will utilize the INS Kalman filter for attitude estimation.

3.3.2 Vector Processing Engine

The Vector Processing Engine (VPE) is a collection of sophisticated algorithms which provide 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. This adaptive tuning eliminates the need in most cases for the user to perform any custom filter tuning for different applications.

3.3.3 AHRS Kalman Filter

Since the INS Kalman filter relies upon a continuous stream of GPS measurements to operate, the VN-200 supports automatic transition from INS to AHRS attitude estimation modes. In situations when GPS measurements are not available, the VN-200 will automatically begin to use the magnetometer and the accelerometer to estimate attitude. The transition is handled automatically by the VN-200, and performed in a seamless fashion, thus eliminating any potential jump discontinuities from appearing in the attitude or angular rate output when the transition to and from AHRS/INS mode is performed. Optionally the user can also manually select between using the INS or AHRS attitude estimation modes. The type of estimation algorithm used is controlled by the INS Scenario field in the INS basic configuration register (Register 67).

3.3.4 Hard/Soft Iron Estimator

The NavFilter subsystem also includes a separate EKF which provides real-time estimation of the local magnetic hard and soft iron distortions. Hard and soft iron distortions are local magnetic field distortions created by nearby ferrous material which moves with the sensor (attached to the same vehicle or rigid-body as the sensor). These ferrous materials distort the direction and magnitude of the local measured magnetic field, thus negatively impacting the ability of an AHRS to reliably and accurately estimate heading based on the magnetometer measurements. To remove the unwanted effect of these materials, a hard & soft iron calibration needs to be performed which requires rotating the sensor around in multiple circles while collecting magnetic data for off-line calculation of the magnetic hard & soft iron calibration coefficients. This calibration can be very time consuming, and might not be possible for some applications. The onboard hard/soft iron estimator runs 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 the hard/soft iron may change slowly over time. On the VN-200 the onboard hard/soft iron estimator is turned off by default, and can be configured or enabled by the user the Magnetic Calibration Control Register (see Section 11.1.1).

3.3.5 World Magnetic Model

The world magnetic model (WMM) is a large spatial-scale representation of the Earth's magnetic field. The internal model used on the VN-200 is consistent with the current WMM2010 model which consist of a spherical-harmonic expansion of the magnetic potential of the geomagnetic field generated in the Earth's core. By default the world magnetic model on the VN-200 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 which is then subsequently used as the fixed magnetic field reference strength. Control of the world magnetic model is performed using the Reference Vector Configuration register (Register 83).

3.3.6 World Gravity Model

The world gravity model (WGM) is a large spatial-scale representation of the Earth's gravity potential as a function of position on the globe. The internal model used on the VN-200 is consistent with the Earth Gravity Model (EGM96), which consist of a spherical-harmonic expansion of the Earth's geopotential. By default the world gravity model on the VN-200 is enabled, and automatically is set based on the estimated INS position. Control of the world gravity model is performed using the Reference Vector Configuration register (Register 83).

3.4 Communication Interface

The VN-200 provides three separate communication interfaces; two physically separate serial ports and one SPI (Serial Peripheral Interface) bus.

3.4.1 Serial Interface

The serial interface consists of two physically separate bi-directional UARTs. Each UART supports baud rates from 9600 bps up to a maximum of 921600 bps.

The surface mount version of the VN-200 offers both UARTS with 3V TTL voltage level inputs and outputs.

The rugged version includes an onboard TTL to RS-232 level shifter, thus at the 10-pin connector one serial port is offered with RS-232 voltages levels (Serial 1), while the other serial port (Serial 2) remains at 3V TTL logic levels.

> It is important to note that the ability to update the firmware using the onboard bootloader is only supported on the serial port 1 interface. It is highly recommended that if serial port 1 is not used for normal operation, a means of accessing it is designed into the product to support future firmware updates.

3.4.2 SPI Interface

The SPI interface consists of a standard 4-wire synchronous serial data link which is capable of high data rates up to 16 Mbps. The VN-200 operates as slave on the bus enabled by the master using the slave select (SPI_CS) line. See section 4.2 for more information on the operation of the SPI interface.

3.5 Communication Protocol

The VN-200 utilizes a simple command based communication protocol for both the serial and SPI interfaces. For the serial interface an ASCII protocol is used for command and register polling, whereas the SPI interfaces utilizes a binary protocol. Optionally the serial interface also provides support for streaming real-time sensor measurements using binary output packets.

3.5.1 Serial ASCII

On the serial interface a full ASCII protocol provides support for all commands, and register polling. The ASCII protocol is very similar to the widely used NMEA 0183 protocol supported by most GPS receivers, and consists of comma delimited parameters printed in human readable text. Below is an example command request and response on the VN-200 used to poll the attitude (register 8) using the ASCII protocol.

Figure 11 - Example Serial Request

```
$VNRRG,8*4B
```

Figure 12 - Example Serial Response

```
$VNRRG,08,-114.314,+000.058,-001.773*5F
```

Chapter 6 provides a list of all commands and registers supported by each software subsystem on the VN-200. For each command and register an example ASCII response is given to demonstrating the ASCII formatting.

3.5.2 Serial Binary

The serial interface offers support for streaming sensor measurements from the sensor at fixed rates using simple binary output packets. These binary output packets provide a low-overhead means of streaming high-speed sensor measurements from the device minimizing both the required bandwidth and the necessary overhead required to parse the incoming measurements for the host system. Section 5 provides a detailed overview on how to parse and configure the binary output messages on the serial interface.

3.5.3 Serial Command Prompt

A simple command prompt is also provided on the serial interface which provides support for advanced device configuration and diagnostics. The serial command prompt is an optional feature that is designed to provide more detailed diagnostic view of overall system performance than is possible using normal command & register structure. It is strictly intended to be used by a human operator, using a simple serial terminal to type commands to the device using a serial terminal, and is not designed to be used programmatically. Each software subsystem described in Chapter 6 provides information on the diagnostic commands supported by the serial command prompt at the end of each subsystem section.

4 Basic Communication

The VN-200 module supports two communication interfaces: serial and SPI. On the serial interface, the module communicates over a universal asynchronous receiver/transmitter (UART) and uses ASCII text for its command and data format. On the SPI interface, the VN-200 module communicates as a slave device on a Serial Peripheral Interface (SPI) data bus and uses a binary command and data format. Both interfaces support the complete command set implemented by the module. A general overview of the command format for each interface is given in the next two sections and formatting specific to each command and associated parameters is provided in the protocol and register sections.

4.1 Serial Interface

On the serial interface, the VN-200 uses ASCII text for its command format. All commands start with a dollar sign, followed by a five character command, a comma, command specific parameters, an asterisk, a checksum, and a newline character. An example command is shown below.

```
$VNRRG,11*73
```

4.2 SPI Interface

The VN-200 supports a Serial Peripheral Interface (SPI) communication interface. The SPI interface consists of synchronous serial communication interface where devices communicate in a master/slave mode. The VN-200 operates as a slave while the device communicating with the VN-200 will act as a master. The master provides a clock to the slave which synchronizes the data transfer to the rising and falling edge of the clock signal. Due to its synchronous communication, high data transfer rates, and master/slave operation, the SPI communication interface is ideal for board-level communication over short distances since it doesn't require a complex software protocol stack and is fairly straightforward to program against on embedded devices.

4.2.1 SPI Hardware Requirements

Four hardware lines are required to implement a SPI interface with the VN-200; a clock (SPI_SCK), two data lines (SPI_MOSI and SPI_MISO), and a slave select pin (SPI_CS). The master is responsible for driving both the clock signal and the slave select lines. The slave select line should be pulled low when the master wants to communicate with the slave. If multiple slave devices are used on the same bus, then each slave will have its own dedicated slave select line, while sharing the clock and data lines. The VN-200 will leave the SPI_MISO line in a high impedance state while the SPI_CS line is high, enabling communication with other slave devices on the same SPI bus. When the master is finished communicating with the slave the slave select line is pulled high. The clock line should idle high when not in use. The SPI_MISO and SPI_MOSI pins should both transition between logic states on the falling edge of the SPI_SCK clock signal. Data on both the SPI_MISO and SPI_MOSI should be sampled on the rising edge of the SPI_SCK line. The VN-200 uses 3V digital logic for the SPI interface. If you are interfacing with a 5V system, it is recommended that you use a logic level translation circuit to ensure reliable communication.

SPI Master Settings	
Slave Select	Active Low
Clock Polarity	Idle High (CPOL=1)
Clock Phase	Sample second clock edge (CPHA=1)
Data Format	Most significant bit first (MSB)
Byte Order	Least significant byte first (little-endian)

4.2.2 Software Requirements

Communication with the VN-200 over SPI is conducted with multiple transactions. A transaction for the purpose of this document is defined as a single operation, such as reading or writing to a register on the VN-200 or issuing a command such as requesting a device reset. A single transaction consists to two separate data packets sent to the VN-200. Each packet consists of a four byte header followed by a data payload. The header for the packet differs depending upon whether it is a request packet or a response packet. For each packet sent to the VN-200 the slave select line (SPI_CS) should be pulled low at the beginning of the packet and pulled high at the end.

Figure 13 - Packet Headers

4-Byte Request Header (MOSI)			
Command ID	Argument	0x00	0x00

4-Byte Response Header (MISO)			
0x00	Command ID	Argument	0x00

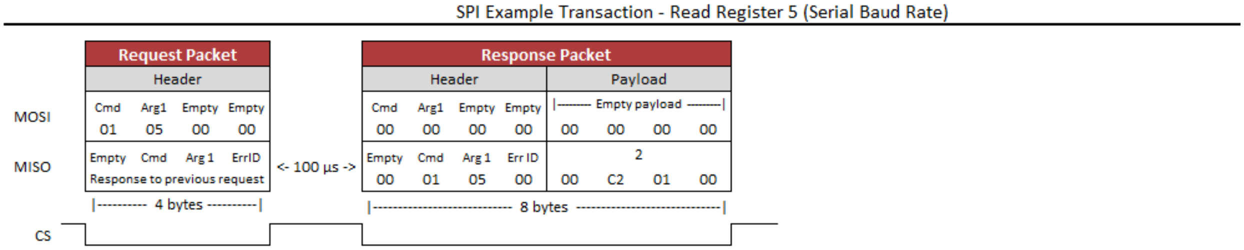
4.2.3 SPI Example Commands

The sections that follow provided some example SPI transactions for the various types of commands available on the VN-200.

SPI Read Register Example

Below is an example of a single transaction with the VN-200 to read register 5.

SPI Example Transaction - Read Register 5 (Serial Baud Rate)

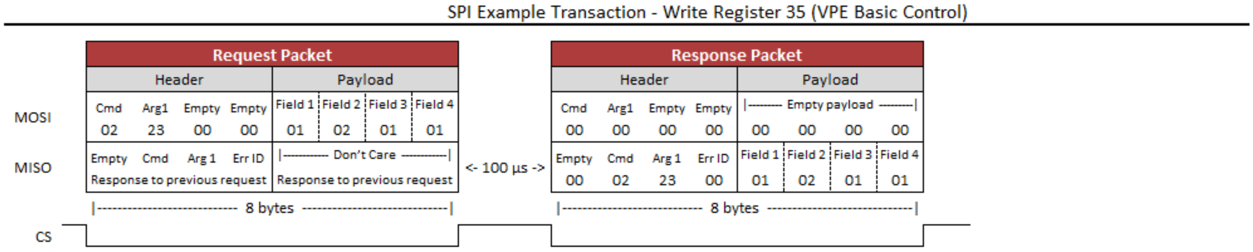


The first packet is the request packet and consists of the master sending out the MOSI line a four byte header with no payload. The first byte in the header has the command ID of 1, which corresponds to a read register request. The second byte is the argument. In the case of the read register command this corresponds to the register ID, which in this case is register 5. The next two bytes are always zero in the header. After this packet is sent the master should raise the slave select line (SPI_CS) and wait at least 50 microseconds before issuing the respond packet. During this time the VN-200 will process the read register request and place the requested data in its SPI output buffer. On the response packet the master should clock in N bytes of zeroes on the MOSI line, where N is equal to 4 plus the size of the register being read, which in this example is register 5 (4 bytes). The header for packets being received from the VN-200 has a different structure with the first byte always being zero. The second and third byte in the header is the command ID and the argument (register ID) of the response. The fourth byte in the header is the error code. If an error occurred while attempting to service the request the VN-200 will issue a non-zero error code in this byte with no payload. In the payload of the response packet the four bytes received correspond to the value of register 5 which in this case is 115200. As you can see from the example multi-byte values are sent in little endian format with the least significant byte sent first (0h01C200 = 115200).

SPI Write Register Example

Below is an example of a write register transaction. In this example the values of {1, 2, 1, 1} are being written to the four fields in the VPE Control Register (Register 35).

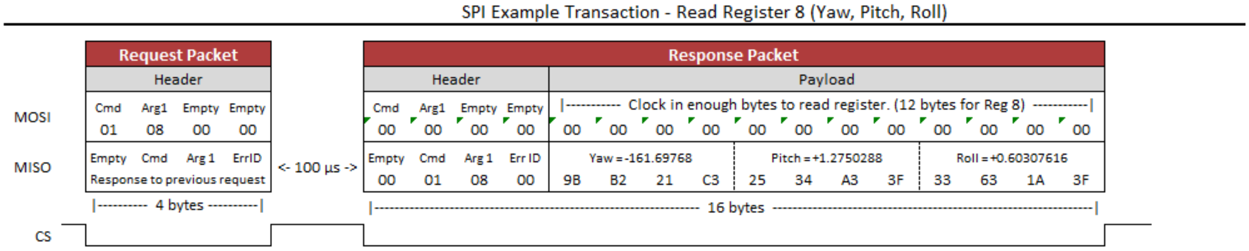
SPI Example Transaction - Write Register 35 (VPE Basic Control)



In the case of writing to a register, the values to be loaded into the register are in the payload of the request packet. The payload of the response packet contains the contents of the register after the write register command has been processed. In the case that no error occurred the payload of the response packet should be the same as the request. Because of this it is sufficient to just clock in only four bytes on the response packet to verify that the write register took effect, which is indicated by a zero error code.

SPI Read Register Example – Floating Point Registers

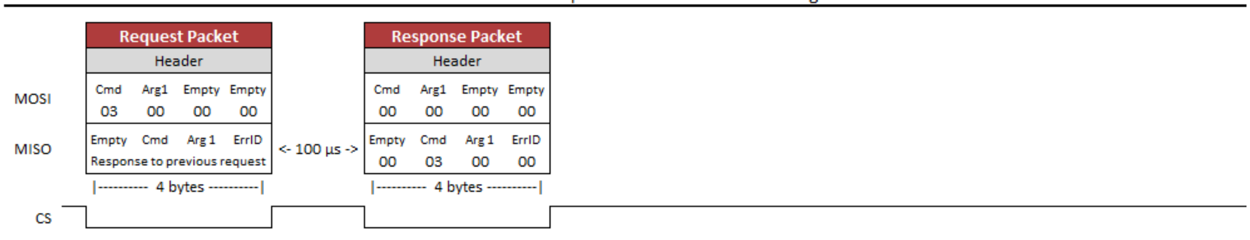
SPI Example Transaction - Read Register 8 (Yaw, Pitch, Roll)



The above examples show a transaction involving reading a register with floating point values. In this case Register 8 is read which contains the sensor attitude (Yaw, Pitch, & Roll). The floating point values are stored as 32-bit IEEE floating point numbers in little endian byte order.

SPI Write Settings Command Example

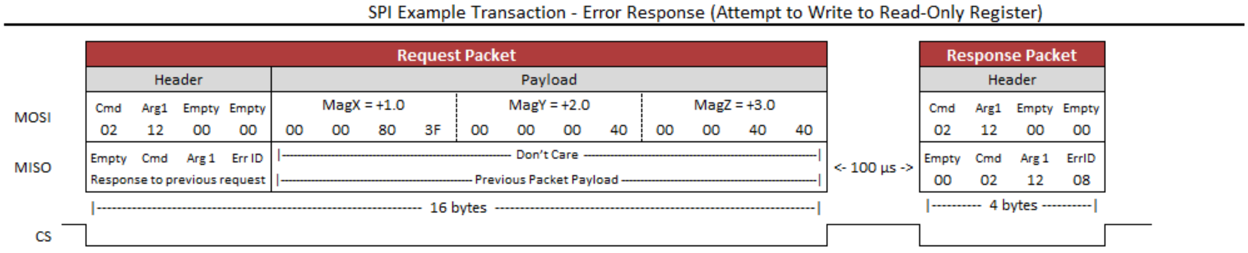
SPI Example Transaction - Write Settings Command



The above example shows an example transaction that consists of issuing a write settings command to the VN-200. The different commands accepted by the VN-200 are listed in Section 6.1.

SPI Transaction Error Example

SPI Example Transaction - Error Response (Attempt to Write to Read-Only Register)



The above example demonstrates what will happen when an error occurs during a transaction. In this case the user attempted to write to a read-only register. The fourth byte of the response packet header shows an Error ID of 8 was returned, which corresponds to an Invalid Register. The different error codes are listed in Table 14.

4.3 System Error Codes

In the event of an error, the VN-200 will output $VNERR, followed by an error code. The possible error codes are listed in the table below with a description of the error.

Table 14 – Error Codes

Error Name	Code	Description
Hard Fault	1	If this error occurs, then the firmware on the VN-200 has experienced a hard fault exception. To recover from this error the processor will force a restart, and a discontinuity will occur in the serial output. The processor will restart within 50 ms of a hard fault error.
Serial Buffer Overflow	2	The processor’s serial input buffer has experienced an overflow. The processor has a 256 character input buffer.
Invalid Checksum	3	The checksum for the received command was invalid.
Invalid Command	4	The user has requested an invalid command.
Not Enough Parameters	5	The user did not supply the minimum number of required parameters for the requested command.
Too Many Parameters	6	The user supplied too many parameters for the requested command.
Invalid Parameter	7	The user supplied a parameter for the requested command which was invalid.
Invalid Register	8	An invalid register was specified.
Unauthorized Access	9	The user does not have permission to write to this register.
Watchdog Reset	10	A watchdog reset has occurred. In the event of a non-recoverable error the internal watchdog will reset the processor within 50 ms of the error.
Output Buffer Overflow	11	The output buffer has experienced an overflow. The processor has a 2048 character output buffer.
Insufficient Baud Rate	12	The baud rate is not high enough to support the requested asynchronous data output at the requested data rate.
Error Buffer Overflow	255	An overflow event has occurred on the system error buffer.

4.4 Checksum / CRC

The serial interface provides the option for either an 8-bit checksum or a 16-bit CRC. In the event neither the checksum nor the CRC is needed, they can be turned off by the user.

4.4.1 Checksum Bypass

When communicating with the sensor using a serial terminal, the checksum calculation can be bypassed by replacing the hexadecimal digits in the checksum with uppercase X characters. This works for both the 8-bit and 16-bit checksum. An example command to read register 1 is shown below using the checksum bypass feature.

```
$VNRRG,1*XX
```

4.4.2 8-bit Checksum

The 8-bit checksum is an XOR of all bytes between, but not including, the dollar sign ($) and asterisk (*). All comma delimiters are included in the checksum calculation. The resultant checksum is an 8-bit number and is represented in the command as two hexadecimal characters. The C function snippet below calculates the correct checksum.

Example C Code

```c
// Calculates the 8-bit checksum for the given byte sequence.
unsigned char calculateChecksum(unsigned char data[], unsigned int length)
{
    unsigned int i;
    unsigned char cksum = 0;

    for(i=0; i<length; i++){
        cksum ^= data[i];
    }

    return cksum;
}
```

4.4.3 16-bit CRC

For cases where the 8-bit checksum doesn't provide enough error detection, a full 16-bit CRC is available. The VN-200 uses the CRC16-CCITT algorithm. The resultant CRC is a 16-bit number and is represented in the command as four hexadecimal characters. The C function snippet below calculates the correct CRC.

Example C Code

```
// Calculates the 16-bit CRC for the given ASCII or binary message.
unsigned short calculateCRC(unsigned char data[], unsigned int length)
{
  unsigned int i;
  unsigned short crc = 0;

  for(i=0; i<length; i++){
    crc  = (unsigned char)(crc >> 8) | (crc << 8);
    crc ^= data[i];
    crc ^= (unsigned char)(crc & 0xff) >> 4;
    crc ^= crc << 12;
    crc ^= (crc & 0x00ff) << 5;
  }

  return crc;
}
```

5 User Configurable Binary Output Messages

The VN-200 supports 3 separate user configurable binary output messages available on the serial interface. Each message can be configured by the user to contain any of the available output measurement types from the IMU, NavState, NavFilter, or the GPS subsystems. The device can be configured to asynchronously output each message at a fixed rate based upon a divisor of the IMU internal sampling rate (IMU Rate).

5.1 Available Output Types

All real-time measurements either measured or estimated by the VN-200 are available using the user output messages. The different output types are organized into 6 separate output groups. The first group is a combination of the most common outputs from the remaining 5 groups. The other 5 groups are shown below.

Figure 14 – Binary Outputs

Time	IMU	GPS	Attitude	INS
• TimeStartup	• Status	• UTC	• Status	• Status
• TimeGps	• UncompMag	• Tow	• YawPitchRoll	• PosLla
• GpsTow	• UncompAccel	• Week	• Quaternion	• PosEcef
• GpsWeek	• UncompAngularRate	• NumSats	• DCM	• VelBody
• TimeSyncIn	• Temp	• Fix	• MagNed	• VelNed
• TimeGpsPps	• Pres	• PosLla	• AccelNed	• VelEcef
• TimeUTC	• DeltaTheta	• PosEcef	• LinearAccelBody	• MagEcef
• SyncInCnt	• DeltaVel	• VelNed	• LinearAccelNed	• AccelEcef
	• Mag	• VelEcef	• YprU	• LinearAccelEcef
	• Accel	• PosU		• PosU
	• AngularRate	• VelU		• VelU
	• SatFlags	• TimeU		
		• Sats		

5.2 Configuring the Output Types

Configuration of the 3 output messages is performed using the User Output Configuration Registers (Register 75-79). There are 3 separate configuration registers, one for each available output message. Section 6.2.11 describes in more detail the format for these registers. In each of these configuration registers the user can select which output types they want the message to include by specifying the OutputGroup and the OutputFields parameters.

5.2.1 OutputGroup

The OutputGroup parameter is a single byte where the bits select which output groups are active in the message.

Name	Bit Offset	Description
Output Group 1	0	Common Group
Output Group 2	1	Time Group
Output Group 3	2	IMU Group
Output Group 4	3	GPS Group
Output Group 5	4	Attitude Group
Output Group 6	5	INS Group

Output group 7 is not used on the VN-200. The bit for this unused output group must be set to zero.

5.2.2 OutputFields

The OutputFields is an array of 16-bit words, with the array length equal to the number of active groups in the OutputGroup. The OutputFields selects which output fields are active for each output group.

Below is a list of the available output fields for each output group.

Bit Offset	Group 1 Common	Group 2 Time	Group 3 IMU	Group 4 GPS	Group 5 Attitude	Group 6 INS
0	TimeStartup	TimeStartup	ImuStatus	UTC	VpeStatus	InsStatus
1	TimeGps	TimeGps	UncompMag	Tow	YawPitchRoll	PosLla
2	TimeSyncIn	GpsTow	UncompAccel	Week	Quaternion	PosEcef
3	YawPitchRoll	GpsWeek	UncompGyro	NumSats	DCM	VelBody
4	Quaternion	TimeSyncIn	Temp	Fix	MagNed	VelNed
5	AngularRate	TimeGpsPps	Pres	PosLla	AccelNed	VelEcef
6	Position	TimeUTC	DeltaTheta	PosEcef	LinearAccelBody	MagEcef
7	Velocity	SyncInCnt	DeltaVel	VelNed	LinearAccelNed	AccelEcef
8	Accel		Mag	VelEcef	YprU	LinearAccelEcef
9	Imu		Accel	PosU		PosU
10	MagPres		AngularRate	VelU		VelU
11	DeltaTheta		SensSat	TimeU		
12	InsStatus			SvStat		
13	SyncInCnt					
14	TimeGpsPps					
15						

5.2.3 Setup the Configuration Register

Once you have determined the desired outputs for your output messages, you will need to configure the User Output Message Configuration Registers (Register 75 – 77). These registers are described in detail in Section 6.2.11, however for reference the format of the register is shown below.

Binary Output Register 1-3				
Register ID :	75-77	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	These registers allow the user to construct a custom output message that contains a collection of desired estimated states and sensor measurements.			
Size (Bytes):	6-22			
Example Response:	$VNWRG,75,2,4,1,8*XX			

Offset	Name	Format	Unit	Description
0	AsyncMode	uint16	-	Selects whether the output message should be sent out on the serial port(s) at a fixed rate. 0 = None. User message is not automatically sent out either serial port. 1 = Message is sent out serial port 1 at a fixed rate. 2 = Message is sent out serial port 2 at a fixed rate. 3 = Message is sent out both serial ports at a fixed rate.
2	RateDivisor	uint16	-	Sets the fixed rate at which the message is sent out the selected serial port(s). The number given is a divisor of the ***ImuRate*** which is nominally 800Hz. For example to have the sensor output at 50Hz you would set the Divisor equal to 16.
4	OutputGroup	uint16	-	Selects which output groups are active in the message. The number of **OutputFields** in this message should equal the number of active bits in the **OutputGroup**.
6	OutputField(1)	uint16	-	Active output fields for the first active group.
4+2*N	OutputField(N)	uint16	-	Active output fields for the Nth active group.

5.2.1 Example Case 1 – Selecting outputs from only the Common Group

For many applications you might be able to get by with only the output types available in the common group. For these situations the configuration of the output message is simple. Suppose only the following information shown below is desired.

Bit Offset	Group 1 Common
0	TimeStartup
3	YawPitchRoll
5	AngularRate

For this example we will assume that the data will be polled using serial port 2 at 50 Hz.

To configure this output message you would send the following command to the VN-200.

```
$VNWRG,75,2,16,01,0029*XX
```

Now let's dissect this command to see what is actually being set:

Field	Value	Description
Header	$VN	ASCII message header
Command	WRG	Write register command
Register ID	77	Register 75 (Config register for first output message)
AsyncMode	2	Message set to output on serial port 2.
RateDivisor	16	Divisor = 16. If the *ImuRate* = 800Hz then, the message output rate will be (800 / 16 = 50 Hz).
OutputGroup	01	Groups = 0x01. (Binary group 1 enabled)
GroupField 1	0029	Group 1 Field = 0x0029. In binary 0x0029 = 0b00101001. The active bits correspond to the following active output fields: Bit 0 – TimeStartup Bit 3 – YawPitchRoll Bit 5 - AngularRate
Checksum	XX	Payload terminator and checksum. XX instructs the VN-200 to bypass the checksum evaluation. This allows us to manually type messages in a serial terminal without needing to calculate a valid checksum.
End Line	\r\n	Carriage return and line feed. Terminates the ASCII message.

5.2.2 Example Case 2 – Outputs from multiple Output Groups

This example case demonstrates how to select multiple output fields from more than one output group. Assume that the following bold output types are desired:

Bit Offset	Group 1 Common	Group 3 IMU	Group 5 Attitude
0	TimeStartup		
1			
2		UncompAccel	Quaternion
3		UncompAngularRate	
4			MagNed

Also assume that you want the message to stream at 50 Hz over serial port 1.

To configure this output message you would send the following command to the VN-200.

```
$VNWRG,75,1,16,15,0001,000C,0014*XX
```

Now let's dissect this command to see what is actually being set:

Field	Value	Description
Header	$VN	ASCII message header
Command	WRG	Write register command
Register ID	75	Register 75 (Config register for first output message)
AsyncMode	1	Message sent on serial port 1.
RateDivisor	16	Divisor = 16. If the ***ImuRate*** = 800Hz then, the message output rate will be (800 / 16 = 50 Hz).
OutputGroup	15	Groups = 0x15. In binary 0x15 = 0x00010101. The active bits correspond to the following active output groups: Bit 0 – Common Bit 2 – Imu Bit 4 - Attitude
GroupField 1	0001	Group 1 Field = 0x0001. In binary 0x0001 = 0b00000001. The active bits correspond to the following active output fields: Bit 0 – TimeStartup
GroupField 2	000C	Group 2 Field = 0x000C. In binary 0x000C = 0b00001100. The active bits correspond to the following active output fields: Bit 3 – UncompAccel Bit 4 – UncompGyro
GroupField 3	0014	Group 3 Field = 0x0014. In binary 0x0014 = 0b00010100. The active bits correspond to the following active output fields: Bit 2 – Qtn Bit 4 – MagNed
Checksum	XX	Payload terminator and checksum. XX instructs the VN-200 to bypass the checksum evaluation. This allows us to manually type messages in a serial terminal without needing to calculate a valid checksum.
End Line	\r\n	Carriage return and line feed. Terminates the ASCII message.

5.3 Serial Output Message Format

The binary output message packets on the serial interface consist of a simple message header, payload, and a 16-bit CRC. An example packet is shown below for reference. The header is variable length depending upon the number of groups active in the message.

	Header						Payload				CRC	
Field	Sync	Groups	Group Field 1		Group Field 2		Payload				CRC	
Byte Offset	0	1	2	3	4	5	6	7	…	N	N+1	N+2
Type	u8	u8	u16		u16		Variable				u16	

5.3.1 Sync Byte

The sync byte is the first byte in the header. Its value will always be equal to 0xFA.

5.3.2 Groups

The group consist of a single byte which determines which message groups have been selected. The user can select from a wide assortment of different output types, which are organized into 8 different groups. The group byte acts as a bit field with each individual bit determining which binary groups are active for the given packet. The various groups are shown below.

Name	Bit Offset	Description
Binary Group 1	0	General Purpose Group
Binary Group 2	1	Time and Event Count Group
Binary Group 3	2	Inertial Measurement Unit Group
Binary Group 4	3	GPS Measurement Group
Binary Group 5	4	AHRS Group
Binary Group 6	5	INS Group
Binary Group 7	6	Reserved for future use. Must be set to zero.
Binary Group 8	7	Reserved for future use. Must be set to zero.

5.3.3 Group Fields

The group fields consist of N number of 16-bit bit fields that represent which output types have been selected in the active binary groups. The number of group fields in the header will depend upon how many groups are active in the message. The number of group fields present in the header will always be equal to the number of active bits in the group byte. When parsing the binary packet you can count the number of active bits present in the group byte, and then you can assume that this number of group fields will be present in the header. For example if only binary group 1 is selected (Group Byte = 0x01), then only one Group field will be present in the header, thus the header will be 4 bytes in length. If both binary group 1 and 3 are active (Group Byte = 0x05), then two Group field elements will be present in the header (4 bytes), thus the header in this case will be 6 bytes in length.

5.3.4 Payload

The payload will consist of the output data selected based upon the bits selected in the group byte and the group field bytes. All output data in the payload section consist of the active outputs selected for binary group 1, followed by the active outputs selected for binary group 2, and so forth. No padding bytes are used between output fields.

5.3.5 CRC

The CRC consists of a 16-bit CRC of the packet. The CRC is calculated over the packet starting just after the sync byte in the header (not including the sync byte) and ending at the end of the payload. More information about the CRC algorithm and example code for how to perform the calculation is shown in Section 4.4. The CRC is selected such that if you compute the 16-bit CRC starting with the group byte and include the CRC itself, a valid packet will result in 0x0000 computed by the running CRC calculation over the entire packet. This provides a simple way of detecting packet corruption by simply checking to see if the CRC calculation of the entire packet (not including the sync byte) results in zero.

5.3.6 Payload Length

When parsing the packet you will need to know the length of the payload (in bytes) in order to know where the packet ends in the data stream. In order to reduce the overhead of the packet header length, the length of the payload is not included in the header. Instead it should be derived based upon determining the type of data present in the packet. All output data types are fixed length, thus the total length of the payload can be determined based upon inspection of the group byte and the group field bytes. In most applications you will likely only use a few binary output types, thus hard coding the payload length in your parser is the easiest approach. If you want to develop a more generic parser that can handle all available data output types supported by the VN-200, the easiest approach is to use a table lookup. Below is a table with the payload size (in bytes) for all available output types.

Table 15 - Binary Output Payload Length In Bytes

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Field 1	8	8	2	8	2	2
Field 2	8	8	12	8	12	24
Field 3	8	8	12	2	16	24
Field 4	12	2	12	1	36	12
Field 5	16	8	4	1	12	12
Field 6	12	8	4	24	12	12
Field 7	24	8	16	24	12	12
Field 8	12	4	12	12	12	12
Field 9	12	0	12	12	12	12
Field 10	24	0	12	12	12	4
Field 11	20	0	12	4	28	4
Field 12	28	0	2	4	24	68
Field 13	2	0	40	32	0	64
Field 14	4	0	0	0	0	0
Field 15	8	0	0	0	0	0
Field 16	0	0	0	0	0	0

The above lookup table can be implemented in C as shown below using a simple 2D array. Since none of the individual outputs types exceed 256 bytes in length, this lookup table can be implemented as an array of bytes, which consumes only 96 bytes of memory.

Example Code

```
// 2D array to determine the payload length for a binary output packet. The first
// index of the array is the group number, and the second index
// is the group field index. Both indices are assumed to be zero based.

const unsigned char groupLen[6][16] =
{
{8,  8,  8,  12, 16, 12, 24, 12, 12, 24, 20, 28, 2,  4,  8,  0}, //Group 1
{8,  8,  8,  2,  8,  8,  8,  4,  0,  0,  0,  0,  0,  0,  0,  0}, //Group 2
{2,  12, 12, 12, 4,  4,  16, 12, 12, 12, 12, 2,  40, 0,  0,  0}, //Group 3
{8,  8,  2,  1,  1,  24, 24, 12, 12, 12, 4,  4,  32, 0,  0,  0}, //Group 4
{2,  12, 16, 36, 12, 12, 12, 12, 12, 12, 28, 24, 0,  0,  0,  0}, //Group 5
{2,  24, 24, 12, 12, 12, 12, 12, 12, 4,  4,  68, 64, 0,  0,  0}, //Group 6
};
```

5.3.7 Example Cases

To help you better understand how the binary protocol works, the next two sections provide an overview of how the binary output packets are formed for two separate example cases.

Example Case 1

For example 1 we will assume that only binary group 1 is active, and only the yaw, pitch, and roll output is active within this binary group. In this case the header will have the following form.

Header					Payload												CRC	
Field	Sync	Group	Group 1 Fields		YawPitchRoll												CRC	
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Byte Value (Hex)	FA	01	08	00	93	50	2E	42	83	3E	F1	3F	48	B5	04	BB	92	88
Type	u8	u8	u16		float				float				float				u16	
Value	0xFA	1	8		0x422E5093 +43.578686 (Yaw)				0x3FF13E83 +1.8847202 (Pitch)				0xBB04B548 -2.0249654e-3 (Roll)				0x9288	

Example Case 2

For the second example case we will assume that both binary group 1 and 3 are active. In binary group 1, the Ypr output is selected, and in binary group 3, the Temp output is selected.

Header						
Field	Sync	Group	Group 1 Fields		Group 3 Fields	
Byte Offset	0	1	2	3	4	5
Byte Value (Hex)	FA	01	08	00	01	00
Type	u8	u8	u16		u16	
Value	0xFA	0x01	0x08		0x01	

Payload																	CRC
Field	YawPitchRoll												Temp				CRC
Byte Offset	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Byte Value (Hex)	A4	15	02	42	4D	DF	EB	3F	F6	1A	36	BE	BF	2D	A4	41	A8	3A
Type	float				float				float				float				u16	
Value	0x420215A4 +32.521133 (Yaw)				0X3FEBDF4D +1.8427521 (Pitch)				0XBE361AF6 -1.7783722e-1 (Roll)				0X41A42DBF +20.522337 (Temp)				0XA83A	

5.4 Binary Group 1 – Common Outputs

Binary group 1 contains a wide assortment of commonly used data required for most applications. All of the outputs found in group 1 are also present in the other groups. In this sense, group 1 is a subset of commonly used outputs from the other groups. This simplifies the configuration of binary output messages for applications that only require access to the commonly used data found in group 1. For these applications you can hard code the group field to 1, and not worry about implemented support for the other binary groups. Using group 1 for commonly used outputs also has the advantage of reducing the overall packet size, since the packet length is dependent upon the number of binary groups active.

Table 16 – Binary Group 1

Name	Bit Offset	Description
TimeStartup	0	Time since startup.
TimeGps	1	GPS time.
TimeSyncIn	2	Time since last SyncIn trigger.
Ypr	3	Estimated attitude as yaw pitch and roll angles.
Qtn	4	Estimated attitude as a quaternion.
AngularRate	5	Compensated angular rate.
Position	6	Estimated position. (LLA)
Velocity	7	Estimated velocity. (NED)
Accel	8	Estimated acceleration (compensated). (Body)
Imu	9	Calibrated uncompensated gyro and accelerometer measurements.
MagPres	10	Calibrated magnetic (compensated), temperature, and pressure measurements.
DeltaTheta	11	Delta time, theta, and velocity.
InsStatus	12	INS status.
SyncInCnt	13	SyncIn count.
TimeGpsPps	14	Time since last GPS PPS trigger.
Resv	15	Reserved for future use. Should be set to zero.

5.4.1 Time Startup

The system time since startup measured in nano seconds. The time since startup is based upon the internal TXCO oscillator for the MCU. The accuracy of the internal TXCO is +/- 20ppm (-40C to 85C). This field is equivalent to the TimeStartup field in group 2.

	TimeStartup							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.4.2 TimeGps

The absolute GPS time since start of GPS epoch 1980 expressed in nano seconds. This field is equivalent to the TimeGps field in group 2.

	TimeGps							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.4.3 TimeSyncIn

The time since the last SyncIn trigger event expressed in nano seconds. This field s equivalent to the TimeSyncIn field in group 2.

	TimeSyncIn							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.4.4 YawPitchRoll

The estimated attitude Yaw, Pitch, and Roll angles measured in degrees. The attitude is given as a 3,2,1 Euler angle sequence describing the body frame with respect to the local North East Down (NED) frame. This field is equivalent to the YawPitchRoll field in group 5.

	YawPitchRoll											
	yaw				pitch				roll			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.4.5 Quaternion

The estimated attitude quaternion. The last term is the scalar value. The attitude is given as the body frame with respect to the local North East Down (NED) frame. This field is equivalent to the Quaternion field in group 5.

	Quaternion															
	qtn[0]				qtn[1]				qtn[2]				qtn[3]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Type	float				float				float				float			

5.4.6 AngularRate

The estimated angular rate measured in rad/s. The angular rates are compensated by the onboard filter bias estimates. The angular rate is expressed in the body frame. This field is equivalent to the AngularRate field in group 3.

	AngularRate											
	rate[0]				rate[1]				rate[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.4.7 Position

The estimated position given as latitude, longitude, and altitude given in [deg, deg, m] respectfully. This field is equivalent to the PosLla field in group 6.

	Position																							
	latitude								longitude								altitude							
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	double								double								double							

5.4.8 Velocity

The estimated velocity in the North East Down (NED) frame, given in m/s. This field is equivalent to the VelNed field in group 6.

	Velocity											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.4.9 Accel

The estimated acceleration in the body frame, given in m/s^2. This acceleration includes gravity and has been bias compensated by the onboard INS Kalman filter. This field is equivalent to the Accel field in group 3.

	Accel											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.4.10 Imu

The uncompensated IMU angular rate and acceleration measurements. The angular rate is given in rad/s, and the acceleration is given in m/s^2. These measurements correspond to the calibrated angular rate and acceleration measurements straight from the IMU. The measurements have not been corrected for bias offset by the onboard AHRS/INS Kalman filter. This field is equivalent to the UncompGyro and UncompAccel fields in group 3.

	Imu																							
	rate[0]				rate[1]				rate[2]				accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	float				float				float				float				float				float			

5.4.11 MagPres

The compensated magnetic, temperature, and pressure measurements from the IMU. The magnetic measurement is given in Gauss, and has been corrected for hard/soft iron corrections (if enabled). The temperature measurement is given in Celsius. The pressure measurement is given in kPa. This field is equivalent to the Mag, Temp, and Pres fields in group 3.

	MagPres																			
	mag[0]				mag[1]				mag[2]				temp				pres			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Type	float				float				float				float				float			

5.4.12 DeltaThetaVel

The delta time, angle, and velocity measurements. The delta time (dtime) is the time interval that the delta angle and velocities are integrated over. The delta theta (dtheta) is the delta rotation angles incurred due to rotation, since the last time the values were outputted by the device. The delta velocity (dvel) is the delta velocity incurred due to motion, since the last time the values were outputted by the device. These delta angles and delta velocities are calculated based upon the onboard conning and sculling integration performed onboard the sensor at the IMU rate (default 800Hz). The integration for both the delta angles and velocities are reset each time either of the values are either polled or sent out due to a scheduled asynchronous ASCII or binary output. This field is equivalent to the DeltaTheta and DeltaVel fields in group 3 with the inclusion of the additional delta time parameter.

	DeltaThetaVel															
	dtime				dtheta[0]				dtheta[1]				dtheta[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Type	float				float				float				float			

	DeltaThetaVel (continued)											
	dvel[0]				dvel[1]				dvel[2]			
Byte Offset	16	17	18	19	20	21	22	23	24	25	26	27
Type	float				float				float			

5.4.13 InsStatus

The INS status bitfield. This field is equivalent to the InsSatus field in group 6. See register 63 for more information on the individual bits in this field.

	SolStatus	
Byte Offset	0	1
Type	u16	

5.4.14 SyncInCnt

The number of SyncIn trigger events that have occurred. This field is equivalent to the SyncInCnt field in group 2.

	SyncInCnt			
Byte Offset	0	1	2	3
Type	u32			

5.4.15 TimeGpsPps

The time since the last GPS PPS trigger event expressed in nano seconds. This field is equivalent to the TimePPS field in group 2.

	TimeGpsPps							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5 Binary Group 2 – Time Outputs

Binary group 2 provides all timing and event counter related outputs. Some of these outputs (such as the TimeGps, TimePps, and TimeUtc), require either that the internal GPS to be enabled, or an external GPS must be present.

Table 17 - Binary Group 2

Name	Bit Offset	Description
TimeStartup	0	Time since startup.
TimeGps	1	Absolute GPS time.
GpsTow	2	Time since start of GPS week.
GpsWeek	3	GPS week.
TimeSyncIn	4	Time since last SyncIn trigger.
TimePPS	5	Time since last GPS PPS trigger.
TimeUTC	6	UTC time.
SyncInCnt	7	SyncIn trigger count.
Resv	8-15	Reserved for future use. Should be set to zero.

5.5.1 TimeStartup

The system time since startup measured in nano seconds. The time since startup is based upon the internal TXCO oscillator for the MCU. The accuracy of the internal TXCO is +/- 20ppm (-40C to 85C).

	TimeStartup							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5.2 TimeGps

The GPS time of week expressed in nano seconds.

	TimeGps							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5.3 GpsTow

The time since the start of the current GPS time week expressed in nano seconds.

	GpsTow							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5.4 GpsWeek

The current GPS week.

	GpsWeek	
Byte Offset	0	1
Type	u16	

5.5.5 TimeSyncIn

The time since the last SyncIn event trigger expressed in nano seconds.

	TimeSyncIn							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5.6 TimeGpsPps

The time since the last GPS PPS trigger event expressed in nano seconds.

	TimePps							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.5.7 TimeUtc

The current UTC time. The year is given as a signed byte year offset from the year 2000. For example the year 2013 would be given as year 13.

	TimeUtc							
Fields	year	month	day	hour	min	sec	ms	
Byte Offset	0	1	2	3	4	5	6	7
Type	s8	u8	u8	u8	u8	u8	u16	

5.5.8 SyncInCnt

The number of SyncIn trigger events that have occurred.

	SyncInCnt			
Byte Offset	0	1	2	3
Type	u32			

5.6 Binary Group 3 – IMU Outputs

Binary group 3 provides all outputs which are dependent upon the measurements collected from the onboard IMU, or an external IMU (if enabled).

Table 18 – Binary Group 3

Name	Bit Offset	Description
ImuStatus	0	Reserved for future use.
UncompMag	1	Uncompensated magnetic measurement.
UncompAccel	2	Uncompensated acceleration measurement.
UncompGyro	3	Uncompensated angular rate measurement.
Temp	4	Temperature measurement.
Pres	5	Pressure measurement.
DeltaTheta	6	Delta theta angles.
DeltaV	7	Delta velocity.
Mag	8	Compensated magnetic measurement.
Accel	9	Compensated acceleration measurement.
AngularRate	10	Compensated angular rate measurement.
SensSat	11	Sensor saturation bit field.
Resv	12-15	Reserved for future use. Should be set to zero.

5.6.1 ImuStatus

Status is reserved for future use. Not currently used in the current code, as such will always report 0.

	ImuStatus	
Byte Offset	0	1
Type	u16	

5.6.2 UncompMag

The IMU magnetic field measured in units of Gauss, given in the body frame. This measurement is compensated by the static calibration (individual factory calibration stored in flash), and the user compensation, however it is not compensated by the onboard Hard/Soft Iron estimator.

	UncompMag											
	mag[0]				mag[1]				mag[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.3 UncompAccel

The IMU acceleration measured in units of m/s^2, given in the body frame. This measurement is compensated by the static calibration (individual factory calibration stored in flash), however it is not compensated by any dynamic calibration such as bias compensation from the onboard INS Kalman filter.

	UncompAccel											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.4 UncompGyro

The IMU angular rate measured in units of rad/s, given in the body frame. This measurement is compensated by the static calibration (individual factory calibration stored in flash), however it is not compensated by any dynamic calibration such as the bias compensation from the onboard AHRS/INS Kalman filters.

	UncompGyro											
	gyro[0]				gyro[1]				gyro[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.5 Temp

The IMU temperature measured in units of Celsius.

	Temp			
Byte Offset	0	1	2	3
Type	float			

5.6.6 Pres

The IMU pressure measured in kilopascals. This is an absolute pressure measurement. Typical pressure at sea level would be around 100 kPa.

	Pres			
Byte Offset	0	1	2	3
Type	float			

5.6.7 DeltaTheta

The delta theta (dtheta) is the delta rotation angles incurred due to rotation, since the last time the values were output by the device. The delta angles are calculated based upon the onboard conning and sculling integration performed onboard the sensor at the IMU sampling rate (nominally 800Hz). The delta time (dtime) is the time interval that the delta angle and velocities are integrated over. The integration for the delta angles are reset each time the values are either polled or sent out due to a scheduled asynchronous ASCII or binary output. Time is given in sections. Delta angles are given in degrees.

	DeltaTheta															
Fields	dtime				dtheta[0]				dtheta[1]				dtheta[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Type	float				float				float				float			

5.6.8 DeltaV

The delta velocity (dvel) is the delta velocity incurred due to motion, since the last time the values were output by the device. The delta velocities are calculated based upon the onboard conning and sculling integration performed onboard the sensor at the IMU sampling rate (nominally 800Hz). The integration for the delta velocities are reset each time the values are either polled or sent out due to a scheduled asynchronous ASCII or binary output. Delta velocity is given in meters per second.

	DeltaVel											
Fields	dvel[0]				dvel[1]				dvel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.9 Mag

The IMU compensated magnetic field measured units of Gauss, and given in the body frame. This measurement is compensated by the static calibration (individual factory calibration stored in flash), the user compensation, and the dynamic calibration from the onboard Hard/Soft Iron estimator.

	Mag											
	mag[0]				mag[1]				mag[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.10 Accel

The compensated acceleration measured in units of m/s^2, and given in the body frame. This measurement is compensated by the static calibration (individual factory calibration stored in flash), the user compensation, and the dynamic bias compensation from the onboard INS Kalman filter.

	Accel											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.11 AngularRate

The compensated angular rate measured in units of rad/s, and given in the body frame. This measurement is compensated by the static calibration (individual factor calibration stored in flash), the user compensation, and the dynamic bias compensation from the onboard INS Kalman filter.

	AngularRate											
	gyro[0]				gyro[1]				gyro[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.6.12 **SensSat**

This field provides flags identifying whether any of the measurements are currently saturated.

	SensSat	
Byte Offset	0	1
Type	u16	

Table 19 - SensSat Bit Field Description

Name	Bit Offset	Description
MagX	0	Magnetometer X-axis is saturated.
MagY	1	Magnetometer Y-axis is saturated.
MagZ	2	Magnetometer Z-axis is saturated.
AccX	3	Accelerometer X-axis is saturated.
AccY	4	Accelerometer Y-axis is saturated.
AccZ	5	Accelerometer Z-axis is saturated.
GyroX	6	Gyro X-axis is saturated.
GyroY	7	Gyro Y-axis is saturated.
GyroZ	8	Gyro Z-axis is saturated.
Pres	9	Pressure measurement is saturated.
Reserved	10-15	Reserved for future use.

5.7 Binary Group 4 – GPS Outputs

Binary group 4 provides all outputs which are dependent upon the measurements collected from the onboard GPS, or external GPS (if enabled). All data in this group is updated at the rate of the GPS receiver (nominally 5Hz for the internal GPS).

> If data is asynchronously sent from group 4 at a rate equal to the GPS update rate, then packets will be sent out when updated by the GPS receiver. For all other rates, the output will be based on the divisor selected and the internal IMU sampling rate.

Table 20 - Binary Group 4

Name	Bit Offset	Description
UTC	0	GPS UTC Time
Tow	1	GPS time of week
Week	2	GPS week
NumSats	3	Number of tracked satellites
Fix	4	GPS fix
PosLla	5	GPS position (latitude, longitude, altitude)
PosEcef	6	GPS position (ECEF)
VelNed	7	GPS velocity (NED)
VelEcef	8	GPS velocity (ECEF)
PosU	9	GPS position uncertainty (NED)
VelU	10	GPS velocity uncertainty
TimeU	11	GPS time uncertainty
Resv	12-15	Reserved for future use. Should be set to zero.

5.7.1 UTC

The current UTC time. The year is given as a signed byte year offset from the year 2000. For example the year 2013 would be given as year 13.

	UTC							
Fields	year	month	day	hour	min	sec	ms	
Byte Offset	0	1	2	3	4	5	6	7
Type	s8	u8	u8	u8	u8	u8	u16	

5.7.2 Tow

The GPS time of week given in nano seconds.

	Tow							
Byte Offset	0	1	2	3	4	5	6	7
Type	uint64							

5.7.3 Week

The current GPS week.

	Week	
Byte Offset	0	1
Type	u16	

5.7.4 NumSats

The number of tracked GPS satellites.

	NumSats
Byte Offset	0
Type	u8

5.7.5 Fix

The current GPS fix.

	Fix
Byte Offset	0
Type	u8

Table 21 - GPS Fix

Value	Description
0	No fix
1	Time only
2	2D
3	3D

5.7.6 PosLla

The current GPS position measurement given as the geodetic latitude, longitude and altitude above the ellipsoid. The units are in [deg, deg, m] respectfully.

	PosLla																							
	latitude								longitude								altitude							
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	double								double								double							

5.7.7 PosEcef

The current GPS position given in the Earth centered Earth fixed (ECEF) coordinate frame, given in meters.

	PosEcef																							
	pos[0]								pos[1]								pos[2]							
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	double								double								double							

5.7.8 VelNed

The current GPS velocity in the North East Down (NED) coordinate frame, given in m/s.

	VelNed											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.7.9 VelEcef

The current GPS velocity in the Earth centered Earth fixed (ECEF) coordinate frame, given in m/s.

	VelEcef											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.7.10 PosU

The current GPS position uncertainty in the North East Down (NED) coordinate frame, given in meters.

	PosU											
	posU[0]				posU[1]				posU[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.7.11 VelU

The current GPS velocity uncertainty, given in m/s.

	VelU			
Byte Offset	0	1	2	3
Type	float			

5.7.12 TimeU

The current GPS time uncertainty, given in nano seconds.

	TimeU			
Byte Offset	0	1	2	3
Type	u32			

5.8 Binary Group 5 – Attitude Outputs

Binary group 5 provides all estimated outputs which are dependent upon the estimated attitude solution. The attitude will be derived from either the AHRS or the INS, depending upon which filter is currently active and tracking. All of the fields in this group will only be valid if the AHRS/INS filter is currently enabled and tracking.

Table 22 - Binary Group 5

Name	Bit Offset	Description
VpeStatus	0	VPE Status
Ypr	1	Yaw Pitch Roll
Qtn	2	Quaternion
DCM	3	Directional Cosine Matrix
MagNed	4	Compensated magnetic (NED)
AccelNed	5	Compensated acceleration (NED)
LinearAccelBody	6	Compensated linear acceleration (no gravity)
LinearAccelNed	7	Compensated linear acceleration (no gravity) (NED)
YprU	8	Yaw Pitch Roll uncertainty
Resv	9-15	Reserved for future use. Should be set to zero.

5.8.1 VpeStatus

The VPE status bitfield.

	VpeStatus	
Byte Offset	0	1
Type	u16	

Table 23 - VpeStatus BitField

Name	Bit Offset	Format	Unit	Description
AttitudeQuality	0	2 bits	-	Provides an indication of the quality of the attitude solution.
GyroSaturation	2	1 bit	-	At least one gyro axis is currently saturated.
GyroSaturationRecovery	3	1 bit	-	Filter is in the process of recovering from a gyro saturation event.
MagDisturbance	4	2 bit	-	A magnetic DC disturbance has been detected. 0 – No magnetic disturbance 1 to 3 – Magnetic disturbance is present.
MagSaturation	6	1 bit	-	At least one magnetometer axis is currently saturated.
AccDisturbance	7	2 bit	-	A strong acceleration disturbance has been detected. 0 – No acceleration disturbance. 1 to 3 – Acceleration disturbance has been detected.
AccSaturation	9	1 bit	-	At least one accelerometer axis is currently saturated.
Reserved	10	1 bit	-	Reserved for internal use. May change state at run-time.
KnownMagDisturbance	11	1 bit	-	A known magnetic disturbance has been reported by the user and the magnetometer is currently tuned out.
KnownAccelDisturbance	12	1 bit	-	A known acceleration disturbance has been reported by the user and the accelerometer is currently tuned out.
Reserved	13	3 bits	-	Reserved for future use.

Table 24 - AttitudeQuality Field

Value	Description
0	Excellent
1	Good
2	Bad
3	Not tracking

5.8.2 YawPitchRoll

The estimated attitude Yaw, Pitch, and Roll angles measured in degrees. The attitude is given as a 3,2,1 Euler angle sequence describing the body frame with respect to the local North East Down (NED) frame.

	YawPitchRoll											
	yaw				pitch				roll			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.3 Quaternion

The estimated attitude quaternion. The last term is the scalar value. The attitude is given as the body frame with respect to the local North East Down (NED) frame.

	Quaternion															
	qtn[0]				qtn[1]				qtn[2]				qtn[3]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Type	float				float				float				float			

5.8.4 DCM

The estimated attitude directional cosine matrix given in column major order. The DCM maps vectors from the North East Down (NED) frame into the body frame.

	Dcm																							
Fields	dcm[0]				dcm[1]				dcm[2]				dcm[3]				dcm[4]				dcm[5]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	float				float				float				float				float				float			

	Dcm (continued)											
Fields	dcm[6]				dcm[7]				dcm[8]			
Byte Offset	24	25	26	27	28	29	30	31	32	33	34	35
Type	float				float				float			

5.8.5 MagNed

The current estimated magnetic field (Gauss), given in the North East Down (NED) frame. The current attitude solution is used to map the measurement from the measured body frame to the inertial (NED) frame. This measurement is compensated by both the static calibration (individual factory calibration stored in flash), and the dynamic calibration such as the user or onboard Hard/Soft Iron compensation registers.

	MagNed											
	mag[0]				mag[1]				mag[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.6 AccelNed

The estimated acceleration (with gravity) reported in m/s^2, given in the North East Down (NED) frame. The acceleration measurement has been bias compensated by the onboard INS filter. This measurement is attitude dependent, since the attitude is used to map the measurement from the body frame into the inertial (NED) frame. If the device is stationary and the INS filter is tracking, the measurement should be nominally equivalent to the gravity reference vector in the inertial frame (NED).

	AccelNed											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.7 LinearAccelBody

The estimated linear acceleration (without gravity) reported in m/s^2, and given in the body frame. The acceleration measurement has been bias compensated by the onboard INS filter, and the gravity component has been removed using the current gravity reference vector model. This measurement is attitude dependent, since the attitude solution is required to map the gravity reference vector (known in the inertial NED frame), into the body frame so that it can be removed from the measurement. If the device is stationary and the onboard INS filter is tracking, the measurement nominally will read 0 in all three axes.

	LinearAccelBody											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.8 LinearAccelNed

The estimated linear acceleration (without gravity) reported in m/s^2, and given in the North East Down (NED) frame. This measurement is attitude dependent as the attitude solution is used to map the measurement from the body frame into the inertial (NED) frame. This acceleration measurement has been bias compensated by the onboard INS filter, and the gravity component has been removed using the current gravity reference vector estimate. If the device is stationary and the onboard INS filter is tracking, the measurement nominally will read 0 in all three axes.

	LinearAccelNed											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.9 AngularRate

The estimated angular rotation rate reported in rad/s, given in the body frame. This angular rate measurement has been bias compensated by the onboard AHRS/INS Kalman filter. If the device is stationary (not rotating) and the onboard AHRS/INS filter is tracking, the measurement nominally will read 0 in all three axes.

	AngularRate											
	rate[0]				rate[1]				rate[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.8.10 YprU

The estimated attitude (Yaw, Pitch, Roll) uncertainty (1 Sigma), reported in degrees.

	YprU											
	yaw				pitch				roll			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

The estimated attitude (YprU) field is not valid when the INS Scenario mode in the INS Basic Configuration register is set to AHRS mode. See section 10.3.1 for more details.

5.9 Binary Group 6 – INS Outputs

Binary group 6 provides all estimated outputs which are dependent upon the onboard INS state solution. All of the fields in this group will only be valid if the INS filter is currently enabled and tracking.

Table 25 - Binary Group 6

Name	Bit Offset	Description
InsStatus	0	Ins Status
PosLla	1	Ins Position (latitude, longitude, altitude)
PosEcef	2	Ins Position (ECEF)
VelBody	3	Ins Velocity (Body)
VelNed	4	Ins Velocity (NED)
VelEcef	5	Ins Velocity (ECEF)
MagEcef	6	Compensated magnetic (ECEF)
AccelEcef	7	Compensated acceleration (ECEF)
LinearAccelEcef	8	Compensated linear acceleration (no gravity) (ECEF)
PosU	9	Ins Position Uncertainty
VelU	10	Ins Velocity Uncertainty
Resv	11-15	Reserved for future use. Should be set to zero.

5.9.1 InsStatus

The INS status bitfield. See register 63 for more information on the individual bits in this field.

	InsStatus	
Byte Offset	0	1
Type	u16	

5.9.2 PosLla

The estimated position given as latitude, longitude, and altitude given in [deg, deg, m] respectfully.

	PosLla																							
	latitude								longitude								altitude							
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	double								double								double							

5.9.3 PosEcef

The estimate position given in the Earth centered Earth fixed (ECEF) frame, reported in meters.

	PosEcef																							
	pos[0]								pos[1]								pos[2]							
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Type	double								double								double							

5.9.4 VelBody

The estimated velocity in the body frame, given in m/s.

	VelBody											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.5 VelNed

The estimated velocity in the North East Down (NED) frame, given in m/s.

	VelNed											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.6 VelEcef

The estimated velocity in the Earth centered Earth fixed (ECEF) frame, given in m/s.

	VelEcef											
	vel[0]				vel[1]				vel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.7 MagEcef

The compensated magnetic measurement in the Earth centered Earth fixed (ECEF) frame, given in Gauss.

	MagEcef											
	mag[0]				mag[1]				mag[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.8 AccelEcef

The estimated acceleration (with gravity) reported in m/s^2, given in the Earth centered Earth fixed (ECEF) frame. The acceleration measurement has been bias compensated by the onboard INS filter. This measurement is attitude dependent, since the attitude is used to map the measurement from the body frame into the inertial (ECEF) frame. If the device is stationary and the INS filter is tracking, the measurement should be nominally equivalent to the gravity reference vector in the inertial frame (ECEF).

	AccelEcef											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.9 LinearAccelEcef

The estimated linear acceleration (without gravity) reported in m/s^2, and given in the Earth centered Earth fixed (ECEF) frame. This measurement is attitude dependent as the attitude solution is used to map the measurement from the body frame into the inertial (ECEF) frame. This acceleration measurement has been bias compensated by the onboard INS filter, and the gravity component has been removed using the current gravity reference vector estimate. If the device is stationary and the onboard INS filter is tracking, the measurement will nominally read 0 in all three axes.

	LinearAccelEcef											
	accel[0]				accel[1]				accel[2]			
Byte Offset	0	1	2	3	4	5	6	7	8	9	10	11
Type	float				float				float			

5.9.10 PosU

The estimated uncertainty (1 Sigma) in the current position estimate, given in meters.

	PosU			
Byte Offset	0	1	2	3
Type	float			

5.9.11 VelU

The estimated uncertainty (1 Sigma) in the current velocity estimate, given in m/s.

	VelU			
Byte Offset	0	1	2	3
Type	float			

6 System Module

6.1 Commands

6.1.1 Read Register Command

This command allows the user to read any of the registers on the VN-200 module. The only required parameter is the ID of the register to be read. The first parameter of the response will contain the same register ID followed by a variable number of parameters. The number of parameters and their formatting is specific to the requested register. Refer to the appropriate register Section contained in Section 6 for details on this formatting. If an invalid register is requested, an error code will be returned.

Table 26 - Example Read Register Command

Example Command	Message
UART Command	$VNRRG,5*46
UART Response	$VNRRG,5,9600*65
SPI Command	01 05 00 00 (shown as hex)
SPI Response	00 01 05 00 80 25 00 00 (shown as hex)

6.1.2 Write Register Command

This command is used to write data values to a specified register on the VN-200 module. The ID of the register to be written to is the first parameter. This is followed by the data values specific to that register. Refer to the appropriate register in Section 6 for this formatting. If an invalid register is requested, an error code will be returned.

Table 27 - Example Write Register Command

Example Command	Message
UART Command	$VNWRG,5,9600*60
UART Response	$VNWRG,5,9600*60
SPI Command	02 05 00 00 80 25 00 00 (shown as hex)
SPI Response	00 02 05 00 80 25 00 00 (shown as hex)

6.1.3 Write Settings Command

This command will write the current register settings into non-volatile memory. Once the settings are stored in non-volatile (Flash) memory, the VN-200 module can be power cycled or reset, and the register will be reloaded from non-volatile memory. The module can always be reset to the factory settings by issuing the Restore Factory Settings command or by pulling pin 7 (Restore) high during reset.

Table 28 - Example Write Settings Command

Example Command	Message
UART Command	$VNWNV*57
UART Response	$VNWNV*57
SPI Command	03 00 00 00 (shown as hex)
SPI Response	00 03 00 00 (shown as hex)

Due to limitations in the flash write speed the write settings command takes ~ 500ms to complete. Any commands that are sent to the sensor during this time will be responded to after the operation is complete.

6.1.4 Restore Factory Settings Command

This command will restore the VN-200 module's factory default settings and will reset the module. There are no parameters for this command. The module will respond to this command before restoring the factory settings.

Table 29 - Example Restore Factory Settings Command

Example Command	Message
UART Command	$VNRFS*5F
UART Response	$VNRFS*5F
SPI Command	04 00 00 00 (shown as hex)
SPI Response	00 04 00 00 (shown as hex)

6.1.5 Reset Command

This command will reset the module. There are no parameters required for this command. The module will first respond to the command and will then perform a reset. Upon a reset all registers will be reloaded with the values saved in non-volatile memory. If no values are stored in non-volatile memory, the device will default to factory settings. Also upon reset the VN-200 will re-initialize its Kalman filter, thus the filter will take a few seconds to completely converge on the correct attitude and correct for gyro bias. This command is equivalent in functionality to the hardware reset performed by pulling pin 21 (NRST) low.

Table 30 - Example Reset Command

Example Command	Message
UART Command	$VNRST*4D
UART Response	$VNRST*4D
SPI Command	06 00 00 00 (shown as hex)
SPI Response	00 06 00 00 (shown as hex)

6.1.6 Firmware Update Command

This command is used to enter the boot loader for performing firmware updates. Upon receiving this command on serial port 1, the VN-200 will enter into firmware reprogramming mode. The easiest method of updating firmware is to use one of the VectorNav Firmware Update Tools. If you wish however to incorporate the ability to update the firmware into your own system, the protocol and procedure for updating the firmware is outlined in the **AN013 Firmware Update Protocol** application note.

Table 31 - Example Firmware Update Command

Example Command	Message
UART Command	$VNFWU*XX
UART Response	$VNFWU*XX

Firmware updates are only supported on serial port 1 (pin 12 & 13). If you plan on using either serial port 2 or SPI as your primary means of communicating with the sensor, it is recommended that you also provide support in your design to communicate with the sensor using serial port 1 to facilitate firmware updates.

6.1.7 Serial Command Prompt Command

This command allows you to enter into the command prompt mode on either serial port. The command mode supports a wide range of diagnostics and configuration options that go beyond the abilities of the normal read/write configuration register interface.

Table 32 - Example Command Prompt Command

Example Command	Message
UART Command	$VNCMD*XX
UART Response	$VNCMD*XX

6.1.8 Asynchronous Output Pause Command

This command allows the user to temporarily pause the asynchronous outputs on the given serial port. When paused both the ASCII and the 3 binary asynchronous output messages will temporarily stop outputting from the device on the serial port for which this command is received. The state of the asynchronous output register and the binary output configuration registers will not be changed when the asynchronous outputs are paused. This command is useful when you want to send configuration commands to the VN-200, but do not want to deal with the additional overhead of having to parse a constant stream of asynchronous output messages while waiting for the response to your configuration commands. It is also useful when you want to type commands to the device from a serial command prompt. The below example commands demonstrate how to pause and resume asynchronous outputs.

Table 33 - Example Asynchronous Pause/Resume Commands

Example Command	Message
Pause Async Outputs	$VNASY,0*XX
Resume Async Outputs	$VNASY,1*XX

6.2 Configuration Registers

6.2.1 User Tag Register

User Tag				
Register ID :	0	**Firmware :** 1.0.0.0		**Access :** Read / Write
Comment :	User assigned tag register. Any values can be assigned to this register. They will be stored to flash upon issuing a write settings command.			
Size (Bytes):	20			
Example Response:	$VNRRG,00,SENSOR_A14*52			

Offset	Name	Format	Unit	Description
0	Tag	char	-	User defined tag register. Up to 20 bytes or characters. If a string with more than 20 characters is given, then the string will be truncated to the first 20.

Only printable ASCII characters are allowed for the user tag register.

Allowable characters include any character in the hexadecimal range of 0x20 to 0x7E, excluding 0x24 (‘$’), 0x2C (‘,’), and 0x2A (‘*’). The use any other character will result in an invalid parameter error code returned. This restriction is required to ensure that the value set in the user tag register remains accessible using both the SPI and serial ASCII protocols.

6.2.2 Model Number Register

Model Number					
Register ID :	1	**Firmware :**	1.0.0.0	**Access :**	Read Only
Comment :	Model Number				
Size (Bytes):	24				
Example Response:	$VNRRG,01,VN-200T-DEV*74				

Offset	Name	Format	Unit	Description
0	Product Name	char	-	Product name. Max 24 characters.

6.2.3 Hardware Revision Register

Hardware Revision Register					
Register ID :	2	**Firmware :**	1.0.0.0	**Access :**	Read Only
Comment :	Hardware revision.				
Size (Bytes):	4				
Example Response:	$VNRRG,02,1*6C				

Offset	Name	Format	Unit	Description
0	Revision	uint32	-	Hardware revision.

6.2.4 Serial Number Register

Serial Number					
Register ID :	3	**Firmware :**	1.0.0.0	**Access :**	Read Only
Comment :	Serial Number				
Size (Bytes):	4				
Example Response:	$VNRRG,03,0100011981*5D				

Offset	Name	Format	Unit	Description
0	SerialNum	uint32	-	Serial Number (32-bit unsigned integer)

6.2.5 Firmware Version Register

Firmware Version Register				
Register ID :	4	**Firmware :** 1.0.0.0		**Access :** Read Only
Comment :	Firmware version.			
Size (Bytes):	4			
Example Response:	$VNRRG,04,0.1.7.0*73			

Offset	Name	Format	Unit	Description
0	Major Version	uint8	-	Major release version of firmware.
1	Minor Version	uint8	-	Minor release version of firmware
2	Feature Version	uint8	-	Feature release version of the firmware.
3	HotFix	uint8	-	Hot fix number. Numbers above 100 are reserved for custom firmware versions.

6.2.6 Serial Baud Rate Register

Serial Baud Rate				
Register ID :	5	Firmware : 1.0.0.0		Access : Read / Write
Comment :	Serial baud rate.			
Size (Bytes):	4			
Example Command:	$VNWRG,05,115200*58			
Offset	**Name**	**Format**	**Unit**	**Description**
0	Baud Rate	uint32	-	Serial baud rate.
4	Serial Port	uint8	-	Optional. The serial port to change the baud rate on. If this parameter is not provided then the baud rate will be changed for the active serial port. 1 – Serial Port 1 2 – Serial Port 2

Table 34 – Baud Rate Settings

Acceptable Baud Rates
9600
19200
38400
57600
115200
128000
230400
460800
921600

The serial port parameter in this register is optional. If it is not provided, the baud rate will be changed on the active serial port. The response to this register will include the serial port parameter if the optional parameter is provided. If the second parameter is not provided then the response will not include this parameter.

Upon receiving a baud rate change request, the VN-200 will send the response prior to changing the baud rate.

6.2.7 Async Data Output Type Register

Asynchronous Data Output Type					
Register ID :	6	**Firmware :**	1.0.0.0	**Access :**	Read / Write
Comment :	Asynchronous data output type.				
Size (Bytes):	4				
Example Command:	$VNWRG,06,0*6C				

Offset	Name	Format	Unit	Description
0	ADOR	uint32	-	Output register.
4	Serial Port	uint8	-	Optional. The serial port to change the asynchronous data type on. If this parameter is not provided then the ADOR will be changed for the active serial port. 1 – Serial Port 1 2 – Serial Port 2

This register controls the type of data that will be asynchronously outputted by the module. With this register, the user can specify which data register will be automatically outputted when it gets updated with a new reading. Table 35 below lists which registers can be set to asynchronously output, the value to specify which register to output, and the header of the asynchronous data packet. Asynchronous data output can be disabled by setting this register to zero. The asynchronous data output will be sent out automatically at a frequency specified by the Async Data Output Frequency Register (Section 0).

> The serial port parameter in this register is optional. If it is not provided, the ADOF will be changed on the active serial port. The response to this register will include the serial port parameter if the optional parameter is provided. If the second parameter is not provided, the response will not include this parameter.

Table 35 – Asynchronous Solution Output Settings

Setting	Asynchronous Solution Output Type	Header	Formatting Section
0	Asynchronous output turned off	N/A	
1	Yaw, Pitch, Roll	VNYPR	
2	Quaternion	VNQTN	
8	Quaternion, Magnetic, Acceleration and Angular Rates	VNQMR	
10	Magnetic Measurements	VNMAG	
11	Acceleration Measurements	VNACC	
12	Angular Rate Measurements	VNGYR	
13	Magnetic, Acceleration, and Angular Rate Measurements	VNMAR	
14	Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rate Measurements	VNYMR	
16	Yaw, Pitch, Roll, Body True Acceleration, and Angular Rates	VNYBA	
17	Yaw, Pitch, Roll, Inertial True Acceleration, and Angular Rates	VNYIA	
19	IMU Measurements	VNIMU	
20	GPS LLA	VNGPS	
21	GPS ECEF	VNGPE	
22	INS LLA	VNINS	
23	INS ECEF	VNINE	
28	INS LLA 2	VNISL	
29	INS ECEF 2	VNISE	
30	Delta theta and delta velocity	VNDTV	

6.2.8 Async Data Output Frequency Register

Asynchronous Data Output Frequency				
	Register ID :	7	Firmware : 1.0.0.0	Access : Read / Write
	Comment :	Asynchronous data output frequency.		
	Size (Bytes):	4		
	Example Command:	$VNWRG,07,40*59		
Offset	**Name**	**Format**	**Unit**	**Description**
0	ADOF	uint32	Hz	Output frequency.
4	Serial Port	uint8	-	Optional. The serial port to change the asynchronous data type frequency on. If this parameter is not provided then the ADOF will be changed for the active serial port. 1 – Serial Port 1 2 – Serial Port 2

Table 36 - ADOR Data Rates

Acceptable Data Rates (Hz)
1
2
4
5
10
20
25
40
50
100
200

The serial port parameter in this register is optional. If it is not provided, the ADOF will be changed on the active serial port. The response to this register will include the serial port parameter if the optional parameter is provided. If the second parameter is not provided, the response will not include this parameter.

6.2.9 Synchronization Control

Synchronization Control				
	Register ID :	32	Firmware : v1.0.0.0	Access : Read / Write
	Comment :	Contains parameters which allow the timing of the VN-200 to be synchronized with external devices.		
	Size (Bytes):	20		
	Example Response:	$VNRRG,32,3,0,0,0,6,1,0,100000000,0*6B		
Offset	**Name**	**Format**	**Unit**	**Description**
0	SyncInMode	uint8	-	Input signal synchronization mode
1	SyncInEdge	uint8	-	Input signal synchronization edge selection
2	SyncInSkipFactor	uint16	-	Input signal trigger skip factor
4	RESERVED	uint32	-	Reserved for future use. Defaults to 0.
8	SyncOutMode	uint8	-	Output synchronization signal mode
9	SyncOutPolarity	uint8	-	Output synchronization signal polarity
10	SyncOutSkipFactor	uint16	-	Output synchronization signal skip factor
12	SyncOutPulseWidth	uint32	ns	Output synchronization signal pulse width
16	RESERVED	uint32	-	Reserved for future use. Defaults to 0.

SyncInMode

The SyncInMode register controls the behavior of the SyncIn event. If the mode is set to COUNT then the internal clock will be used to control the IMU sampling. If SyncInMode is set to IMU then the IMU sampling loop will run on a SyncIn event. The relationship between the SyncIn event and a SyncIn trigger is defined by the SyncInEdge and SyncInSkipFactor parameters. If set to ASYNC then the VN-200 will output asynchronous serial messages upon each trigger event.

Table 37 – SyncIn Mode

Mode	Pin	Value	Description
COUNT	SYNC_IN	3	Count number of trigger events on SYNC_IN (pin 22).
IMU	SYNC_IN	4	Start IMU sampling on trigger of SYNC_IN (pin 22).
ASYNC	SYNC_IN	5	Output asynchronous message on trigger of SYNC_IN (pin 22).

SyncInEdge

The SyncInEdge register controls the type of edge the signal is set to trigger on. The factory default state is to trigger on a rising edge.

Table 38 – SyncInEdge Mode

Value	Description
0	Trigger on rising edge
1	Trigger on falling edge

SyncInSkipFactor

The SyncInSkipFactor defines how many times trigger edges defined by SyncInEdge should occur prior to triggering a SyncIn event. The action performed on a SyncIn event is determined by the SyncIn mode. As an example if the SyncInSkipFactor was set to 4 and a 1 kHz signal was attached to the SyncIn pin, then the SyncIn event would only occur at 200 Hz.

SyncOutMode

The SyncOutMode register controls the behavior of the SyncOut pin. If this is set to IMU then the SyncOut will start the pulse when the internal IMU sample loop starts. This mode is used to make a sensor the Master in a multi-sensor network array. If this is set to IMU_READY mode then the pulse will start when IMU measurements become available. If this is set to INS mode then the pulse will start when attitude measurements are made available. Changes to this register take effect immediately.

Table 39 – SyncOutMode

Mode	Value	Description
NONE	0	None
IMU_START	1	Trigger at start of IMU sampling
IMU_READY	2	Trigger when IMU measurements are available
INS	3	Trigger when attitude measurements are available
GPS_PPS	6	Trigger on a GPS PPS event (1 Hz) when a 3D fix is valid.

SyncOutPolarity

The SyncOutPolarity register controls the polarity of the output pulse on the SyncOut pin. Changes to this register take effect immediately.

Table 40 – SyncOutPolarity

Value	Description
0	Negative Pulse
1	Positive Pulse

SyncOutSkipFactor

The SyncOutSkipFactor defines how many times the sync out event should be skipped before actually triggering the SyncOut pin.

SyncOutPulseWidth

The SyncOutPulseWidth field controls the desired width of the SyncOut pulse. The default value is 100,000,000 (100 ms).

6.2.10 Communication Protocol Control

Communication Protocol Control					
Register ID :	30	**Firmware :**	1.0.0.0	**Access :**	Read / Write
Comment :	Contains parameters that controls the communication protocol used by the VN-200.				
Size (Bytes):	7				
Example Response:	$VNRRG,30,0,0,0,0,1,0,1*6C				

Offset	Name	Format	Unit	Description
0	SerialCount	uint8	-	Provides the ability to append a counter or time to the end of the serial asynchronous messages.
1	SerialStatus	uint8	-	Provides the ability to append the status to the end of the serial asynchronous messages.
2	SPICount	uint8	-	Provides the ability to append a counter to the end of the SPI packets.
3	SPIStatus	uint8	-	Provides the ability to append the status to the end of the SPI packets.
4	SerialChecksum	uint8	-	Choose the type of checksum used for serial communications.
5	SPIChecksum	uint8	-	Choose the type of checksum used for the SPI communications.
6	ErrorMode	uint8	-	Choose the action taken when errors are generated.

Serial Count

The SerialCount field provides a means of appending a time or counter to the end of all asynchronous communication messages transmitted on the serial interface. The values for each of these counters come directly from the Synchronization Status Register (Register 33).

With the SerialCount field set to OFF a typical serial asynchronous message would appear as the following:

```
$VNYPR,+010.071,+000.278,-002.026*60
```

With the SerialCount field set to one of the non-zero values the same asynchronous message would appear instead as:

```
$VNYPR,+010.071,+000.278,-002.026,T1162704*2F
```

When the SerialCount field is enabled the counter will always be appended to the end of the message just prior to the checksum. The counter will be preceded by the T character to distinguish it from the status field.

Table 41 – SerialCount Field

Mode	Value	Description
NONE	0	OFF
SYNCIN_COUNT	1	SyncIn Counter
SYNCIN_TIME	2	SyncIn Time
SYNCOUT_COUNT	3	SyncOut Counter
GPS_PPS	4	Gps Pps Time

SerialStatus

The SerialStatus field provides a means of tracking real-time status information pertaining to the overall state of the sensor measurements and onboard filtering algorithm. As with the SerialCount, a typical serial asynchronous message would appear as the following:

```
$VNYPR,+010.071,+000.278,-002.026*60
```

With the SerialStatus field set to one of the non-zero values, the same asynchronous message would appear instead as:

```
$VNYPR,+010.071,+000.278,-002.026,S0000*1F
```

When the SerialStatus field is enabled the status will always be appended to the end of the message just prior to the checksum. If both the SerialCount and SerialStatus are enabled then the SerialStatus will be displayed first. The counter will be preceded by the S character to distinguish it from the counter field. The status consists of 4 hexadecimal characters.

Table 42 – SerialStatus

Value	Description
0	OFF
1	VPE Status
2	INS Status

SPICount

The SPICount field provides a means of appending a time or counter to the end of all SPI packets. The values for each of these counters come directly from the Synchronization Status Register.

Table 43 – SPICount Field

Mode	Value	Description
NONE	0	OFF
SYNCIN_COUNT	1	SyncIn Counter
SYNCIN_TIME	2	SyncIn Time
SYNCOUT_COUNT	3	SyncOut Counter
GPS_PPS	4	Gps Pps Time

SPIStatus

The AsyncStatus field provides a means of tracking real-time status information pertaining to the overall state of the sensor measurements and onboard filtering algorithm. This information is very useful in situations where action must be taken when certain crucial events happen such as the detection of gyro saturation or magnetic interference.

Table 44 – SPIStatus

Value	Description
0	OFF
1	VPE Status
2	INS Status

SerialChecksum

This field controls the type of checksum used for the serial communications. Normally the VN-200 uses an 8-bit checksum identical to the type used for normal GPS NMEA packets. This form of checksum however offers only a limited means of error checking. As an alternative a full 16-bit CRC (CRC16-CCITT with polynomial = 0x07) is also offered. The 2-byte CRC value is printed using 4 hexadecimal digits.

Table 45 – SerialChecksum

Value	Description
1	8-Bit Checksum
3	16-Bit CRC

SPIChecksum

This field controls the type of checksum used for the SPI communications. The checksum is appended to the end of the binary data packet. The 16-bit CRC is identical to the one described above for the SerialChecksum.

Table 46 – SPIChecksum

Value	Description
0	OFF
1	8-Bit Checksum
3	16-Bit CRC

ErrorMode

This field controls the type of action taken by the VN-200 when an error event occurs. If the send error mode is enabled then a message similar to the one shown below will be sent on the serial bus when an error event occurs.

```
$VNERR,03*72
```

Regardless of the state of the ErrorMode, the number of error events is always recorded and is made available in the SysErrors field of the Communication Protocol Status Register.

Table 47 – ErrorMode

Value	Description
0	Ignore Error
1	Send Error
2	Send Error and set ADOR register to OFF

Example Async Messages

The following table shows example asynchronous messages with the AsyncCount and the AsyncStatus values appended to the end.

Example Type	Message
Async Message with AsyncCount Enabled	$VNYPR,+010.071,+000.278,-002.026,T1162704*2F
Async Message with AsyncStatus Enabled	$VNYPR,+010.071,+000.278,-002.026,S0000*1F
Async Message with AsyncCount and AsyncStatus Enabled	$VNYPR,+010.071,+000.278,-002.026,T1162704,S0000*50

6.2.11 Binary Output Register 1

Binary Output Register 1				
Register ID :	75	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	This register allows the user to construct a custom binary output message that contains a collection of desired estimated states and sensor measurements.			
Size (Bytes):	6-22			
Example Response:	$VNWRG,75,2,4,1,8*XX			

Offset	Name	Format	Unit	Description
0	AsyncMode	uint16	-	Selects whether the output message should be sent out on the serial port(s) at a fixed rate. 0 = None. User message is not automatically sent out either serial port. 1 = Message is sent out serial port 1 at a fixed rate. 2 = Message is sent out serial port 2 at a fixed rate. 3 = Message is sent out both serial ports at a fixed rate.
2	RateDivisor	uint16	-	Sets the fixed rate at which the message is sent out the selected serial port(s). The number given is a divisor of the ***ImuRate*** which is nominally 800Hz. For example to have the sensor output at 50Hz you would set the Divisor equal to 4.
4	OutputGroup	uint16	-	Selects which output groups are active in the message. The number of **OutputFields** in this message should equal the number of active bits in the **OutputGroup**.
6	OutputField(1)	uint16	-	Active output fields for the first active group.
4+2*N	OutputField(N)	uint16	-	Active output fields for the Nth active group.

See section 5.2 for information on the format for the Groups and Group Fields.

The size of this register is variable depending upon the number of group fields present. When writing to this register you must provide the same number of group fields as there are bits active in the group byte. If this condition is not met, the unit will respond with an invalid parameter error code on a write register attempt.

The maximum size of a binary packet must not exceed 600 bytes. If you attempt to specify an output group and output fields for a packet with a length greater than 600 bytes (including the header and CRC), you will receive an invalid parameter error when writing to this register.

6.2.12 Binary Output Register 2

Binary Output Register 2					
Register ID :	76	**Firmware :**	v1.0.0.0	**Access :**	Read / Write
Comment :	This register allows the user to construct a custom binary output message that contains a collection of desired estimated states and sensor measurements.				
Size (Bytes):	6-22				
Example Response:	$VNWRG,76,2,4,1,8*XX				

Offset	Name	Format	Unit	Description
0	AsyncMode	uint16	-	Selects whether the output message should be sent out on the serial port(s) at a fixed rate. 0 = None. User message is not automatically sent out either serial port. 1 = Message is sent out serial port 1 at a fixed rate. 2 = Message is sent out serial port 2 at a fixed rate. 3 = Message is sent out both serial ports at a fixed rate.
2	RateDivisor	uint16	-	Sets the fixed rate at which the message is sent out the selected serial port(s). The number given is a divisor of the ***ImuRate*** which is nominally 800Hz. For example to have the sensor output at 50Hz you would set the Divisor equal to 4. If you are polling the message, set the divisor to 1.
4	OutputGroup	uint16	-	Selects which output groups are active in the message. The number of **OutputFields** in this message should equal the number of active bits in the **OutputGroup**.
6	OutputField(1)	uint16	-	Active output fields for the first active group.
4+2*N	OutputField(N)	uint16	-	Active output fields for the Nth active group.

See section 5.2 for information on the format for the Groups and Group Fields.

The size of this register is variable depending upon the number of group fields present. When writing to this register you must provide the same number of group fields as there are bits active in the group byte. If this condition is not met, the unit will respond with an invalid parameter error code on a write register attempt.

The maximum size of a binary packet must not exceed 600 bytes. If you attempt to specify an output group and output fields for a packet with a length greater than 600 bytes (including the header and CRC), you will receive an invalid parameter error when writing to this register.

6.2.13 Binary Output Register 3

Binary Output Register 3				
Register ID :	77	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	This register allows the user to construct a custom binary output message that contains a collection of desired estimated states and sensor measurements.			
Size (Bytes):	6-22			
Example Response:	$VNWRG,77,2,4,1,8*XX			
Offset	**Name**	**Format**	**Unit**	**Description**
0	AsyncMode	uint16	-	Selects whether the output message should be sent out on the serial port(s) at a fixed rate. 0 = None. User message is not automatically sent out either serial port. 1 = Message is sent out serial port 1 at a fixed rate. 2 = Message is sent out serial port 2 at a fixed rate. 3 = Message is sent out both serial ports at a fixed rate.
2	RateDivisor	uint16	-	Sets the fixed rate at which the message is sent out the selected serial port(s). The number given is a divisor of the ***ImuRate*** which is nominally 800Hz. For example to have the sensor output at 50Hz you would set the Divisor equal to 4. If you are polling the message, set the divisor to 1.
4	OutputGroup	uint16	-	Selects which output groups are active in the message. The number of **OutputFields** in this message should equal the number of active bits in the **OutputGroup**.
6	OutputField(1)	uint16	-	Active output fields for the first active group.
4+2*N	OutputField(N)	uint16	-	Active output fields for the Nth active group.

See section 5.2 for information on the format for the Groups and Group Fields.

The size of this register is variable depending upon the number of group fields present. When writing to this register you must provide the same number of group fields as there are bits active in the group byte. If this condition is not met, the unit will respond with an invalid parameter error code on a write register attempt.

The maximum size of a binary packet must not exceed 600 bytes. If you attempt to specify an output group and output fields for a packet with a length greater than 600 bytes (including the header and CRC), you will receive an invalid parameter error when writing to this register.

6.3 Status Registers

6.3.1 Synchronization Status

Synchronization Status				
Register ID :	33	**Firmware :** v1.0.0.0	**Access :**	Read / Write
Comment :	Contains status parameters that pertaining to the communication synchronization features.			
Size (Bytes):	12			
Example Response:	$VNRRG,33,2552498,0,0*6A			

Offset	Name	Format	Unit	Description
0	SyncInCount	uint32	-	Keeps track of the number of times that the SyncIn trigger even has occured. This register can be used to correlate the attitude to an event on an external system such as a camera or GPS. It is also possible to have the value of this register appended to each asynchronous data packet on the serial bus. This can be done by setting the AsyncStatus field in the Communication Protocol register to 1.
4	SyncInTime	uint32	µs	Keeps track of the amount of time that has elapsed since the last SyncIn trigger event. If the SyncIn pin is connected to the PPS (Pulse Per Second) line on a GPS and the AsyncStatus field in the Communication Protocol Register is set to 1, then each asynchronous measurement will be time stamped relative to the last received GPS measurement.
8	SyncOutCount	uint32	-	Keeps track of the number of times that the SyncOut trigger event has occurred. This register can be used to index subsequent measurement outputs, which is particularly useful when logging sensor data.

Writing zero to the SyncInCount or the SyncOutCount will reset the status counter. Any other value other than zero will not have an effect. The SyncInTime is read only and cannot be reset to zero.

6.4 Factory Defaults

Settings Name	Default Factory Value
User Tag	NULL (Empty string)
Serial Baud Rate	115200
Async Data Output Frequency	40 Hz
Async Data Output Type	INS_LLA
Synchronization Control	3,0,0,0,6,1,0,100000000,0
Communication Protocol Control	0,0,0,0,1,0,1
Binary Output Register 1	0, 0, 0
Binary Output Register 2	0, 0, 0
Binary Output Register 3	0, 0, 0

6.5 Command Prompt

The command prompt provides a fast and simple means of configuring and monitoring the status of the sensor by typing commands to the unit using the serial port.

6.5.1 List Available Commands

Commands for the System subsystem can be accessed by typing in 'system' at the command prompt. To view all available commands, type 'system ?'. Below is a view of a terminal window showing a list of the available commands.

```
system ?

System Module Commands:

Command:    Description:
--------    ----------------------------------------
info        Device specific information such as serial number and firmware version.
comm        Information on the communication interfaces.
errors      Overview of the logged system errors.
reset       Perform a software reset on the unit.
save        Save register settings to flash memory.
restore     Restore register settings to their factory default state.
```

6.5.2 System Info

```
system info

--------------------------------  System Info  ---------------------------------

Hardware:
      Product Model:  VN-200S-DEV
      Serial Number:  100013003
  MCU Serial Number:  34323439044731322F002100
  Hardware Revision:  2
      Form Revision:  1

Software:
   Firmware Version:  1.0.0.0
           Revision:  592
       Build Number:  1079

--------------------------------------------------------------------------------
```

6.5.3 System Comm

```
system comm

----------------------  System Communication Interfaces  -----------------------

Communication Stats:
  Serial Messages Parsed              : 29
  Spi Messages Parsed                 : 0
  Max Serial RX Buffer Usage          : 0
  Max Serial TX Buffer Usage          : 4
  Max Spi RX Buffer Usage             : 0
  Max Spi TX Buffer Usage             : 0
```

```
  Current Serial 1 TX Bandwidth Usage : 00.0
  Current Serial 2 TX Bandwidth Usage : 49.3

  Max Serial 1 TX Bandwidth Usage : 49.3
  Max Serial 2 TX Bandwidth Usage : 50.5

  Min Serial 1 TX Bandwidth Usage : 00.0
  Min Serial 2 TX Bandwidth Usage : 48.1

-------------------------------------------------------------------------------
```

6.5.4 System Errors

```
system errors

------------------------------  System Errors  -------------------------------

  Hard Fault Exceptions              : 0
  Serial Input Buffer Overflow       : 0
  Serial Output Buffer Overflow      : 0
  Serial Insufficient Bandwidth      : 0
  Invalid Checksums                  : 6
  Invalid Commands                   : 2
  Input Error - Too Few Parameters   : 0
  Input Error - Too Many Parameters  : 0
  Input Error - Invalid Parameter    : 0
  Input Error - Invalid Register     : 0
  Input Error - Unauthorized Access  : 2
  Input Error - Watchdog Reset       : 0

-------------------------------------------------------------------------------
```

6.5.5 System Reset

```
system reset
```

6.5.6 System Save

```
system save
```

7 IMU Subsystem

7.1 IMU Measurement Registers

7.1.1 IMU Measurements

This register provides direct access to the calibrated magnetometer, accelerometer, gyro, barometric pressure, and temperature measurements available from the onboard IMU.

IMU Measurements					
Register ID :	54	**Async Header :**	IMU	**Access :**	Read Only
Comment :	Provides the calibrated IMU measurements including barometric pressure.				
Size (Bytes):	44				
Example Read Response:	$VNRRG,54,-02.0841,+00.6045,+02.8911,+00.381,-00.154,-09.657,-00.005683, +00.000262,+00.001475,+21.6,+00099.761*5B				

Offset	Name	Format	Unit	Description
0	MagX	float	Gauss	Uncompensated Magnetic X-axis.
4	MagY	float	Gauss	Uncompensated Magnetic Y-axis.
8	MagZ	float	Gauss	Uncompensated Magnetic Z-axis.
12	AccelX	float	m/s^2	Uncompensated Acceleration X-axis.
16	AccelY	float	m/s^2	Uncompensated Acceleration Y-axis.
20	AccelZ	float	m/s^2	Uncompensated Acceleration Z-axis.
24	GyroX	float	rad/s	Uncompensated Angular rate X-axis.
28	GyroY	float	rad/s	Uncompensated Angular rate Y-axis.
32	GyroZ	float	rad/s	Uncompensated Angular rate Z-axis.
36	Temp	float	C	IMU Temperature.
40	Pressure	float	kPa	Barometric pressure.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNIMU header.

7.1.2 Delta Theta and Delta Velocity

Delta Theta and Delta Velocity				
Register ID :	80	Async Header: DTV		Access : Read
Comment :	This register contains the output values of the onboard coning and sculling algorithm.			
Size (Bytes):	28			
Example Response:	$VNRRG,80,+0.665016,-000.119,-000.409,-000.025,+000.011,-000.084,-006.702*6A			

Offset	Name	Format	Unit	Description
0	DeltaTime	float	sec	Delta time for the integration interval
4	DeltaThetaX	float	deg	Delta rotation vector component in the x-axis.
8	DeltaThetaY	float	deg	Delta rotation vector component in the y-axis.
12	DeltaThetaZ	float	deg	Delta rotation vector component in the z-axis.
16	DeltaVelocityX	float	m/s	Delta velocity vector component in the x-axis.
20	DeltaVelocityY	float	m/s	Delta velocity vector component in the y-axis.
24	DeltaVelocityZ	float	m/s	Delta velocity vector component in the z-axis.

The Delta Theta and Delta Velocity register contains the computed outputs from the onboard coning and sculling algorithm. The coning and sculling integrations are performed at the IMU sample rate (nominally at 800Hz) and reset when the register data is output. If polling this register, the values will represent the delta time, angles, and velocity since the register was last polled. If the Delta Theta/Velocity data is selected for asynchronous output via the Async Data Output Type register (Register 6, type 30), the integrals will be reset each time the data is asynchronously output at the configured rate.

The delta time output contains the length of the time interval over which the deltas were calculated. This can be used to check the interval time or to compute nonlinear "average" rates and accelerations from the integrated values.

The delta theta is output as a principal rotation vector, defined as the product of the unit vector of the principal rotation axis and the principal rotation angle in degrees. For small rotations, a typical use case for delta angles, the principal rotation vector elements may be treated individually as rotations in degrees about the individual sensor axes (in any Euler rotation sequence) with little error.

The delta velocity output provides the integration of the acceleration in the chosen frame, taking into account the coupling effects of any simultaneous rotation experienced.

The coning and sculling algorithm can be configured to operate in multiple frames and with a variety of compensations applied. See the Delta Theta and Delta Velocity Configuration register (Register 82) for further details.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNDTV header.

7.2 IMU Configuration Registers

7.2.1 Magnetometer Compensation

Magnetometer Compensation					
Register ID :	23	Firmware :	1.0.0.0	Access:	Read / Write
Comment :	Allows the magnetometer to be compensated for hard/soft iron effects.				
Size (Bytes):	48				
Example Command:	$VNRRG,23,1,0,0,0,1,0,0,0,1,0,0,0*73				

Offset	Name	Format	Unit	Description
0	C[0,0]	float	-	
4	C[0,1]	float	-	
8	C[0,2]	float	-	
12	C[1,0]	float	-	
16	C[1,1]	float	-	
20	C[1,2]	float	-	
24	C[2,0]	float	-	
28	C[2,1]	float	-	
32	C[2,2]	float	-	
36	B[0]	float	-	
40	B[1]	float	-	
44	B[2]	float	-	

This register contains twelve values representing the hard and soft iron compensation parameters. The magnetic measurements are compensated for both hard and soft iron using the following model. Under normal circumstances this register can be left in its factory default state. In the event that there are disturbances in the magnetic field due to hard or soft iron effects, then these registers allow for further compensation. These registers can also be used to compensate for significant changes to the magnetometer bias, gain, and axis alignment during installation. Note that this magnetometer compensation is separate from the compensation that occurs during the calibration process at the factory. Setting this register to the default state of an identity matrix and zero offset will not eliminate the magnetometer gain, bias, and axis alignment that occur during factory calibration. These registers only need to be changed from their default values in the event that hard/soft iron compensation needs to be performed, or changes in bias, gain, and axis alignment have occurred at some point between the times the chip was calibrated at the factory and when it is used in the field.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} MX - B0 \\ MY - B1 \\ MZ - B2 \end{Bmatrix}$$

The variables $\{MX, MY, MZ\}$ are components of the measured magnetic field. The {X, Y, Z} variables are the new magnetic field measurements outputted after compensation for hard/soft iron effects. All twelve numbers are represented by single-precision floating points.

7.2.2 Acceleration Compensation

Accelerometer Compensation					
Register ID :	25	Firmware :	1.0.0.0	Access :	Read / Write
Comment :	Allows the accelerometer to be further compensated for scale factor, misalignment, and bias errors.				
Size (Bytes):	48				
Example Command:	$VNRRG,25,1,0,0,0,1,0,0,0,1,0,0,0*75				

Offset	Name	Format	Unit	Description
0	C[0,0]	float	-	
4	C[0,1]	float	-	
8	C[0,2]	float	-	
12	C[1,0]	float	-	
16	C[1,1]	float	-	
20	C[1,2]	float	-	
24	C[2,0]	float	-	
28	C[2,1]	float	-	
32	C[2,2]	float	-	
36	B[0]	float	-	
40	B[1]	float	-	
44	B[2]	float	-	

This register contains twelve values representing the accelerometer compensation parameters. The accelerometer measurements are compensated for changes in bias, gain, and axis alignment that can occur during the installation of the chip on the customer's board using the following model. Under normal circumstances this register can be left in its factory default state. In the event that there are significant changes to the accelerometer bias, gain, and axis alignment during installation, then these registers allow for further compensation. Note that this accelerometer compensation is separate from the compensation that occurs during the calibration process at the factory. Setting this register to the default state of an identity matrix and zero offset will not eliminate the accelerometer gain, bias, and axis alignment that occur during factory calibration. These registers only need to be changed from their default values in the event that changes in bias, gain, and axis alignment have occurred at some point between the times the chip was calibrated at the factory and when it is used in the field.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} AX - B0 \\ AY - B1 \\ AZ - B2 \end{Bmatrix}$$

The variables {AX,AY,AZ} are components of the measured acceleration. The {X, Y, Z} variables are the new acceleration measurements outputted after compensation for changes during sensor mounting. All twelve numbers are represented by single-precision floating points.

7.2.3 Gyro Compensation

Gyro Compensation					
Register ID :	84	**Firmware :**	v1.0.0.0	**Access :**	Read / Write
Comment :	Allows the gyro to be further compensated for scale factor, misalignment, and bias errors.				
Size (Bytes):	48				
Example Command:	$VNRRG,84,1,0,0,0,1,0,0,0,1,0,0,0*7E				

Offset	Name	Format	Unit	Description
0	C[0,0]	float	-	
4	C[0,1]	float	-	
8	C[0,2]	float	-	
12	C[1,0]	float	-	
16	C[1,1]	float	-	
20	C[1,2]	float	-	
24	C[2,0]	float	-	
28	C[2,1]	float	-	
32	C[2,2]	float	-	
36	B[0]	float	-	
40	B[1]	float	-	
44	B[2]	float	-	

This register contains twelve values representing the gyro compensation parameters. The gyro measurements are compensated for changes in bias, gain, and axis alignment that can occur during the installation of the chip on the customer's board using the following model. Under normal circumstances this register can be left in its factory default state. In the event that there are significant changes to the gyro bias, gain, and axis alignment during installation or during the life of the part; these registers allow for further compensation. Note that this gyro compensation is separate from the compensation that occurs during the calibration process at the factory. Setting this register to the default state of an identity matrix and zero offset will not eliminate the gyro gain, bias, and axis alignment that occur during factory calibration. These registers only need to be changed from their default values in the event that changes in bias, gain, and axis alignment have occurred at some point between the times the chip was calibrated at the factory and when it is used in the field.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} GX - B0 \\ GY - B1 \\ GZ - B2 \end{Bmatrix}$$

The variables $\{GX, GY, GZ\}_{IMU}$ are components of the measured angular rate. The $\{GX, GY, GZ\}_{Comp}$ variables are the new acceleration measurements outputted after compensation for changes during sensor mounting. All twelve numbers are represented by single-precision floating points.

7.2.4 Reference Frame Rotation

Reference Frame Rotation					
Register ID :	26	**Firmware :**	1.0.0.0	**Access :**	Read / Write
Comment :	Allows the measurements of the VN-200 to be rotated into a different reference frame.				
Size (Bytes):	36				
Example Response:	$VNRRG,26,1,0,0,0,1,0,0,0,1*6A				

Offset	Name	Format	Unit	Description
0	C[0,0]	float	-	
4	C[0,1]	float	-	
8	C[0,2]	float	-	
12	C[1,0]	float	-	
16	C[1,1]	float	-	
20	C[1,2]	float	-	
24	C[2,0]	float	-	
28	C[2,1]	float	-	
32	C[2,2]	float	-	

This register contains a transformation matrix that allows for the transformation of measured acceleration, magnetic, and angular rates from the body frame of the VN-200 to any other arbitrary frame of reference. The use of this register allows for the sensor to be placed in any arbitrary orientation with respect to the user's desired body coordinate frame. This register can also be used to correct for any orientation errors due to mounting the VN-200 on the user's circuit board.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_U = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_B$$

The variables $\{X, Y, Z\}_B$ are a measured parameter such as acceleration in the body reference frame with respect to the VN-200. The variables $\{X, Y, Z\}_U$ are a measured parameter such as acceleration in the user's frame of reference. The reference frame rotation register thus needs to be loaded with the transformation matrix that will transform measurements from the body reference frame of the VN-200 to the desired user frame of reference. It is crucial that these two frames of reference be rigidly attached to each other. All nine numbers are represented by single-precision floating points.

> The reference frame rotation is performed on all vector measurements prior to entering the INS filter. As such, changing this register while the attitude filter is running will lead to unexpected behavior in the INS output. To prevent this, the register is cached on startup and changes will not take effect during runtime. After setting the reference frame rotation register to its new value, send a write settings command and then reset the VN-200. This will allow the INS filter to startup with the newly set reference frame rotation.

7.2.5 IMU Filtering Configuration

IMU Filtering Configuration					
Register ID :	85	Firmware :	v1.0.0.0	Access :	Read / Write
Comment :	Controls the level of filtering performed on the raw IMU measurements.				
Size (Bytes):	15				
Example Response:	$VNRRG,85,0,5,5,5,0,0,3,3,3,0*78				

Offset	Name	Format	Unit	Description
0	MagWindowSize	uint16	-	Number of previous measurements averaged for magnetic measurements.
2	AccelWindowSize	uint16	-	Number of previous measurements averaged for acceleration measurements.
4	GyroWindowSize	uint16	-	Number of previous measurements averaged for gyro measurements.
6	TempWindowSize	uint16	-	Number of previous measurements averaged for temperature measurements.
8	PresWindowSize	uint16	-	Number of previous measurements averaged for pressure measurements.
10	MagFilterMode	uint8	-	Filtering mode for magnetic measurements. See table below for options.
11	AccelFilterMode	uint8	-	Filtering mode for acceleration measurements. See table below for options.
12	GyroFilterMode	uint8	-	Filtering mode for gyro measurements. See table below for options.
13	TempFilterMode	uint8	-	Filtering mode for temperature measurements. See table below for options.
14	PresFilterMode	uint8	-	Filtering mode for pressure measurements. See table below for options.

This register allows the user to configure the FIR filtering what is applied to the IMU measurements. The filter is a uniformly-weighted moving window (boxcar) filter of configurable size. The filtering does not affect the values used by the internal filter, but only the output values.

WindowSize

The WindowSize parameters for each sensor define the number of samples at the IMU rate (default 800Hz) which will be averaged for each output measurement.

FilterMode

The FilterMode parameters for each sensor select which output quantities the filtering should be applied to. Filtering can be applied to either the uncompensated IMU measurements, compensated (HSI and biases compensated by onboard filters, if applicable), or both.

Table 48 - IMU Filtering Modes

Value	Description
0	No Filtering
1	Filtering performed only on raw uncompensated IMU measurements.
2	Filtering performed only on compensated IMU measurements.
3	Filtering performed on both uncompensated and compensated IMU measurements.

7.2.6 Delta Theta and Delta Velocity Configuration

Delta Theta and Delta Velocity Configuration				
Register ID :	82	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	This register contains configuration options for the internal coning/sculling calculations			
Size (Bytes):	6			
Example Response:	$VNRRG,82,0,0,0,0,0*65			

Offset	Name	Format	Unit	Description
0	IntegrationFrame	uint8	-	Output frame for delta velocity quantities
1	GyroCompensation	uint8	-	Compensation to apply to angular rate
2	AccelCompensation	uint8	-	Compensation(s) to apply to accelerations
3	Reserved	uint8	-	Reserved for future use. Should be set to 0.
4	Reserved	uint16	-	Reserved for future use. Should be set to 0.

The Delta Theta and Delta Velocity Configuration register allows configuration of the onboard coning and sculling used to generate integrated motion values from the angular rate and acceleration IMU quantities. The fully-coupled coning and sculling integrals are computed at the IMU sample rate (nominal 800 Hz).

IntegrationFrame

The IntegrationFrame register setting selects the reference frame used for coning and sculling. Note that using any frame other than the body frame will rely on the onboard Kalman filter's attitude estimate. The factory default state is to integrate in the sensor body frame.

Table 49 – IntegrationFrame

Value	Description
0	Body frame
1	NED frame

GyroCompensation

The GyroCompensation register setting selects the compensation to be applied to the angular rate measurements before integration. If bias compensation is selected, the onboard Kalman filter's real-time estimate of the gyro biases will be used to compensate the IMU measurements before integration. The factory default state is to integrate the uncompensated angular rates from the IMU.

Table 50 – GyroCompensation

Value	Description
0	None
1	Bias

AccelCompensation

The AccelCompensation register setting selects the compensation to be applied to the acceleration measurements before integration. If bias compensation is selected, the onboard Kalman filter's real-time estimate of the accel biases will be used to compensate the IMU measurements before integration. The factory default state is to integrate the uncompensated acceleration from the IMU.

Table 51 – AccelCompensation

Value	Description
0	None
1	Bias

7.3 Factory Defaults

Settings Name	Default Factory Value
Magnetometer Compensation	1,0,0,0,1,0,0,0,1,0,0,0
Accelerometer Compensation	1,0,0,0,1,0,0,0,1,0,0,0
Gyro Compensation	1,0,0,0,1,0,0,0,1,0,0,0
Reference Frame Rotation	1,0,0,0,1,0,0,0,1
IMU Filtering Configuration	0,4,4,4,0,0,3,3,3,0
Delta Theta and Delta Velocity Configuration	0,0,0,0,0

7.4 Command Prompt

The command prompt provides a fast and simple means of configuring and monitoring the status of the sensor by typing commands to the unit using the serial port.

7.4.1 List Available Commands

Commands for the System subsystem can be accessed by typing in ‘imu’ at the command prompt. To view all available commands, type ‘imu ?’. Below is a view of a terminal window showing a list of the available commands.

```
imu ?

Imu Module Commands:

Command:    Description:
--------    --------------------------------------------------------------------
info        Imu specific information such as serial number and firmware version.
meas        Current Imu measurement, and run-time statistics.
```

7.4.2 IMU Info

```
imu info

------------------------------  Imu Information  ------------------------------

Magnetometer - HSI Settings (Register 44)
  Mode : Using Onboard

Magnetometer - User HSI Calibration (Register 23)
  +01.000  +00.000  +00.000  +00.000
  +00.000  +01.000  +00.000  +00.000
  +00.000  +00.000  +01.000  +00.000

Magnetometer - Onboard HSI Calibration (Register 47)
  +01.000  +00.000  +00.000  -00.000
  +00.000  +01.000  +00.000  -00.000
  +00.000  +00.000  +01.000  -00.000

Accelerometer - User Calibration (Register 25)
  +01.000  +00.000  +00.000  +00.000
  +00.000  +01.000  +00.000  +00.000
  +00.000  +00.000  +01.000  +00.000

Sensor Self Test: (performed at startup)
  Mag   : Passed
  Accel : Passed
  Gyro  : Passed
  Pres  : Passed

--------------------------------------------------------------------------------
```

7.4.3 IMU Meas

```
imu meas

------------------------------  Imu Measurement  ------------------------------
Current Sensor Measurements:
  Mag X     : -000.866 [Gauss]
  Mag Y     : +001.016 [Gauss]
  Mag Z     : +002.365 [Gauss]
  Acel X    : +004.178 [m/s]
  Acel Y    : -000.637 [m/s]
  Acel Z    : -008.927 [m/s]
  Gyro X    : -000.417 [deg/s]
  Gyro Y    : +000.668 [deg/s]
  Gyro Z    : -001.102 [deg/s]
  Temp      : +027.94 [C]
  Temp Rate: +0.04 [C/min]
  Pres      : +101.36 [kPa]

Current Sensor Noise: (measured over last 5 seconds)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       mGauss    +03.228   +02.934   +04.159
  Accel     mg        +01.854   +02.115   +02.872
  Gyro      deg/s     +0.0631   +0.0544   +0.0580
  Temp      C         +0.0026
  Pres      Pa        +007.36

Minimum Sensor Noise: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       mGauss    +02.877   +02.659   +03.673
  Accel     mg        +01.785   +01.966   +02.599
  Gyro      deg/s     +0.0587   +0.0487   +0.0537
  Temp      C         +0.0011
  Pres      Pa        +006.13

Minimum Sensor Measurement: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       Gauss     -00.236   +00.244   +00.577
  Accel     g         +00.414   -00.077   -00.949
  Gyro      deg/s     -002.92   -005.33   -002.03
  Temp      C         +27.83
  Pres      kPa       +101.30

Maximum Sensor Measurement: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       Gauss     +00.000   +00.271   +00.611
  Accel     g         +00.439   +00.000   +00.000
  Gyro      deg/s     +002.02   +006.44   +000.00
  Temp      C         +28.01
  Pres      kPa       +101.38

Sensor Saturation Events: (since startup)
  Sensor    X-Axis    Y-Axis    Z-Axis
  Mag       0         0         0
  Accel     0         0         0
  Gyro      0         0         0
  Pressure  0
  Temp      0
-------------------------------------------------------------------------------
```

8 GPS Subsystem

8.1 Measurement Registers

8.1.1 GPS Solution - LLA

GPS Solution - LLA				
Register ID :	58	**Async Header :** GPS		**Access :** Read Only
Comment :				
Size (Bytes):	72			
Example Read Response:	$VNRRG,58,333733.000159,1694,3,05,+32.95622080,-096.71415970,+00169.457,-000.850,-000.580,-002.860,+005.573,+003.644,+009.760,+003.320,2.00E-08*0E			

Offset	Name	Format	Unit	Description
0	Time	double	sec	GPS time of week in seconds.
8	Week	uint16	week	GPS week.
10	GpsFix	uint8	-	GPS fix type. See table below.
11	NumSats	uint8	-	Number of GPS satellites used in solution.
12	-	-	-	--- 4 PADDING BYTES ---
16	Latitude	double	deg	Latitude in degrees.
24	Longitude	double	deg	Longitude in degrees.
32	Altitude	double	m	Altitude above ellipsoid. (WGS84)
40	NedVelX	float	m/s	Velocity measurement in north direction.
44	NedVelY	float	m/s	Velocity measurement in east direction.
48	NedVelZ	float	m/s	Velocity measurement in down direction.
52	NorthAcc	float	m	North position accuracy estimate. (North)
56	EastAcc	float	m	East position accuracy estimate. (East)
60	VertAcc	float	m	Vertical position accuracy estimate. (Down)
64	SpeedAcc	float	m/s	Speed accuracy estimate.
68	TimeAcc	float	sec	Time accuracy estimate.

Table 52 - GPS Fix

Value	Description
0	No fix
1	Time only
2	2D
3	3D

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNGPS header.

8.1.2 GPS Solution - ECEF

GPS Solution – ECEF					
Register ID :	59	**Async Header :**	GPE	**Access :**	Read Only
Comment :	Available at 5Hz only.				
Size (Bytes):	72				
Example Read Response:	$VNRRG,59,333752.800322,1694,3,06,-0626351.600,-5320522.490,+3449975.910,-000.810,-002.970,+000.850,+010.170,+010.170,+010.170,+002.740,1.80E-08*35				

Offset	Name	Format	Unit	Description
0	Tow	double	sec	GPS time of week.
8	Week	uint16	week	Current GPS week.
10	GpsFix	uint8	-	GPS fix type. See table below.
11	NumSats	uint8	-	Number of GPS satellites used in solution.
12	-	-	-	--- 4 PADDING BYTES ---
16	PositionX	double	m	ECEF X coordinate.
24	PositionY	double	m	ECEF Y coordinate.
32	PositionZ	double	m	ECEF Z coordinate.
40	VelocityX	float	m/s	ECEF X velocity.
44	VelocityY	float	m/s	ECEF Y velocity.
48	VelocityZ	float	m/s	ECEF Z velocity.
52	PosAccX	float	m	ECEF X position accuracy estimate.
56	PosAccY	float	m	ECEF Y position accuracy estimate.
60	PosAccZ	float	m	ECEF Z position accuracy estimate.
64	SpeedAcc	float	m/s	Speed accuracy estimate.
68	TimeAcc	float	sec	Time accuracy estimate.

Table 53 - GPS Fix

Value	Description
0	No fix
1	Time only
2	2D
3	3D

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNGPE header.

8.2 Configuration Registers

8.2.1 GPS Configuration

GPS Configuration				
Register ID :	55	**Firmware :** 1.0.0.0		**Access :** Read / Write
Comment :				
Size (Bytes):	5			
Example Response:	$VNWRG,55,0,0,5,0,0*6F			
Offset	**Name**	**Format**	**Unit**	**Description**
0	Mode	uint8	-	GPS mode. 0 = Use onboard GPS. 1 = Use external GPS. 2 = Use external VN-200 as GPS.
1	PpsSource	uint8	-	GPS PPS mode. 0 = GPS PPS signal is present on the GPS_PPS pin (pin 24) and should trigger on a rising edge. 1 = GPS PPS signal is present on the GPS_PPS pin (pin 24) and should trigger on a falling edge. 2 = GPS PPS signal is present on the SyncIn pin (pin 22) and should trigger on a rising edge. 3 = GPS PPS signal is present on the SyncIn pin (pin 22) and should trigger on a falling edge.
2	Reserved	uint8	-	Reserved for internal use. Value must be set to 5.
3	Reserved	uint8	-	Reserved for future use. Field should be set to zero.
4	Reserved	uint8	-	Reserved for future use. Field should be set to zero.

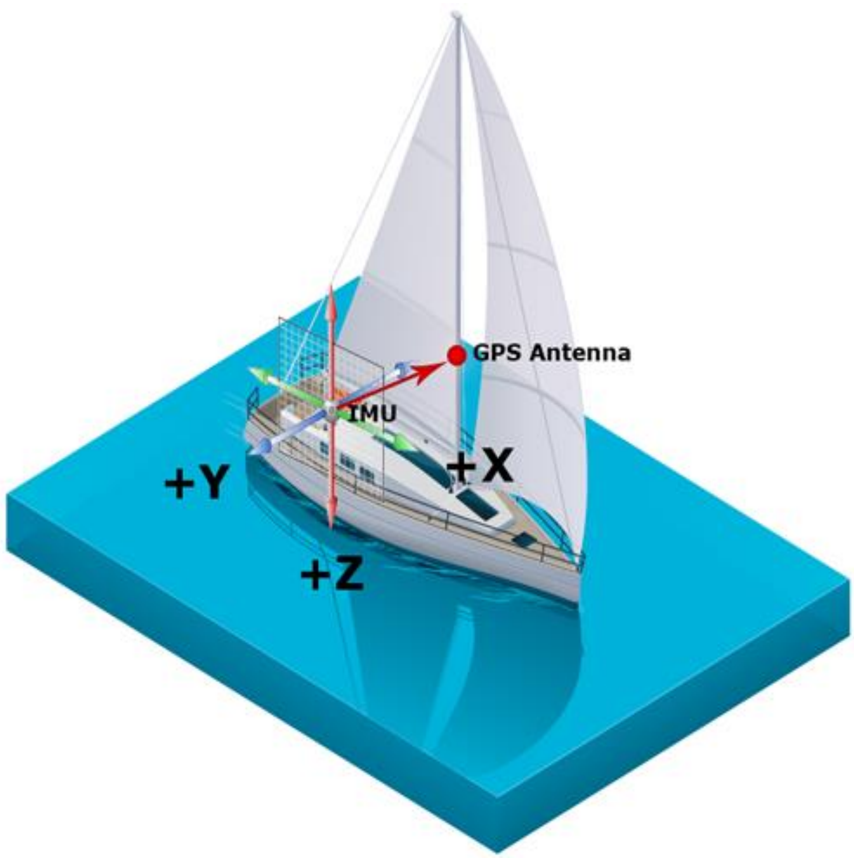
8.2.2 GPS Antenna Offset

GPS Antenna Offset				
Register ID :	57	**Firmware :** 1.0.0.0		**Access :** Read / Write
Comment :	Configures the position offset of the GPS antenna from the VN-200 in the vehicle reference frame.			
Size (Bytes):	12			
Example Response:	$VNRRG,57,0,0,0*68			

Offset	Name	Format	Unit	Description
0	PositionX	float	m	Relative position of GPS antenna. (X-axis)
4	PositionY	float	m	Relative position of GPS antenna. (Y-axis)
8	PositionZ	float	m	Relative position of GPS antenna. (Z-axis)

The position of the GPS antenna relative to the sensor in the vehicle coordinate frame also referred to as the GPS antenna lever arm. In the example scenario shown in Figure 8 below, the GPS antenna offset is X= +2.5m, Y= +0.0m, Z= -2.0m.

Figure 8 - GPS Antenna Offset



8.3 Factory Defaults

Settings Name	Default Factory Value
GPS Configuration	0,0,5,0,0
GPS Antenna Offset	0,0,0

8.4 Command Prompt

The command prompt provides a fast and simple means of configuring and monitoring the status of the sensor by typing commands to the unit using the serial port.

8.4.1 List Available Commands

Commands for the System subsystem can be accessed by typing in ‘gps’ at the command prompt. To view all available commands, type ‘gps ?’. Below is a view of a terminal window showing a list of the available commands.

```
gps ?

Gps Module Commands:

Command:    Description:
--------    --------------------------------------------------------------------
meas        Current gps measurement, signal strength, and visible satellites.
```

8.4.2 GPS Meas

```
gps meas

------------------------------  Gps Measurement  -------------------------------
Gps Solution:
  Sats visible : 18
  Sats used    : 14
  Latitude     : +32.89195060 deg
  Longitude    : -096.70376560 deg
  Altitude     : +00165.150 m
  Pos Acc      : 05.94  07.83  05.26 m
  Vel Acc      : 00.59 m/s
  Time Acc     : 2 ns

Space Vehicle Info:
  Ch   SV    CN0    Residual     Nav    Qi     El     Az     Orbit  Healthy      DGPS
  14   1     40     +0.11        Y      7      15     142    Eph    Y            Y
  2    3     43     +0.46        Y      7      28     44     Eph    Y            Y
  5    6     37     +0.00        Y      7      7      40     Eph    Y            Y
  6    7     50     -0.53        Y      7      71     6      Eph    Y            Y
  7    8     47     +0.29        Y      7      42     322    Eph    Y            Y
  8    9     47     -0.58        Y      7      40     320    Eph    Y            Y
  10   11    43     -0.32        Y      7      35     125    Eph    Y            Y
  12   13    47     +0.40        Y      7      45     186    Eph    Y            Y
  0    19    47     +0.15        Y      7      51     57     Eph    Y            Y
  1    23    42     -1.36        Y      7      18     170    Eph    Y            Y
  4    27    41     +0.19        Y      7      18     41     Eph    Y            Y
  3    28    48     -0.33        Y      7      36     273    Eph    Y            Y
  11   135   47     +0.68        Y      7      36     233    Eph    Y            N
  13   138   49     +0.25        Y      7      50     199    Eph    Y            N
  9    10    30     +0.00        N      7      3      244    Eph    Y            N
  255  17    0      +0.00        N      0      4      210    ---    Y            N
  255  26    0      +0.00        N      0      5      324    ---    Y            N
  15   122   0      +0.00        N      1      29     241    none   N            N
--------------------------------------------------------------------------------
```

9 Attitude Subsystem

9.1 Measurement Registers

9.1.1 Yaw Pitch Roll

Yaw, Pitch, and Roll					
Register ID :	8	**Async Header :**	YPR	**Access :**	Read Only
Comment :	Attitude solution as yaw, pitch, and roll in degrees. The yaw, pitch, and roll is given as a 3,2,1 Euler angle rotation sequence describing the orientation of the sensor with respect to the inertial North East Down (NED) frame.				
Size (Bytes):	12				
Example Response:	$VNRRG,8,+006.271,+000.031,-002.000*66				

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Yaw angle.
4	Pitch	float	deg	Pitch angle.
8	Roll	float	deg	Roll angle.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNYPR header.

9.1.2 Attitude Quaternion

Quaternion				
Register ID :	9	**Async Header :** QTN		**Access :** Read Only
Comment :	Attitude solution as a quaternion.			
Size (Bytes):	16			
Example Response:	$VNRRG,9,-0.017386,-0.000303,+0.055490,+0.998308*4F			

Offset	Name	Format	Unit	Description
0	Quat[0]	float	-	Calculated attitude as quaternion.
4	Quat[1]	float	-	Calculated attitude as quaternion.
8	Quat[2]	float	-	Calculated attitude as quaternion.
12	Quat[3]	float	-	Calculated attitude as quaternion. Scalar component.

This register contains four values representing the quaternion vector. The quaternion provides a redundant, nonsingular attitude representation that is well suited for describing arbitrary, large rotations. The quaternion is a non-dimensional 4x1 unit vector with the fourth value as the scalar term. The fields of this register are represented with fixed point precision for the serial protocol and 32-bit floating point precision for the SPI protocol. This is a read-only register. All filtering and other mathematical operations performed by the VN-200 are performed using quaternions. The quaternion used by the VN-200 has the following form.

$$q[0] = e_x * \sin\left(\frac{\vartheta}{2}\right)$$

$$q[1] = e_y * \sin\left(\frac{\vartheta}{2}\right)$$

$$q[2] = e_z * \sin\left(\frac{\vartheta}{2}\right)$$

$$q[3] = \cos\left(\frac{\vartheta}{2}\right)$$

Where $e = \begin{Bmatrix} e_x \\ e_y \\ e_z \end{Bmatrix}$ is the principal axis and ϑ is the principal angle.

> You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNQTN header.

9.1.3 Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rates

Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rates

Register ID :	27	**Async Header :**	YMR	**Access :**	Read Only
Comment :	Attitude solution, magnetic, acceleration, and compensated angular rates.				
Size (Bytes):	48				
Example Response:	$VNRRG,27,+006.380,+000.023,-001.953,+1.0640,-0.2531,+3.0614,+00.005,+00.344,-09.758,-0.001222,-0.000450,-0.001218*4F				

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Calculated attitude heading angle in degrees.
4	Pitch	float	deg	Calculated attitude pitch angle in degrees.
8	Roll	float	deg	Calculated attitude roll angle in degrees.
12	MagX	float	Gauss	Compensated magnetometer measurement in x-axis.
16	MagY	float	Gauss	Compensated magnetometer measurement in y-axis.
20	MagZ	float	Gauss	Compensated magnetometer measurement in z-axis.
24	AccelX	float	m/s^2	Compensated accelerometer measurement in x-axis.
28	AccelY	float	m/s^2	Compensated accelerometer measurement in y-axis.
32	AccelZ	float	m/s^2	Compensated accelerometer measurement in z-axis.
36	GyroX	float	rad/s	Compensated angular rate in x-axis.
40	GyroY	float	rad/s	Compensated angular rate in y-axis.
44	GyroZ	float	rad/s	Compensated angular rate in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNYMR header.

9.1.4 Quaternion, Magnetic, Acceleration and Angular Rates

Quaternion, Magnetic, Acceleration, and Angular Rates

Register ID :	15	**Async Header :**	QMR	**Access :**	Read Only
Comment :	Attitude solution, magnetic, acceleration, and compensated angular rates.				
Size (Bytes):	52				
Example Response:	$VNRRG,15,-0.017057,-0.000767,+0.056534,+0.998255,+1.0670,-0.2568,+3.0696,-00.019,+00.320,-09.802,-0.002801,-0.001186,-0.001582*65				

Offset	Name	Format	Unit	Description
0	Quat[0]	float	-	Calculated attitude as quaternion.
4	Quat[1]	float	-	Calculated attitude as quaternion.
8	Quat[2]	float	-	Calculated attitude as quaternion.
12	Quat[3]	float	-	Calculated attitude as quaternion. Scalar component.
16	MagX	float	Gauss	Compensated magnetometer measurement in x-axis.
20	MagY	float	Gauss	Compensated magnetometer measurement in y-axis.
24	MagZ	float	Gauss	Compensated magnetometer measurement in z-axis.
28	AccelX	float	m/s^2	Compensated accelerometer measurement in x-axis.
32	AccelY	float	m/s^2	Compensated accelerometer measurement in y-axis.
36	AccelZ	float	m/s^2	Compensated accelerometer measurement in z-axis.
40	GyroX	float	rad/s	Compensated angular rate in x-axis.
44	GyroY	float	rad/s	Compensated angular rate in y-axis.
48	GyroZ	float	rad/s	Compensated angular rate in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNQMR header.

9.1.5 Magnetic Measurements

Magnetic Measurements				
Register ID :	17	Async Header : MAG		Access : Read Only
Comment :	Magnetometer measurements.			
Size (Bytes):	12			
Example Response:	$VNRRG,17,+1.0647,-0.2498,+3.0628*66			

Offset	Name	Format	Unit	Description
0	MagX	float	Gauss	Compensated magnetometer measurement in x-axis.
4	MagY	float	Gauss	Compensated magnetometer measurement in y-axis.
8	MagZ	float	Gauss	Compensated magnetometer measurement in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNMAG header.

9.1.6 Acceleration Measurements

Acceleration Measurements					
Register ID :	18	**Async Header :**	ACC	**Access :**	Read Only
Comment :	Acceleration measurements.				
Size (Bytes):	12				
Example Response:	$VNRRG,18,+00.013,+00.354,-09.801*65				

Offset	Name	Format	Unit	Description
0	AccelX	float	m/s^2	Compensated accelerometer measurement in x-axis.
4	AccelY	float	m/s^2	Compensated accelerometer measurement in y-axis.
8	AccelZ	float	m/s^2	Compensated accelerometer measurement in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNACC header.

9.1.7 Angular Rate Measurements

Angular Rate Measurements				
Register ID : 19		**Async Header :** GYR		**Access :** Read Only
Comment : Compensated angular rates.				
Size (Bytes): 12				
Example Response: $VNRRG,19,+0.002112,-0.000362,-0.000876*6C				
Offset	**Name**	**Format**	**Unit**	**Description**
0	GyroX	float	rad/s	Compensated angular rate in x-axis.
4	GyroY	float	rad/s	Compensated angular rate in y-axis.
8	GyroZ	float	rad/s	Compensated angular rate in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNGYR header.

9.1.8 Magnetic, Acceleration and Angular Rates

Magnetic, Acceleration, and Angular Rates

Register ID :	20	**Async Header :**	MAR	**Access :**	Read Only
Comment :	Magnetic, acceleration, and compensated angular rates.				
Size (Bytes):	36				
Example Response:	$VNRRG,20,+1.0684,-0.2578,+3.0649,-00.005,+00.341,-09.780,-0.000963,+0.000840,-0.000466*64				

Offset	Name	Format	Unit	Description
0	MagX	float	Gauss	Compensated magnetometer measurement in x-axis.
4	MagY	float	Gauss	Compensated magnetometer measurement in y-axis.
8	MagZ	float	Gauss	Compensated magnetometer measurement in z-axis.
12	AccelX	float	m/s^2	Compensated accelerometer measurement in x-axis.
16	AccelY	float	m/s^2	Compensated accelerometer measurement in y-axis.
20	AccelZ	float	m/s^2	Compensated accelerometer measurement in z-axis.
24	GyroX	float	rad/s	Compensated angular rate in x-axis.
28	GyroY	float	rad/s	Compensated angular rate in y-axis.
32	GyroZ	float	rad/s	Compensated angular rate in z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNMAR header.

9.1.9 Yaw, Pitch, Roll, True Body Acceleration, and Angular Rates

Yaw, Pitch, Roll, True Body Acceleration, and Angular Rates					
Register ID :	239	**Async Header :**	YBA	**Access :**	Read Only
Comment :	Attitude solution as yaw, pitch, roll and the inertial acceleration.				
Size (Bytes):	36				
Example Response:	$VNRRG,239,-124.743,+001.019,-000.203,+00.019,-00.001,+00.039,+00.001665,-00.000785,+00.000647*55				

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Calculated attitude heading angle in degrees.
4	Pitch	float	deg	Calculated attitude pitch angle in degrees.
8	Roll	float	deg	Calculated attitude roll angle in degrees.
12	BodyAccelX	float	m/s^2	Linear acceleration estimate in the body X-axis. (no gravity)
16	BodyAccelY	float	m/s^2	Linear acceleration estimate in the body Y-axis. (no gravity)
20	BodyAccelZ	float	m/s^2	Linear acceleration estimate in the body Z-axis. (no gravity)
24	GyroX	float	rad/s	Compensated angular rate in the body X-axis.
28	GyroY	float	rad/s	Compensated angular rate in the body Y-axis.
32	GyroZ	float	rad/s	Compensated angular rate in the body Z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNYBA header.

This register contains the true measured acceleration. The accelerometer measures both acceleration and the effect of static gravity in the body frame. This register contains the true acceleration which does not contain gravity and should measure 0 when the device is stationary.

9.1.10 Yaw, Pitch, Roll, True Inertial Acceleration, and Angular Rates

Yaw, Pitch, Roll, True Inertial Acceleration and Angular Rates

Register ID :	240	**Async Header :**	YIA	**Access :**	Read Only
Comment :	Attitude solution as yaw, pitch, roll and the inertial acceleration.				
Size (Bytes):	36				
Example Response:	$VNRRG,240,-124.642,+000.993,-000.203,+00.009,-00.027,+00.084,-00.000479,-00.000522,+00.000076*5F				

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Calculated attitude heading angle in degrees.
4	Pitch	float	deg	Calculated attitude pitch angle in degrees.
8	Roll	float	deg	Calculated attitude roll angle in degrees.
12	InertialAccelX	float	m/s^2	Compensated acceleration estimate in the inertial NED X-axis. (no gravity)
16	InertialAccelY	float	m/s^2	Compensated acceleration estimate in the inertial NED Y-axis. (no gravity)
20	InertialAccelZ	float	m/s^2	Compensated acceleration estimate in the inertial NED Z-axis. (no gravity)
24	GyroX	float	rad/s	Compensated angular rate in the body X-axis.
28	GyroY	float	rad/s	Compensated angular rate in the body Y-axis.
32	GyroZ	float	rad/s	Compensated angular rate in the body Z-axis.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNYIA header.

This register contains the true measured acceleration. The accelerometer measures both acceleration and the effect of static gravity in the body frame. This register contains the true acceleration which does not contain gravity and should measure 0 when the device is stationary. The true acceleration provided in this register is measured in the inertial frame. This means that an up/down movement will always appear as an acceleration in the Z-axis on this register regardless of the orientation of the VN-200.

9.2 Configuration Registers

9.2.1 VPE Basic Control

VPE Basic Control					
Register ID :	35	**Firmware :**	v1.0.0.0	**Access :**	Read / Write
Comment :	Provides control over various features relating to the onboard attitude filtering algorithm.				
Size (Bytes):	4				
Example Response:	$VNRRG,35,1,3,1,1*77				

Offset	Name	Format	Unit	Description
0	Enable	uint8	-	Enable / Disable the Vector Processing Engine (VPE).
1	HeadingMode	uint8	-	Heading mode used by the VPE.
2	FilteringMode	uint8	-	Filtering Mode used by the VPE.
3	TuningMode	uint8	-	Tuning Mode used by the VPE.

Table 54 – Enable

Value	State
0	DISABLE
1	ENABLE

Table 55 – HeadingMode

Value	Mode
0	Absolute Heading
1	Relative Heading
2	Indoor Heading

Table 56 - Filtering Mode

Value	Mode
0	OFF
1	MODE 1

Table 57 - Tuning Mode

Value	Mode
0	OFF
1	MODE 1

9.2.2 VPE Magnetometer Basic Tuning

VPE Magnetometer Basic Tuning				
Register ID : 36		**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	Provides basic control of the adaptive filtering and tuning for the magnetometer.			
Size (Bytes):	36			
Example Response:	$VNRRG,36,5,5,5,3,3,3,4,4,4*68			
Offset	**Name**	**Format**	**Unit**	**Description**
0	BaseTuningX	float	0 / 10	Base Magnetic Tuning X-Axis [0 - 10]. This sets the level of confidence placed in the magnetometer X-axis when no disturbances are present. A larger number provides better heading accuracy, but with more sensitivity to magnetic interference.
4	BaseTuningY	float	0 / 10	Base Magnetic Tuning Y-Axis [0 - 10]. This sets the level of confidence placed in the magnetometer Y-axis when no disturbances are present. A larger number provides better heading accuracy, but with more sensitivity to magnetic interference.
8	BaseTuningZ	float	0 / 10	Base Magnetic Tuning Z-Axis [0 - 10]. This sets the level of confidence placed in the magnetometer Z-axis when no disturbances are present. A larger number provides better heading accuracy, but with more sensitivity to magnetic interference.
12	AdaptiveTuningX	float	0 / 10	Level of adaptive tuning for X-Axis.
16	AdaptiveTuningY	float	0 / 10	Level of adaptive tuning for Y-Axis.
20	AdaptiveTuningZ	float	0 / 10	Level of adaptive tuning for Z-Axis.
24	AdaptiveFilteringX	float	0 / 10	Level of adaptive filtering for X-Axis.
28	AdaptiveFilteringY	float	0 / 10	Level of adaptive filtering for Y-Axis.
32	AdaptiveFilteringZ	float	0 / 10	Level of adaptive filtering for Z-Axis.

9.2.3 VPE Accelerometer Basic Tuning

VPE Accelerometer Basic Tuning				
Register ID :	38	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	Provides basic control of the adaptive filtering and tuning for the accelerometer.			
Size (Bytes):	36			
Example Response:	$VNRRG,38,5,5,5,3,3,3,4,4,4*66			
Offset	**Name**	**Format**	**Unit**	**Description**
0	BaseTuningX	float	0 / 10	Base Accelerometer Tuning X-Axis [0 - 10]. This sets the level of confidence placed in the accelerometer X-axis when no disturbances are present. A larger number provides better pitch/roll heading accuracy, but with more sensitivity to acceleration interference.
4	BaseTuningY	float	0 / 10	Base Accelerometer Tuning Y-Axis [0 - 10]. This sets the level of confidence placed in the accelerometer Y-axis when no disturbances are present. A larger number provides better pitch/roll accuracy, but with more sensitivity to acceleration interference.
8	BaseTuningZ	float	0 / 10	Base Accelerometer Tuning Z-Axis [0 - 10]. This sets the level of confidence placed in the accelerometer Z-axis when no disturbances are present. A larger number provides better pitch/roll accuracy, but with more sensitivity to acceleration interference.
12	AdaptiveTuningX	float	0 / 10	Level of adaptive tuning for X-Axis.
16	AdaptiveTuningY	float	0 / 10	Level of adaptive tuning for Y-Axis.
20	AdaptiveTuningZ	float	0 / 10	Level of adaptive tuning for Z-Axis.
24	AdaptiveFilteringX	float	0 / 10	Level of adaptive filtering for X-Axis.
28	AdaptiveFilteringY	float	0 / 10	Level of adaptive filtering for Y-Axis.
32	AdaptiveFilteringZ	float	0 / 10	Level of adaptive filtering for Z-Axis.

9.3 Factory Defaults

Settings Name	Default Factory Value
VPE Basic Control	1,1,1,1
VPE Magnetic Basic Tuning	4,4,4,5,5,5,5.5,5.5,5.5
VPE Accelerometer Basic Tuning	6,6,6,3,3,3,5,5,5

10 INS Subsystem

10.1 Commands

10.1.1 Set Filter Bias Command

This command will instruct the VN-200 to copy the current filter bias estimates into register 74. After sending this command you will need to issue the write settings command (Section 6.1.3) to save the state of this register to flash memory. Once saved the VN-200 will use these bias estimates as the initial state at startup.

Table 58 - Example Gyro Bias Command

Example Command	Message
UART Command	$VNSFB*4D
UART Response	$VNSFB*4D
SPI Command (8 bytes)	11 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 11 00 00 (shown as hex)

10.2 Measurement Registers

10.2.1 INS Solution – LLA

INS Solution - LLA			
Register ID :	63	Async Header : INS	Access : Read Only
Comment :			
Size (Bytes):	72		
Example Response:	$VNRRG,63,333811.902862,1694,0004,+009.500,-004.754,-000.225,+32.95602815,-096.71424297,+00171.195,-000.840,-000.396,-000.109,07.8,01.6,0.23*5F		

Offset	Name	Format	Unit	Description
0	Time	double	sec	GPS time of week in seconds.
8	Week	uint16	week	GPS week.
10	Status	uint16	-	Status flags for INS filter. Hexadecimal format. See table below.
12	Yaw	float	deg	Yaw angle relative to true north.
16	Pitch	float	deg	Pitch angle relative to horizon.
20	Roll	float	deg	Roll angle relative to horizon.
24	Latitude	double	deg	INS solution position in geodetic latitude.
32	Longitude	double	deg	INS solution position in geodetic longitude.
40	Altitude	double	m	Height above ellipsoid. (WGS84)
48	NedVelX	float	m/s	INS solution velocity in NED frame. (North)
52	NedVelY	float	m/s	INS solution velocity in NED frame. (East)
56	NedVelZ	float	m/s	INS solution velocity in NED frame. (Down)
60	AttUncertainty	float	deg	Uncertainty in attitude estimate.
64	PosUncertainty	float	m	Uncertainty in position estimate.
68	VelUncertainty	float	m/s	Uncertainty in velocity estimate.

Table 59 - INS Status

Name	Bit Offset	Format	Description
Mode	0	2 bits	Indicates the current mode of the INS filter. 0 = Not tracking. Insufficient dynamic motion to estimate attitude. 1 = Sufficient dynamic motion, but solution not within performance specs. 2 = INS is tracking and operating within specifications.
GpsFix	2	1 bit	Indicates whether the GPS has a proper fix.
Error	3	4 bits	Sensor measurement error code. See table below. 0 = No errors detected.
Reserved	7	9 bits	Reserved for future use.

Table 60 - Error Bitfield

Name	Bit Offset	Format	Description
Time Error	0	1 bit	High if INS filter loop exceeds 5 ms.
IMU Error	1	1 bit	High if IMU communication error is detected.
Mag/Pres Error	2	1 bit	High if Magnetometer or Pressure sensor error is detected.
GPS Error	3	1 bit	High if GPS communication error is detected.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNINS header.

10.2.2 INS Solution - ECEF

INS Solution – ECEF					
Register ID :	64	Async Header :	INE	Access :	Read Only
Comment :					
Size (Bytes):	72				
Example Response:	$VNRRG,64,333837.222917,1694,0004,+009.315,-004.767,-000.193,-0626356.433,-5320530.947,+3449961.679,-000.224,-000.476,-000.564,07.7,01.5,0.22*65				

Offset	Name	Format	Unit	Description
0	Time	double	sec	GPS time of week in seconds.
8	Week	uint16	week	GPS week.
10	Status	uint16	-	Status flags for INS filter. See table below.
12	Yaw	float	deg	Yaw angle relative to true north.
16	Pitch	float	deg	Pitch angle relative to horizon.
20	Roll	float	deg	Roll angle relative to horizon.
24	PositionX	double	m	INS solution position in ECEF. (X-axis)
32	PositionY	double	m	INS solution position in ECEF. (Y-axis)
40	PositionZ	double	m	INS solution position in ECEF. (Z-axis)
48	VelocityX	float	m/s	INS solution velocity in ECEF frame. (X-axis)
52	VelocityY	float	m/s	INS solution velocity in ECEF frame. (Y-axis)
56	VelocityZ	float	m/s	INS solution velocity in ECEF frame. (Z-axis)
60	AttUncertainty	float	deg	Expected uncertainty in estimated attitude.
64	PosUncertainty	float	m	Expected uncertainty in estimated position.
68	VelUncertainty	float	m/s	Expected uncertainty in estimated velocity.

Table 61 - INS Status

Name	Bit Offset	Format	Description
Mode	0	2 bits	Indicates the current mode of the INS filter. 0 = Not tracking. Insufficient dynamic motion to estimate attitude. 1 = Sufficient dynamic motion, but solution not within performance specs. 2 = INS is tracking and operating within specifications.
GpsFix	2	1 bit	Indicates whether the GPS has a proper fix.
Error	3	4 bits	Sensor measurement error code. See table below. 0 = No errors detected.
Reserved	7	9 bits	Reserved for future use.

Table 62 - Error Bitfield

Name	Bit Offset	Format	Description
Time Error	0	1 bit	High if INS filter loop exceeds 5ms.
IMU Error	1	1 bit	High if IMU communication error is detected.
Mag/Pres Error	2	1 bit	High if Magnetometer or Pressure sensor error is detected.
GPS Error	3	1 bit	High if GPS communication error is detected.

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNINE header.

10.2.3 INS State - LLA

INS State – LLA				
Register ID :	72	**Async Header :** ISL	**Access :**	Read Only
Comment :				
Size (Bytes):	72			
Example Response:	$VNRRG,72,+170.420,+001.398,+001.806,+00.000295,-00.000911,-00.000905,+32.95680804,-096.71414860,+00179.592,+000.181,-000.073,-000.050,+00.209,-00.322,-10.040*52			

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Yaw angle relative to true north.
4	Pitch	float	deg	Pitch angle relative to horizon.
8	Roll	float	deg	Roll angle relative to horizon.
12	Latitude	double	deg	Estimated position in geodetic latitude.
20	Longitude	double	deg	Estimated position in geodetic longitude.
28	Altitude	double	m	Estimated height above ellipsoid. (WGS84)
36	VelocityX	float	m/s	Estimated velocity in NED frame. (North)
40	VelocityY	float	m/s	Estimated velocity in NED frame. (East)
44	VelocityZ	float	m/s	Estimated velocity in NED frame. (Down)
48	AccelX	float	m/s^2	Estimated acceleration in body frame. (X-axis)
52	AccelY	float	m/s^2	Estimated acceleration in body frame. (Y-axis)
56	AccelZ	float	m/s^2	Estimated acceleration in body frame. (Z-axis)
60	AngularRateX	float	rad/s	Estimated angular rate in body frame. (X-axis)
64	AngularRateY	float	rad/s	Estimated angular rate in body frame. (Y-axis)
68	AngularRateZ	float	rad/s	Estimated angular rate in body frame. (Z-axis)

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNISL header.

10.2.4 INS State - ECEF

INS State – ECEF					
Register ID :	73	Async Header :	ISE	Access :	Read Only
Comment :					
Size (Bytes):	72				
Example Read Response:	$VNRRG,73,+170.558,+001.267,+001.762,+00.001502,-00.000403,+00.000394,-626343.88590823,-5320499.92650050,+3450022.606,+000.001,-000.010,+000.094,+00.255,-00.308,-10.060*50				
Example Async Message:	$VNISE,+170.558,+001.267,+001.762,+00.001502,-00.000403,+00.000394,-626343.88590823,-5320499.92650050,+3450022.606,+000.001,-000.010,+000.094,+00.255,-00.308,-10.060*XX				

Offset	Name	Format	Unit	Description
0	Yaw	float	deg	Yaw angle relative to true north.
4	Pitch	float	deg	Pitch angle relative to horizon.
8	Roll	float	deg	Roll angle relative to horizon.
12	PositionX	double	m	Estimated position in ECEF. (X-axis)
20	PositionY	double	m	Estimated position in ECEF. (Y-axis)
28	PositionZ	double	m	Estimated position in ECEF. (Z-axis)
36	VelocityX	float	m/s	Estimated velocity in ECEF frame. (X-axis)
40	VelocityY	float	m/s	Estimated velocity in ECEF frame. (Y-axis
44	VelocityZ	float	m/s	Estimated velocity in ECEF frame. (Z-axis)
48	AccelX	float	m/s^2	Estimated acceleration in body frame. (X-axis)
52	AccelY	float	m/s^2	Estimated acceleration in body frame. (Y-axis)
56	AccelZ	float	m/s^2	Estimated acceleration in body frame. (Z-axis)
60	AngularRateX	float	rad/s	Estimated angular rate in body frame. (X-axis)
64	AngularRateY	float	rad/s	Estimated angular rate in body frame. (Y-axis)
68	AngularRateZ	float	rad/s	Estimated angular rate in body frame. (Z-axis)

You can configure the device to output this register at a fixed rate using the Async Data Output Type register (Register 6). Once configured the data in this register will be sent out with the $VNISE header.

10.3 Configuration Registers

10.3.1 INS Basic Configuration

INS Basic Configuration					
Register ID :	67	**Firmware :**	1.0.0.0	**Access :**	Read / Write
Comment :					
Size (Bytes):	4				
Example Response:	$VNRRG,67,2,1,0,0*71				

Offset	Name	Format	Unit	Description
0	Scenario	uint8	-	INS mode. 0 = AHRS. Attitude estimation only. (Legacy mode) 1 = General purpose INS with barometric pressure sensor. 2 = General purpose INS without barometric pressure sensor.
1	AhrsAiding	uint8	-	Enables AHRS attitude aiding.
2	Resv1	uint8	-	Reserved for future use. Field should be set to zero.
3	Resv2	uint8	-	Reserved for future use. Field should be set to zero.

The estimated attitude (YprU) field in group 5 of the user configurable binary output messages is not valid when the Scenario mode is set to AHRS mode. AHRS mode is a legacy mode that is present for reverse compatibility with previous firmware versions. It is not recommended for use in future designs and may not be supported on future firmware versions.

10.3.2 Startup Filter Bias Estimate

Startup Filter Bias Estimate				
Register ID : 74		**Firmware :** v0.2 and up		**Access :** Read / Write
Comment : Sets the initial estimate for the filter bias states.				
Size (Bytes): 28				
Example Command: $ VNWRG,74,0,0,0,0,0,0,0*69				
Offset	**Name**	**Format**	**Unit**	**Description**
0	GyroBiasX	float	rad/s	X-axis gyro bias.
4	GyroBiasY	float	rad/s	Y-axis gyro bias.
8	GyroBiasZ	float	rad/s	Z-axis gyro bias.
12	AccelBiasX	float	m/s^2	X-axis accelerometer bias.
16	AccelBiasY	float	m/s^2	Y-axis accelerometer bias.
20	AccelBiasZ	float	m/s^2	Z-axis accelerometer bias.
24	PressureBias	float	m	Pressure bias.

10.4 Factory Defaults

Settings Name	Default Factory Value
INS Basic Configuration	2,1,0,0
Startup Filter Bias Estimate	0,0,0,0,0,0,0

11 Hard/Soft Iron Estimator Subsystem

11.1 Configuration Registers

11.1.1 Magnetometer Calibration Control

Magnetometer Calibration Control				
Register ID :	44	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	Controls the magnetometer real-time calibration algorithm.			
Size (Bytes):	4			
Example Response:	$VNRRG,44,1,2,5*69			

Offset	Name	Format	Unit	Description
0	HSIMode	uint8	-	Controls the mode of operation for the onboard real-time magnetometer hard/soft iron compensation algorithm.
1	HSIOutput	uint8	-	Controls the type of measurements that are provided as outputs from the magnetometer sensor and also subsequently used in the attitude filter.
2	ConvergeRate	uint8	-	Controls how quickly the hard/soft iron solution is allowed to converge onto a new solution. The slower the convergence the more accurate the estimate of the hard/soft iron solution. A quicker convergence will provide a less accurate estimate of the hard/soft iron parameters, but for applications where the hard/soft iron changes rapidly may provide a more accurate attitude estimate. Range: 1 to 5 1 = Solution converges slowly over approximately 60-90 seconds. 5 = Solution converges rapidly over approximately 15-20 seconds.

Table 63 – HSI_Mode Field

Mode	Value	Description
HSI_OFF	0	Real-time hard/soft iron calibration algorithm is turned off.
HSI_RUN	1	Runs the real-time hard/soft iron calibration. The algorithm will continue using its existing solution. The algorithm can be started and stopped at any time by switching between the HSI_OFF and HSI_RUN state.
HSI_RESET	2	Resets the real-time hard/soft iron solution.

Table 64 – HSI_Output Field

Mode	Value	Description
NO_ONBOARD	1	Onboard HSI is not applied to the magnetic measurements.
USE_ONBOARD	3	Onboard HSI is applied to the magnetic measurements.

11.2 Status Registers

11.2.1 Calculated Magnetometer Calibration

Calculated Magnetometer Calibration				
Register ID :	47	**Firmware :** v1.0.0.0		**Access :** Read Only
Comment :	Calculated magnetometer calibration values.			
Size (Bytes):	48			
Example Response:	$VNRRG,46,1,0,0,0,1,0,0,0,1,0,0,0*70			

Offset	Name	Format	Unit	Description
0	C[0,0]	float	-	
4	C[0,1]	float	-	
8	C[0,2]	float	-	
12	C[1,0]	float	-	
16	C[1,1]	float	-	
20	C[1,2]	float	-	
24	C[2,0]	float	-	
28	C[2,1]	float	-	
32	C[2,2]	float	-	
36	B[0]	float	-	
40	B[1]	float	-	
44	B[2]	float	-	

This register contains twelve values representing the calculated hard and soft iron compensation parameters. The magnetic measurements are compensated for both hard and soft iron using the following model.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} MX - B0 \\ MY - B1 \\ MZ - B2 \end{Bmatrix}$$

The variables $\{MX, MY, MZ\}$ are components of the measured magnetic field. The {X, Y, Z} variables are the new magnetic field measurements outputted after compensation for hard/soft iron effects.

11.3 Factory Defaults

Settings Name	Default Factory Value
Magnetometer Calibration Control	1,3,5

11.4 Command Prompt

The command prompt provides a fast and simple means of configuring and monitoring the status of the sensor by typing commands to the unit using the serial port.

11.4.1 List Available Commands

Commands for the System subsystem can be accessed by typing in ‘hsi’ at the command prompt. To view all available commands, type ‘hsi ?’. Below is a view of a terminal window showing a list of the available commands.

```
hsi ?

Hard/Soft Iron Estimator Module Commands:

Command:    Description:
--------    --------------------------------------------------------------------
info        Estimator state information and configuration settings.
plotInput   Plot onboard HSI Input.
plotOutput  Plot onboard HSI Output.
```

11.4.2 Info

```
hsi info
-----------------  Hard/Soft Iron Estimator State Information  -----------------
Magnetometer Calibration Control (Register 44):

  HsiMode: Run
  OutMode: Use Onboard
  ConvergeRate: 5

Magnetometer Calibration Status (Register 46):

  LastBin: 0
  NumMeas: 102
  AvgResidual: 0.014
  LastMeas: +0.599  +0.538  +2.910
  Bins[0]: 215
  Bins[1]: 188
  Bins[2]: 135
  Bins[3]: 47
  Bins[4]: 198
  Bins[5]: 231
  Bins[6]: 202

Calculated Magnetometer Calibration (Register 47):

  +00.966  +00.000  +00.000  -00.215
  +00.000  +00.966  +00.000  -00.179
  +00.000  +00.000  +00.966  -00.077


Num Measurements: 358
Filter Run Count: 358
Mag Uncertainty : 0.00
--------------------------------------------------------------------------------
```

11.4.3 PlotInput

```
hsi plotinput

---------------------  HSI Estimator Magnetic Input Plot  ----------------------

                                 Uncalibrated XY

+-------------------+-------------------+-------------------+-------------------+
|                   |          *  *  *  | *   *             |                   |
|                   |      **** *  *  * *      ***          |                   |
|                   | *  *   *   *      |               **  |                   |
|                   *  * *  *    *      |* *      *         |                   |
|                  *** ** *      *   *  **     *            |                   |
|              ***  |   *     * * *   * |                   **   *              |
|               *   |*  *   ** * *      |    *   *  *       |*   *              |
|             *     |     *            *|    *              |                   |
|           *      *|      *  *       * |    *             **       *           |
+---------***-------+-----------*-------*----*--*-----*-----+----------*--------+
|        *          | *            *    *     *             |          **       |
|       * *         *                   | *                 *          ***      |
|     * **   *      |                *  |           *  *    |                   |
|      **           |        *   **     |                   |  *          *     |
|    *            * |      * * *        |               *   |                   |
|    ***            |                  *|      *   * * *    |              *    |
|     *             |      *     *      |            *      |    *     *  *     |
|    *              |   *               |    *              | *             *   |
|     *     **      |                   | *             *   |               *   |
+---*-*-*-----------+---*---------------+--------*-----*----+*------*-------*---+
|   *               | *                 |         *         | *            *    |
|  *   *         *  |                   |                ** |  *                |
|                   |   * *   ** *     *|      *            |        *          |
|   *   ** *        |     *   *        ** *    *  *   *     **    **   *        |
|     *  *          |        *        * |                   |            **     |
|     **            |           *       |         *         |    *              |
|         *     *   *       *           |                 * |           *       |
|     **            |                   |   *             * |          **       |
|      ***   * *    |                   |        *          |         ***       |
+--------**--------*+-------------------+-------------------+-----***-----------+
|        ****  *    |          *    *   * *   *             |*      **          |
|           *  * *  |                   *                   |     **            |
|            ***    |                   |                   |   * *             |
|                *  |   *               |                   * *                 |
|                   |            *      |  *       *        |                   |
|                   |                   |                   |                   |
|                   |  *                |                   |                   |
|                   |                   |                   |                   |
|                   |                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------+

  Plot Center :    +0.000,     +0.000
  Plot Scale  :    +1.042,     +1.042

--------------------------------------------------------------------------------
```

11.4.4 PlotOutput

```
hsi plotoutput

---------------------  HSI Estimator Magnetic Output Plot  ----------------------

                                  Calibrated XY

+-------------------+-------------------+-------------------+-------------------+
|                   |                   |                   |                   |
|                   |                   |                   |                   |
|                   |             **  * *   *    *          |                   |
|                   |          *** *  * * *       **        |                   |
|                   |     * *    *  *   |                * *|                   |
|                   |   *  * * *    *   |  * *      *       |                   |
|                   |  *** ***      *   * ***    *          |                   |
|                  ***      *    ** **  |*                  |**    *            |
|                   *    * *   **  * *  | *    **  *  *     | *    *            |
+-----------------*-+--*------*---------+-------------------+-------------------+
|               *   |         *  *      *      *  *         |*       *          |
|             **    |              *  * | **    *       *   |           **      |
|           * *     |     *             | *  *   *          |*          **      |
|           * *  *  |  *                *             *  *  |             *     |
|          **       |            *  *   |                   |   *               |
|                   |         *   *  *  |                 * |              *    |
|        ***        | *         *       |            * * ** |                   |
|         **        |                   |*        *         |     *     *   *   |
|         *         |      *  *     *   |              *    |   *         *     |
+----------*----**--+-------------------+---*---*---------*-+---------------**---+
|       ***  *      |       *           |          *     *  | *      *      *   |
|       **          |     *             |           *       |  *            *   |
|       *   *       |*                  |                  **   *               |
|        *          |       * *  *** *  | *       *         |         *         |
|         * ****    |        *          |* **    *  *  *    |**     **  *       |
|             *     |            *      *                   |             **    |
|         **        |          *    *   |           *       |      *            |
|          *   *    *  *                |                   *            *      |
|          *       *|                   |     *             *           **      |
+-----------***--*--+--*----------------+----------*--------+-------------------+
|             ***   |             *     |   *               |  *    ***         |
|              *   *|*                 *| *     *           |       **          |
|               ****|                   |                   |      **           |
|                *  |                   |                   | **  *             |
|                   |*      *           |                   |                   |
|                   |                *  |     *      *      |                   |
|                   |      *            |                   |                   |
|                   |                   |                   |                   |
|                   |                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------+

  Plot Center :    +0.000,     +0.000
  Plot Scale  :    +0.946,     +0.946

--------------------------------------------------------------------------------
```

12 World Magnetic & Gravity Module

12.1 Configuration Registers

12.1.1 Magnetic and Gravity Reference Vectors

Magnetic and Gravity Reference Vectors				
Register ID :	21	Firmware : 1.0.0.0	Access:	Read / Write
Comment :	Magnetic and gravity reference vectors.			
Size (Bytes):	24			
Example Command:	$VNWRG,21,1,0,1.8,0,0,-9.79375*56			

Offset	Name	Format	Unit	Description
0	MagRefX	float	Gauss	X-Axis Magnetic Reference
4	MagRefY	float	Gauss	Y-Axis Magnetic Reference
8	MagRefZ	float	Gauss	Z-Axis Magnetic Reference
12	AccRefX	float	m/s^2	X-Axis Gravity Reference
16	AccRefY	float	m/s^2	Y-Axis Gravity Reference
20	AccRefZ	float	m/s^2	Z-Axis Gravity Reference

This register contains the reference vectors for the magnetic and gravitational fields as used by the onboard filter. The values map to either the user-set values or the results of calculations of the onboard reference models (see the Reference Vector Configuration register). When the reference values come from the onboard model(s), those values are read-only. When the reference models are disabled, the values reflect the user reference vectors and will be writable. For example, if the onboard World Magnetic Model is enabled and the onboard Gravitational Model is disabled, only the gravity reference values will be modified on a register write. Note that the user reference vectors will not be overwritten by the onboard models, but will retain their previous values for when the onboard models are disabled.

12.1.2 Reference Vector Configuration

Reference Vector Configuration				
Register ID :	83	**Firmware :** v1.0.0.0		**Access :** Read / Write
Comment :	Control register for both the onboard world magnetic and gravity model corrections.			
Size (Bytes):	32			
Example Response:	$VNRRG,83,0,0,0,0,1000,0.000,+00.00000000,+000.00000000,+00000.000*4E			

Offset	Name	Format	Unit	Description
0	UseMagModel	uint8	-	Set to 1 to use the world magnetic model.
1	UseGravityModel	uint8	-	Set to 1 to use the world gravity model.
2	Resv1	uint8	-	Reserved for future use. Must be set to zero.
3	Resv2	uint8	-	Reserved for future use. Must be set to zero.
4	RecalcThreshold	uint32	-	Maximum distance traveled before magnetic and gravity models are recalculated for the new position.
8	Year	float	year	The reference date expressed as a decimal year. Used for both the magnetic and gravity models.
12				**** 4 byte padding ***
16	Latitude	double	deg	The reference latitude position in degrees.
24	Longitude	double	deg	The reference longitude position in degrees.
32	Altitude	double	m	The reference altitude above the reference ellipsoid in meters.

This register allows configuration of the onboard spherical harmonic models used to calculate the local magnetic and gravitational reference values. Having accurate magnetic reference values improves the accuracy of heading when using the magnetometer and accounts for magnetic declination. Having accurate gravitational reference values improves accuracy by allowing the INS filter to more accurately estimate the accelerometer biases. The VN-200 currently includes the EGM96 gravitational model and the WMM2010 magnetic model. The models are upgradable to allow updating to future models when available.

The magnetic and gravity models can be individually enabled or disabled using the UseMagModel and UseGravityModel parameters, respectively. When disabled, the corresponding values set by the user in the Reference Vector register (see Section 12.1.1) will be used instead of values calculated by the onboard model.

The VN-200 starts up with the user configured reference vector values. Shortly after startup (and if the models are enabled), the location and time set in this register will be used to update the reference vectors. When a 3D GPS fix is available, the location and time reported by the GPS will be used to update the model. If GPS is lost, the reference vectors will hold their last valid values. The model values will be recalculated whenever the current position has changed by the RecaclThreshold or the date has changed by more than approximately 8 hours, whichever comes first.

12.2 Factory Defaults

Settings Name	Default Factory Value
Magnetic and Gravity Reference Vectors	1,0,1.8,0,0,-9.793746
Reference Vector Configuration	1,1,0,0,1000,0,0,0,0

12.3 Command Prompt

The command prompt provides a fast and simple means of configuring and monitoring the status of the sensor by typing commands to the unit using the serial port.

12.3.1 List Available Commands

Commands for the System subsystem can be accessed by typing in 'refmodel' at the command prompt. To view all available commands, type 'refmodel ?'. Below is a view of a terminal window showing a list of the available commands.

```
refmodel ?

World Magnetic & Gravity Reference Model Commands:

Command:    Description:
--------    --------------------------------------------------------------------
info        Information on the current available reference models.
calc        Calculate the magnetic and gravity reference for a given position & time.
```

12.3.2 Info

```
refmodel info

------------  World Magnetic & Gravity Reference Model Information  ------------

World Magnetic Model
  Status                : Present
  Name                  : WMM2010
  Order                 : 12
  Model Start Date      : 01/01/2010
  Model Expiration Date : 01/01/2015

World Gravity Model
  Status                : Present
  Name                  : EGM96
  Order                 : 12
  Model Start Date      : 01/01/1986
  Model Expiration Date : 01/01/2100

Magnetic and Gravity Reference Vectors (Register 21)
  MagRefX     : +001.000
  MagRefY     : +000.000
  MagRefZ     : +001.800
  GravityRefX : +000.000
  GravityRefY : +000.000
  GravityRefZ : -009.794

Reference Vector Configuration (Register 83)
  UseMagneticModel   : 0
  UseGravityModel    : 0
  RecalcThreshold    : 1000 meters
  Year               : 0
  Latitude           : +00.00000000 deg
  Longitude          : +00.000000000 deg
  Altitude           : +00000.000 m
--------------------------------------------------------------------------------
```

12.3.3 Calc

```
refmodel calc

------------  World Magnetic & Gravity Reference Model Calculator  -------------

Enter latitude :
30

Enter longitude :
-94

Enter altitude :
100

Enter decimal year :
2014.5


Calculation Results
------------------------------------------
Latitude  : +30.00000000 deg
Longitude : -094.00000000 deg
Altitude  : +00100.000 m

Magnetic Reference Vector : +000.243, +000.008, +000.409 Gauss
Gravity Reference  Vector : +000.000, +000.000, -009.793 m/s^2
--------------------------------------------------------------------------------
```

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