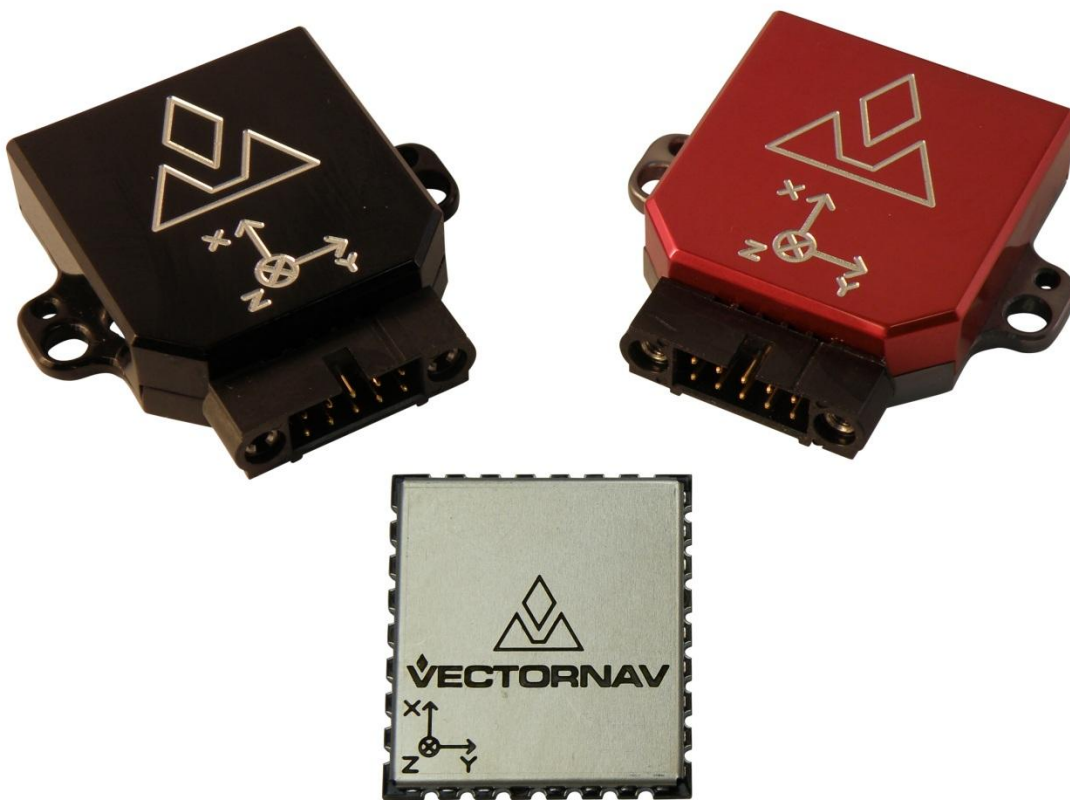




# VN-100 User Manual

Firmware v1.1



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# 1 Introduction

## 1.1 Product Description

The VN-100 is a miniature surface mount high performance Inertial Measurement Unit (IMU) and Attitude Heading Reference System (AHRS). Incorporating the latest solid-state MEMS sensor technology, the VN-100 combines 3-axis accelerometers, 3-axis gyros, and 3-axis magnetic sensors as well as a 32-bit processor into a miniature surface mount module. Along with providing calibrated sensor measurements the VN-100 also computes and outputs a real-time drift free 3D orientation solution that is continuous over the complete 360 degrees of motion.

## 1.2 Product Features

The VN-100 is available in two different configurations, in a surface mounted package (VN-100 SMT), or with an aluminum enclosure (VN-100 Rugged). The VN-100 Rugged provides a robust precision anodized aluminum clamshell enclosure, ensuring precise alignment and calibration, while still retaining the smallest possible footprint.

The VN-100 can be used as either an Inertial Measurement Unit (IMU) or as an orientation sensor (AHRS). As an IMU the VN-100 relies on its high quality factory calibration. Each individual VN-100 is calibrated to remove errors in 10 onboard sensors caused by scale factor, bias and misalignment. This digital alignment also ensures that each of the three 3-axis inertial sensors share the same coordinate frame, which is important for navigation applications.

For applications which require a full orientation solution, the VN-100 offers an onboard Aerospace grade attitude estimation Kalman filter. This algorithm known as the Vector Processing Engine (VPE) provides a drift-free 3D-orientation solution that works in any orientation and is capable of handling both acceleration and magnetic disturbances. For more information about the Vector Processing Engine see Section 2.



### 1.3 Surface Mount Package

For embedded applications the VN-100 is available in a miniature surface mount package.

#### Features

- Small Size: 24 x 22 x 3 mm
- Single Power Supply: 3.2 to 5.5 V
- Communication Interface: Serial TTL & SPI
- Low Power Requirement: < 165 mW @ 3.3V



### 1.4 Rugged Package

The VN-100 Rugged consists of the VN-100 sensor installed in a robust precision aluminum enclosure.

#### Features

- Precision aluminum enclosure
- Locking 10-pin connector
- Mounting tabs with alignment holes
- Compact Size: 33 x 26 x 9 mm
- Single Power Supply: 4.5 to 5.5 V
- Communication Interface: Serial RS-232



### 1.5 Surface Mount Development Kit

The VN-100 Development kit provides the VN-100 surface mount sensor installed onto a small PCB, providing easy access to all of the features and pins on the VN-100. Communication with the VN-100 is provided by either USB or RS-232 serial communication ports. A 20-pin header provides easy access to all of the important pins. The development kit also includes all of the necessary cables, documentation, and support software.

#### Features

- Pre-installed VN-100 Sensor
- Onboard USB->Serial converter
- Onboard TTL->RS-232 converter
- 20-pin 0.1in header for access to VN-100 pins
- Power supply jack – 5V (Can be power from USB)
- Board Size: 2.9" x 2.9"





## 1.6 VN-100 Rugged IMU/AHRS Development Kit

The VN-100 Rugged development kit includes the Rugged sensor along with all of the necessary cables 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 kit also includes all of the relevant documentation and support software.



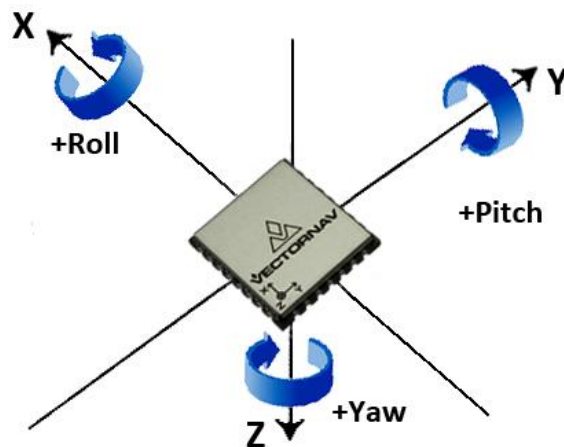
### Features

- 1 VN-100 Rugged Sensor
- 1 10-foot RS-232 cable
- 1 6-foot USB connector cable

#### 1.6.1.1 Sensor Coordinate System

The VN-100 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-100 module is shown in Figure 1.

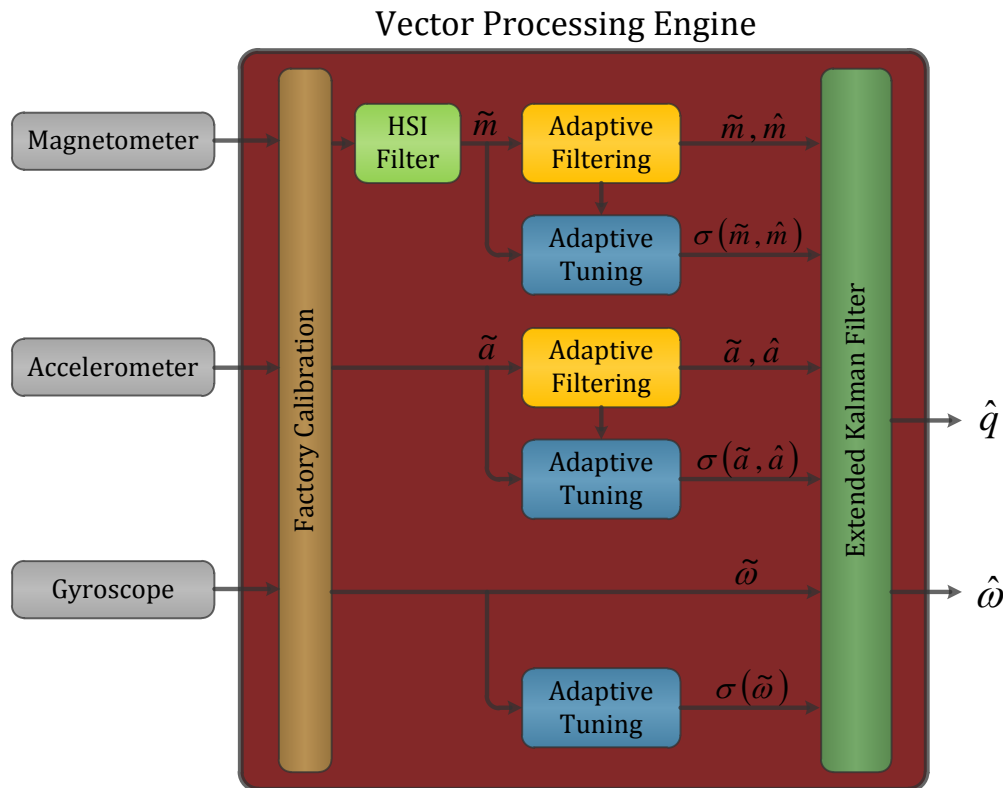
Figure 1 - VN-100 Coordinate System



## 2 VN-100 Vector Processing Engine

### 2.1 Overview

Along with the 9-axis calibrated sensor array the VN-100 also incorporates onboard a 32-bit ARM processor running VectorNav's general purpose attitude estimation algorithm known as the Vector Processing Engine. The Vector Processing Engine (VPE) combines the measurements available from the accelerometers, magnetometers and gyroscopes to derive a high accuracy 3D orientation solution with minimal gyro drift for both static and dynamic conditions.



### 2.2 Components of the VPE

The Vector Processing Engine (VPE) provides a complete embedded sensor fusion framework capable of estimating the orientation and angular rate of an object in real-world environments where both magnetic and acceleration disturbances are present. The VPE combines a collection of logic and filter building blocks into a single software package, minimizing the additional processing necessary by the end user to obtain an accurate attitude estimate. The overall operation of the VPE can be divided into 5 distinct stages.

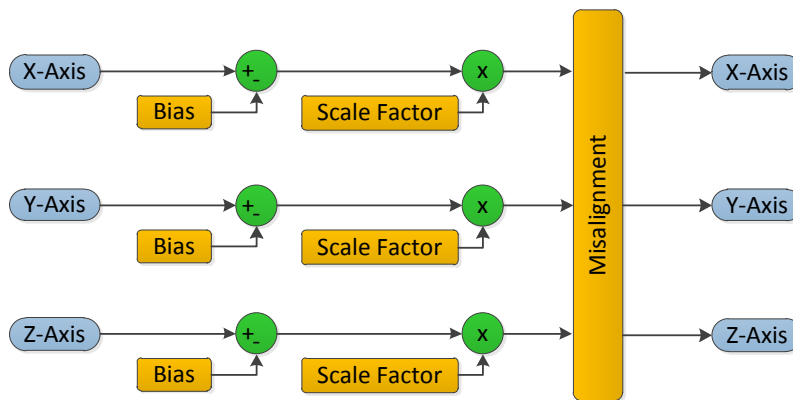
1. Static (Factory) Calibration
2. Dynamic Calibration
3. Adaptive Filtering
4. Adaptive Tuning
5. Attitude Estimation



## 2.3 Static (Factory) Calibration

During the static calibration stage each of the ten sensors (3-axis magnetometer, 3-axis accelerometer, 3-axis gyro, and temperature sensor) are digitally compensated to eliminate the errors due to scale factor, axis-misalignment, biases, and temperature sensitivity. For the gyros, sensitivity to acceleration is also taken into account. Each VectorNav sensor is individually calibrated in temperature-controlled robotic calibration stands at our factory to determine each sensor's unique calibration coefficients. Each sensor is subjected to precisely known rotations and orientations across the specified performance temperature range. The data collected from these tests is used at the factory to calculate the unique calibration coefficients for each individual sensor, and these calibration coefficients are permanently stored in flash. During operation at each time step after the raw measurements are collected from the sensors, the calibration coefficients are digitally applied to compensate for the known systematic errors measured during the factory calibration. This static calibration is automatically applied at each time step by the VN-100 and no additional processing is required by the end user.

Figure 2 - Sensor Calibration



## 2.4 Dynamic (Real-time) Calibration

Some of the sensors have calibration parameters that are time-variant, or are altered when the sensor is installed into its intended application. The magnetometer for example experiences changes to its apparent scale and bias due to the effect of nearby ferrous materials which alter the measured local magnetic field. If not properly accounted for these distortions can result in a significant loss of heading accuracy. Traditionally hard/soft iron distortions are accounted for using off-line post-processing techniques. The VPE utilizes a separate optional Kalman Filter running in the background to estimate on-line the hard/soft iron distortions. This eliminates the need for off-line data processing and allows the VPE to dynamically adapt to potentially varying magnetic conditions. More information about the operation of the automatic hard/soft iron calibration can be found in Section 2.17. The VPE utilizes the main attitude estimation filter to calculate the time varying gyro bias at each time step. By dynamically removing this gyro bias the VPE is able to provide a drift-free orientation and angular rate estimate. The gyro bias is calculated at all times, even during periods of motion, and does not rely on the device to be placed in a stationary state for periodic “zeroing” of the bias.



## 2.5 Adaptive Filtering

The VPE employs adaptive filtering techniques to significantly reduce the effect of high frequency disturbances in both magnetic and acceleration. Prior to entering the attitude filter, the magnetic and acceleration measurements are digitally filtered to reduce high frequency components typically caused by electromagnetic interference and vibration. The level of filtering applied to the inputs is dynamically altered by the VPE in real-time. The VPE calculates the minimal amount of digital filtering required in order to achieve specified orientation accuracy and stability requirements. By applying only the minimal amount of filtering necessary, the VPE reduces the amount of delay added to the input signals. For applications that have very strict latency requirements, the VPE provides the ability to limit the amount of adaptive filtering performed on each of the input signals. For more information on how to adjust the level of adaptive filtering see Section 2.16.

## 2.6 Adaptive Tuning

Kalman filters employ coefficients that specify the uncertainty in the input measurements which are typically used as “tuning parameters” to adjust the behavior of the filter. Normally these tuning parameters have to be adjusted by the engineer to provide adequate performance for a given application. This tuning process can be ad-hoc, time consuming, and application dependent. The VPE employs adaptive tuning logic which provides on-line estimation of the uncertainty of each of the input signals during operation. This uncertainty is then applied directly to the onboard attitude estimation Kalman filter to correctly account for the uncertainty of the inputs. The adaptive tuning reduces the need for manual filter tuning. For more information on how to adjust the level of adaptive tuning performed by the VPE see Section 2.15.

## 2.7 Attitude Estimation

The orientation and angular rate are calculated using a quaternion based Extended Kalman Filter. The estimation algorithm employs quaternion math to eliminate the problem of gimbal lock, allowing the device to provide consistent and stable output in any orientation. Along with estimating the orientation, the filter also estimates the time-varying gyro bias. This provides a drift-free orientation and angular rate estimate even during periods of sustained motion. The attitude is estimated using the vector measurements from both the magnetometer and accelerometers. The magnetometers can be used in either 2D or 3D mode. In 2D mode, the magnetometer will only affect the estimated heading, and the pitch and roll will only be determined by the output of the accelerometer. In 3D mode the magnetometer input is allowed to affect the full attitude solution. For applications where the magnetic field is well defined and free of any un-modeled disturbances, operating in 3D mode will in theory provide the highest level of orientation accuracy. For most applications however, operating with the magnetometer in 2D mode provides the best overall accuracy due to the inherent uncertainty and variability in the local magnetic field. For more information on the settings pertaining to the Attitude Estimation algorithm see Section 7.35.

## 2.8 VPE Magnetic Heading Modes

The VectorNav VPU provides three separate heading modes. Each mode controls how the VPE interprets the magnetic measurements to estimate the heading angle. The three modes are described in detail in the following sections.



## 2.9 Absolute Heading Mode

In Absolute Heading Mode the VPE will assume that the principal long-term DC component of the measured magnetic field is directly related to the earth's magnetic field. As such only short term magnetic disturbances will be tuned out. This mode is ideal for applications that are free from low frequency (less than  $\sim 1\text{Hz}$ ) magnetic disturbances and/or require tracking of an absolute heading. Since this mode assumes that the Earth's magnetic field is the only long-term magnetic field present, it cannot handle constant long-term magnetic disturbances which are of the same order of magnitude as the Earth's magnetic field and cannot be compensated for by performing a hard/soft iron calibration. From the sensor's perspective a constant long-term magnetic disturbance will be indistinguishable from the contribution due to the Earth's magnetic field, and as such if present it will inevitably result in a loss of heading accuracy.



*If a magnetic disturbance occurs due to an event controlled by the user, such as the switching on/off of an electric motor, an absolute heading can still be maintained if the device is notified of the presence of the disturbance. For more information see the Known Magnetic Disturbance Command (Section 6.4.7.)*



*To correctly track an absolute heading you will need to ensure that the hard/soft iron distortions remains well characterized. See Section 2.17 for more information on hard/soft iron distortions and the automated calibration module.*

### Absolute Heading Mode Advantages

- Provides short-term magnetic disturbance rejection while maintaining absolute tracking of the heading relative to the fixed Earth.

### Absolute Heading Mode Disadvantages

- If the magnetic field changes direction relative to the fixed Earth, then its direction will need to be updated using the reference vector register in order to maintain an accurate heading reference.
- Hard/Soft iron distortions that are not properly accounted for will induce heading errors proportional to the magnitude of the hard/soft iron distortion. In some cases this could be as high as 30 - 40 degrees.

## 2.10 Relative Heading Mode

In Relative Heading mode the VPE makes no assumptions as to the long term stability of the magnetic field present. In this mode the VPE will attempt to extract what information it reasonably can from the magnetic measurements in order to maintain an accurate estimate of the gyro bias. The VPE will constantly monitor the stability of the magnetic field and when it sees that its direction is reasonably stable, the VPE will maintain a stable heading estimate. Over long periods of time under conditions where the magnetic field direction changes frequently, in Relative Heading mode it is possible for the VN-100 to accumulate some error in its reported heading relative to true North. In this mode the VPE will not attempt to correct for this accumulated heading error.

Relative Heading mode does not assume that the Earth's magnetic field is the only long-term magnetic field present. As such this mode is capable of handling a much wider range of magnetic field disturbances while still maintaining a stable attitude solution. Relative Heading mode should be used in



situations where the most important requirement is for the attitude sensor is to maintain a stable attitude solution which minimizes the effect of gyro drift while maintaining a stable and accurate pitch and roll solution. Since the Relative Heading mode assumes that other magnetic disturbances can be present which are indistinguishable from the Earth's field, Relative Heading mode cannot always ensure that the calculated heading is always referenced to Earth's magnetic north.



*Use the Relative Heading mode for applications where the stability of the estimated heading is more important than the long-term accuracy relative to true magnetic North. In general, the Relative Heading mode provides better magnetic disturbance rejection than the Absolute Heading mode.*

### Relative Heading Mode Advantages

- Capable of handling short-term and long-term magnetic interference
- Can handle significant errors in the hard/soft iron while still maintaining a stable heading and gyro bias estimate.

### Relative Heading Mode Disadvantages

- Unable to maintain heading estimate relative to true North in environments with frequent long-term magnetic field disturbances.

## 2.11 Indoor Heading Mode

The Indoor Heading mode was designed to meet the needs of applications that require the enhanced magnetic disturbance rejection capability of the Relative Heading mode, yet desire to maintain an absolute heading reference over long periods of time. The Indoor Heading mode extends upon the capabilities of the Relative Heading mode by making certain assumptions as to the origin of the measured magnetic fields consistent with typical indoor environments.

In any environment the measured magnetic field in 3D space is actually the combination of the Earth's magnetic field plus the contribution of other local magnetic fields created by nearby objects containing ferromagnetic materials. For indoor environments this becomes problematic due to the potential close proximity to objects such as metal desk, chairs, speakers, rebar in the concrete floor, and other items which either distort or produce their own magnetic field. The strength of these local magnetic fields are position dependent, and if the strength is on the same order of magnitude as that of the Earth's magnetic field, directly trusting the magnetic measurements to determine heading can lead to inaccurate heading estimates.

While in Indoor Heading mode the VPE inspects the magnetic measurements over long periods of time, performing several different tests on each measurement to quantify the likelihood that the measured field is free of the influence of any position dependent local magnetic fields which would distort the magnetic field direction. Using this probability the VPE then estimates the most likely direction of the Earth's magnetic field and uses this information to correct for the heading error while the device is in motion.



*For the Indoor Heading mode you can adjust how quickly the VPE compensates for known errors in heading. For more information see the Indoor Mode Control register (Section 7.47.)*



### Indoor Heading Mode Advantages

- Capable of handling short-term and long-term magnetic interference
- Can handle significant errors in the hard/soft iron while still maintaining a stable heading and gyro bias estimate.
- Capable of maintaining an accurate absolute heading over extended periods of time.

### Indoor Heading Mode Disadvantages

- Measurement repeatability may be slightly worse than Relative Mode during periods when the VPE corrects for known errors in absolute heading.

## 2.12 Overview of Heading Modes

A summary of the different types of disturbances handled by each magnetic mode is summarized in the table below.

**Table 1 - Types of Disturbances handled by each Magnetic Mode**

Capabilities	Absolute Heading	Relative Heading	Indoor Mode
Handle high frequency magnetic disturbances greater than 1Hz?	Yes	Yes	Yes
Handle constant disturbances lasting less than a few seconds?	Yes	Yes	Yes
Handle constant disturbances lasting longer than a few seconds?	No	Yes	Yes
Maintain accurate heading relative to true North over long periods of time?	Yes	No	Yes*

\* Accuracy depends upon recovery rate settings. See Section 7.47 for more information.

## 2.13 VPE Adaptive Filtering and Tuning Settings

The VPE actively employs both adaptive filtering and adaptive tuning techniques to enhance performance in conditions of dynamic motion and magnetic and acceleration disturbances. The VPE provides the ability to modify the amount of adaptive filtering and tuning applied on both the magnetometer and the accelerometer. In many cases the VPE can be used as is without any need to adjust these settings. For some applications higher performance can be obtained by adjusting the amount of adaptive filtering and tuning performed on the inputs. For both the magnetometer and the accelerometer the following settings are provided.

### 2.14 Static Measurement Uncertainty

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

- This parameter can be adjusted from 0 to 10.
- Zero places no confidence (or infinite uncertainty) in the sensor, thus eliminating its effect on the attitude solution.



- Ten places full confidence (minimal uncertainty) in the sensor and assume that its measurements are always 100% correct.

## 2.15 Adaptive Tuning Gain

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

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

## 2.16 Adaptive Filtering Gain

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

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

Keep in mind that regardless of this setting, the adaptive filtering stage will apply only the minimal amount of filtering necessary to get the job done. As such this parameter provides you with the ability to set the maximum amount of delay that you are willing to accept in the input measurement.

## 2.17 Magnetic Hard/Soft Iron Calibration

Hard and soft iron distortions are caused by ferromagnetic materials that are close to and rigidly attached to the same object as the sensor. Hard iron distortions create an additive magnetic field and add directly to the measured Earth's magnetic field. Hard iron objects include anything that is either magnetic or has been magnetized. Soft iron distortion comes from objects made from materials such as iron, cobalt, and nickel which distort the direction of an existing magnetic field. Because their effect on the field is a function of their direction relative to the Earth's magnetic field, compensating for both hard and soft iron distortions isn't trivial and requires collecting data while the sensor is rotated in many different orientations.

The VPE utilizes a separate Kalman filter running in the background to perform real-time compensation for hard and soft iron disturbances. The hard and soft iron calibration can either be run once and the parameters saved to flash memory for future use, or the calibration can be left running in the background to continuously compensate for possible changes in the hard and soft iron distortions.







*As an embedded sensor in many applications the VN-100 may be mounted in close proximity to removable battery packs. Batteries contain many metals that have both hard and soft iron characteristics. For these applications it may be desirable to leave the hard/soft iron calibration running in the background so that if a battery pack is swapped the sensor will dynamically adjust to any variations in hard/soft iron characteristics different between the battery packs.*

For more information on how to turn on/off the hard/soft iron calibration and adjust its settings see the Magnetic Calibration Control Register (Section 7.44.)



## 3 Operation and Usage Scenarios

The following section provides an overview as to the various ways the VN-100 sensor can be used. It describes in detail how the VN-100 can be used as an IMU or an orientation sensor, various synchronization options, and installation and alignment procedures. This section should serve as a preliminary guide that will get you up and running with the VN-100. For more implementation specific details, see our application notes section on the website.

### 3.1 Using the VN-100 as an Inertial Measurement Unit

As an Inertial Measurement Unit (IMU), the VN-100 is utilized to provide only calibrated acceleration, angular rates, and magnetic field measurements. Typically when the device is used as an IMU, the attitude information isn't required. The VN-100 will always compute the attitude solution onboard regardless of whether it is being used or not.

The VN-100 offers a SyncOut line that can be software configured to trigger either when the IMU or the attitude measurements are available. The device defaults to trigger when the attitude information is available. To reduce the measurement latency when the device is solely used as an IMU, it is recommended that the SyncOut line is switched to trigger when new IMU measurements are available.

The VN-100 provides two different angular rate measurements. The un-compensated rate measurements (available in Register 252) come straight from the calibrated gyro and are not altered by the onboard running Kalman filter. The compensated rate measurements (available in Register 20) are corrected for the gyro bias drift by the onboard Kalman filter. When the Kalman filter is properly tuned the compensated rates are drift-free. Normally however, for an IMU uncompensated angular rates are preferred since gyro bias estimation is usually handled by a higher level filter.

#### *Setting up the VN-100 as an IMU*

To use the VN-100 as an IMU, from the factory default state performs the following steps.

1. Set the SyncOut to trigger when the IMU data is available. For more information on this register see Section 7.33.

Interface	Write Register - Set SyncOut to IMU Mode
Serial	\$VNWRG,32,0,0,0,0,2,0,0,500000,0*5C
SPI	02 20 00 00 00 00 00 00 00 00 00 00 02 00 00 00 00 00 07 A1 20 00 00 00 00

2. Read the IMU data using Register 252 (Section 7.52). This register provides the calibrated magnetometer, accelerometer, and un-compensated angular rate measurements.

Interface	Read Register - IMU Data
Serial	\$VNRRG,252*46
SPI	01 FC 00 00

For information on how to parse the response to this read register command see Section 7.52.



## 3.2 Using the VN-100 as an Orientation Sensor

The VN-100 can be used as either an Inertial Measurement Unit, and orientation sensor, or both. After capturing new IMU measurements, the VN-100 immediately begins computing a new attitude solution (orientation) using its onboard Kalman filter. The attitude is provided either as Euler angles, a quaternion, or a directional cosine matrix. Below are the registers that are commonly used when the VN-100 is used as an orientation sensor.

Register	Register Name	ADOR ID	ADOR Name
8	Yaw, Pitch, Roll	1	YPR
9	Quaternion	2	QTN
16	Directional Cosine Matrix	9	DCM
27	Yaw, Pitch, Roll, and IMU Data	14	YMR
15	Quaternion and IMU Data	8	QMR

The VN-100 offers a SyncOut line that can be software configured to trigger either when the IMU or the attitude measurements are available. The device defaults to trigger when the attitude information is available.



*When using the device as an orientation sensor it is important that the attitude filter is set to the correct operational mode. For more information on which operational mode is best suited for your application see Section 2.8.*

### *Set the Filter Operational Mode*

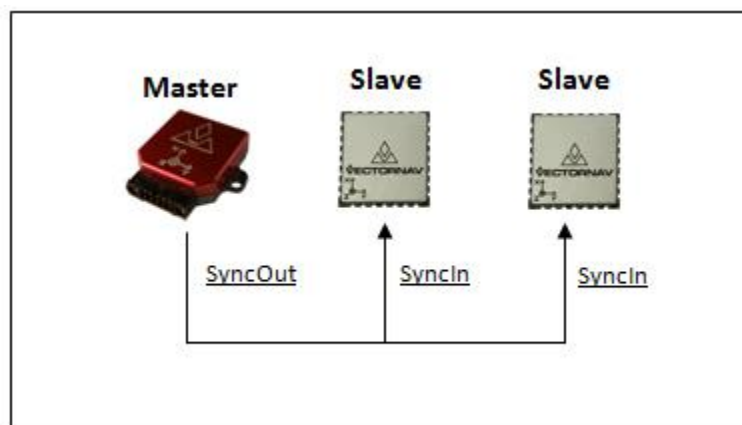
The filter operational mode is selected in the Filter Control Register (Section 7.35).

## 3.3 Synchronizing the VN-100 with other devices

### 3.4 Synchronizing Multiple VN-100's

The synchronization feature can be used to synchronize multiple VN-100 sensors together such that all sensors sample at the same time. To do this, select one sensor to be the master. The remaining sensors in the network will be considered slaves. Connect the SyncOut line of the master to the SyncIn lines of each of the slaves.

Figure 3 - Synchronizing Multiple VN-100's



Using the Synchronization Control Register (Section 7.33), the master unit needs to be set to output a pulse on the SyncOut pin when the ADC sampling begins. To do this send the following command to the master device.

Interface	Write Register - Set Master SyncOut
Serial	\$VNWRG,32,0,0,0,0,1,0,0,500000,0*5F
SPI	02 20 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 07 A1 20 00 00 00 00

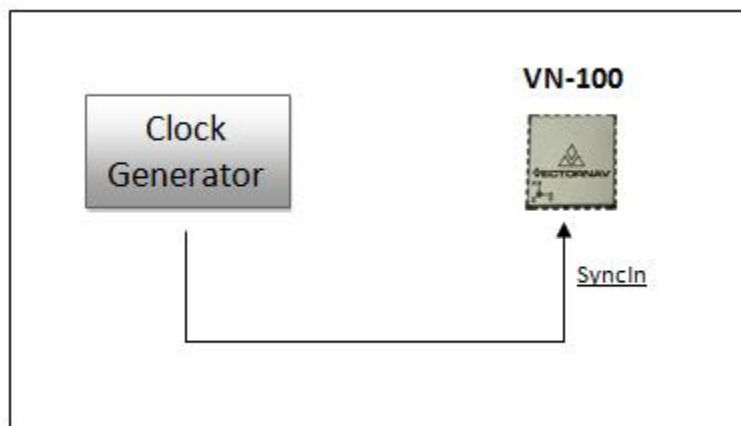
On each slave unit the SyncIn line must be configured to trigger on the ADC sampling. To do this send the following command to the slave devices.

Interface	Write Register - Set Slave SyncIn
Serial	\$VNWRG,32,1,0,0,0,3,0,0,500000,0*5C
SPI	02 20 00 00 01 00 00 00 00 00 00 00 03 00 00 00 00 07 A1 20 00 00 00 00

### 3.5 Running the VN-100 off an external clock

It is also possible to use an external clock to drive the ADC sampling and filter loop of the VN-100. Normally the VN-100 uses its internal clock to run the internal filtering loop which is fixed at 200Hz. An external signal can be used in place of the internal clock provided that the VN-100 can still be run at precisely 200Hz. It is important to note that the VN-100 filter loop must run at precisely 200Hz at all times. During the integration step of the onboard filtering a fixed time step of 5ms is always assumed. If a signal other than 200Hz is used to run the filter, then you will have significant performance degradation due to incorrect propagation of the gyro rates. It is possible to run the VN-100 filter loop at 200Hz using a higher frequency signal, provided that the signal frequency is a multiple of the required 200Hz. For example a 1kHz signal can be used by setting the SyncInSkipFactor in the Synchronization Control Register (Section 7.33) equal to 4. With this setting the device will trigger on every 5th edge selected by the SyncInEdge field.

Figure 4 - Using an external clock



To set the VN-100 to operate using an external clock, send the following command to the device.

Interface	Write Register - Set to Use External Clock
Serial	\$VNWRG,32,1,0,0,0,1,0,0,500000,0*5E
SPI	02 20 00 00 01 00 00 00 00 00 00 00 01 00 00 00 00 07 A1 20 00 00 00 00



**How to deal with different sampling rates**

The VN-100 will sample the IMU Measurement Register (Section 7.52) at the beginning of each filter loop. Since the filter loop always runs at 200Hz, this will occur every 5ms. If the external magnetometer measurements are updated at a rate slower than 200Hz, it is possible that the IMU Measurement Register may not be updated every filter cycle. If this happens then the VN-100 will continue to use the previously set external magnetometer measurement until it receives a new update. If you wish to have the attitude filter only use the magnetometer data to update the attitude filter when the magnetometer measurement updates, then set the ExtMagMode field to 2. In this state, the magnetometer will be tuned out during the time steps that it isn't updated.



# 4 Specifications

## 4.1 Pin-out and Electrical Specifications

### 4.1.1 VN-100 Surface Mount Sensor (SMT)

Figure 7 – Pin assignments (top down view)

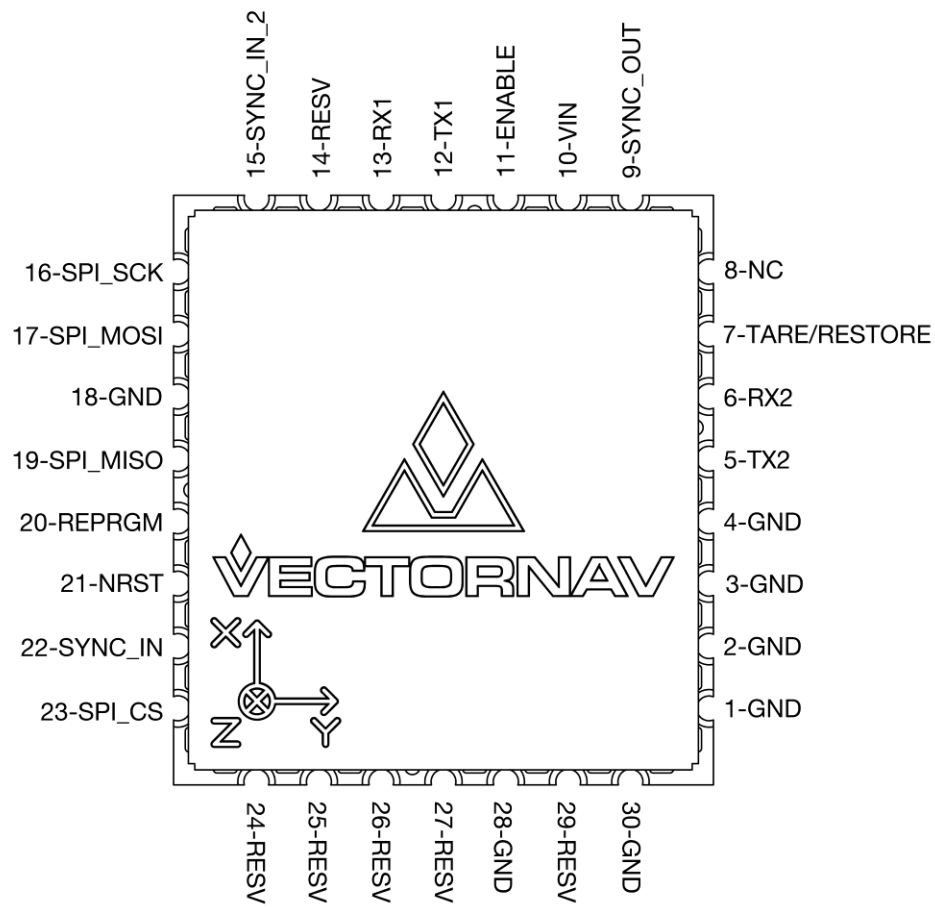


Table 2 – VN-100 SMT Pin Assignments

Pin #	Pin Name	Description
1	GND	Ground.
2	GND	Ground.
3	GND	Ground.
4	GND	Ground.
5	TX2	Serial UART #2 data output. (sensor)
6	RX2	Serial UART #2 data input. (sensor)
7	TARE/RESTORE	Normally used to zero (tare) the attitude. To tare, pulse high for at least 1 $\mu$ s. During power on or device reset, holding this pin high will cause the module to restore its default factory settings. Because of this, the pin cannot be used for tare until at least 5 ms after a power on or reset. Internally held low with 10k resistor.
8	NC	Not used.
9	SYNC_OUT	Time synchronization output signal. See section 7.33 for more details.
10	VIN	3.2 - 5.5V input.
11	ENABLE	Leave high for normal operation. Pull low to enter sleep mode. Internally pulled high with pull-up resistor.
12	TX1	Serial UART #1 data output. (sensor)
13	RX1	Serial UART #1 data input. (sensor)
14	RESV	Reserved for future use. Leave pin floating.
15	SYNC_IN_2	Reserved for future use. For backwards compatibility with older hardware revisions this pin can be configured in software to operate as the time synchronization input signal. For new designs it is recommended that SYNC_IN (pin 22) is used instead. See Section 7.33 for more details.
16	SPI_SCK	SPI clock.
17	SPI_MOSI	SPI input.
18	GND	Ground.
19	SPI_MISO	SPI output.
20	REPRGM	Used to reprogram the module. Must be left floating or set to low for normal operation. Pull high on startup to set the chip in reprogram mode. Internally held low with 10k resistor.
21	NRST	Microcontroller reset line. Pull low for > 20 $\mu$ s to reset MCU. Internally pulled high with 10k.
22	SYNC_IN	Time synchronization input signal. See Section 7.33 for more details.
23	SPI_CS	SPI slave select.
24	RESV	Reserved for future use. Leave pin floating.
25	RESV	Reserved for future use. Leave pin floating.
26	RESV	Reserved for future use. Leave pin floating.
27	RESV	Reserved for future use. Leave pin floating.
28	GND	Ground.
29	RESV	Reserved for future use. Leave pin floating.
30	GND	Ground.





#### 4.1.1.1 VN-100 SMT Power Supply

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

#### 4.1.1.2 VN-100 SMT Serial (UART) Interface

The serial interface on the VN-100 operates with 3V TTL logic.

Table 3 - Serial I/O Specifications

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

#### 4.1.1.3 VN-100 SMT Serial Peripheral Interface (SPI)

Table 4 - Serial I/O Specifications

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

#### 4.1.1.4 VN-100 SMT Reset, SyncIn/Out, and Other General I/O Pins

Table 5 - NRST Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5V		0.8V
Input high level voltage	2V		5.5V
Weak pull-up equivalent resistor	30 k $\Omega$	40 k $\Omega$	50 k $\Omega$
NRST pulse width	20 $\mu$ s		

Table 6 - SyncIn Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5V		0.8V
Input high level voltage	2V		5.5V
Input Frequency	200 Hz	200 Hz	1 kHz
Pulse Width	500 $\mu$ s		

Table 7 - SyncOut Specifications

Specification	Min	Typical	Max
Output low voltage	0V		0.4V
Output high voltage	2.4V		3.0V
Output high to low fall time			125 ns
Output low to high rise time			125 ns
Output Frequency	1 Hz		200 Hz

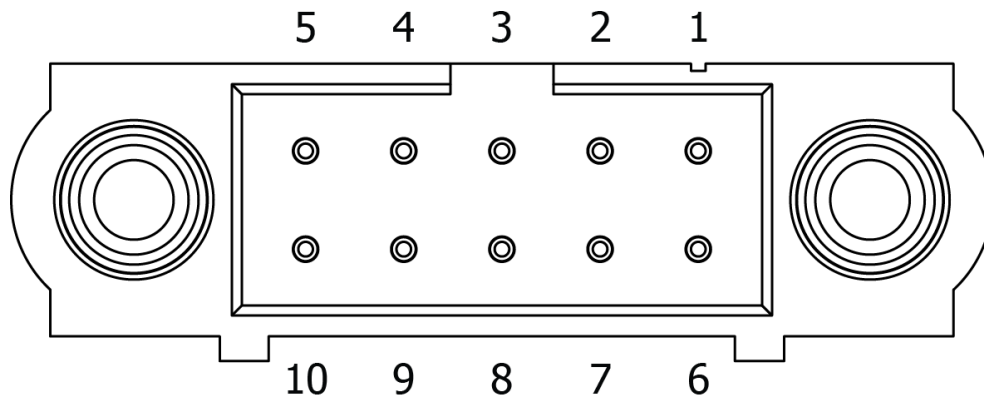


### 4.1.2 VN-100 Rugged

Table 8 – VN-100 Rugged Pin Assignments

Pin #	Pin Name	Description
1	VCC	+5V ( $\pm 0.5V$ )
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	TARE/RESTORE	Input signal used to zero the attitude of the sensor. 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 8 - VN-100 Rugged External Connector



#### 4.1.2.1 VN-100 Rugged Power Supply

The nominal power supply for the VN-100 Rugged is 5V DC.

- The VN-100 Rugged internally has overvoltage protection set at a fixed voltage of 5.8V. Upon an overvoltage event the protection circuitry will disable power to the VN-100 to reduce possibility of damage to the voltage regulator onboard the VN-100.

#### 4.1.2.2 VN-100 Rugged Serial UART Interface

Table 9 - Serial I/O Specifications

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

#### 4.1.2.3 VN-100 Rugged Reset, SyncIn/Out, and Other General I/O Pins

Table 10 - NRST Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5V		0.8V
Input high level voltage	2V		5.5V
Weak pull-up equivalent resistor	30 k $\Omega$	40 k $\Omega$	50 k $\Omega$
NRST pulse width	20 $\mu$ s		

Table 11 - SyncIn Specifications

Specification	Min	Typical	Max
Input low level voltage	-0.5V		0.8V
Input high level voltage	2V		5.5V
Input Frequency	200 Hz	200 Hz	1 kHz
Pulse Width	500 $\mu$ s		

Table 12 - SyncOut Specifications

Specification	Min	Typical	Max
Output low voltage	0V		0.4V
Output high voltage	2.4V		3.0V
Output high to low fall time			125 ns
Output low to high rise time			125 ns
Output Frequency	1 Hz		200 Hz

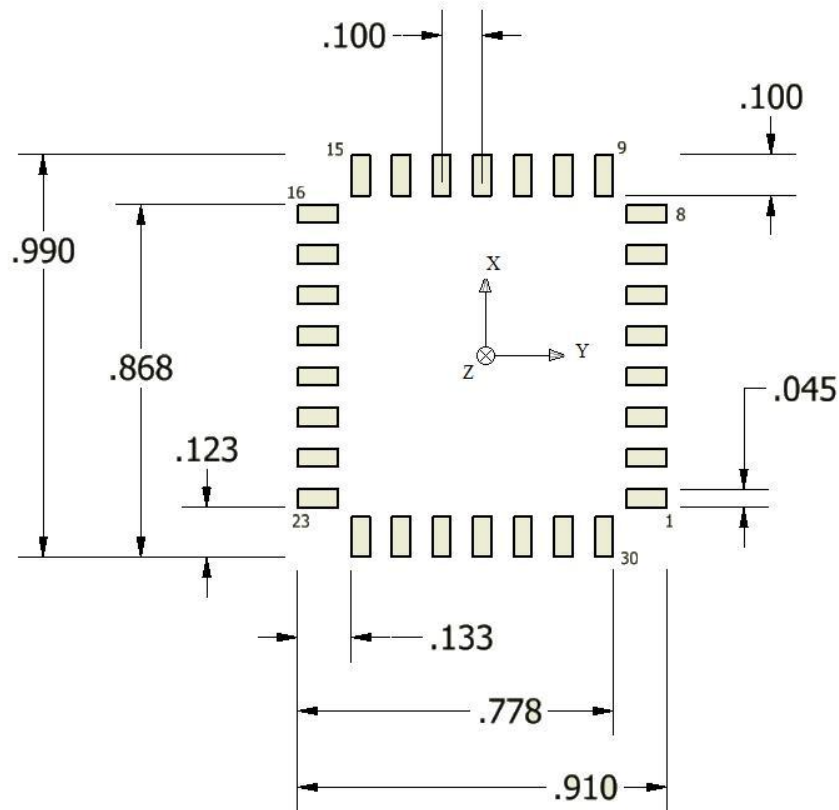


## 4.2 Physical Specifications and Dimensions

### 4.2.1 VN-100 Surface Mount Sensor

#### 4.2.1.1 Footprint

Figure 9 – VN-100 PCB Footprint



\* Measurements are in inches

## 4.3 Absolute Maximum Ratings

Table 13 - Absolute Maximum Ratings

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

# 5 Basic Communication

The VN-100 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-100 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 (Section 5 & 6).

## 5.1 Serial Interface

On the serial interface, the VN-100 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
```

## 5.2 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.

### 5.2.1.1 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.

```
unsigned char calculateChecksum(char* command, int length)
{
    unsigned char xor = 0;

    for(int i = 0; i < length; i++)
        xor ^= (unsigned char)command[i];

    return xor;
}
```

### 5.2.1.2 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-100 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.



```

unsigned short calculateChecksum(char* command, int length)
{
    unsigned int i;
    unsigned short crc = 0;

    for(i=0; i<length; i++){
        crc = (unsigned char)(crc >> 8) | (crc << 8);
        crc ^= command[i];
        crc ^= (u8)(crc & 0xff) >> 4;
        crc ^= (crc << 8) << 4;
        crc ^= ((crc & 0xff) << 4) << 1;
    }

    return crc;
}

```

### 5.3 SPI Interface

The SPI interface uses a lightweight binary message format. The start of a command is signaled by pulling the VN-100 module's chip select pin (pin 23) low. Both the chip select line and clock are active low. The first byte transmitted to the module should be the command ID and then a variable number of bytes will follow dependent on the type of command specified. A communication transaction can be cancelled at any time by releasing the chip select pin. Pulling the pin low again will start a new communication transaction. All binary data is sent to and from the chip with most significant bit (MSB) first in little-endian byte order with pad bytes inserted where required to ensure 16-bit values are aligned to two-byte boundaries and 32-bit values are aligned to 4-byte boundaries. For example the serial baud rate register with a value of 9600 (0x2580) would be sent across the SPI as a 0x80, 0x25, 0x00, 0x00. Data is requested from and written to the device using multiple SPI transactions.

Figure 10 – SPI Timing Diagram

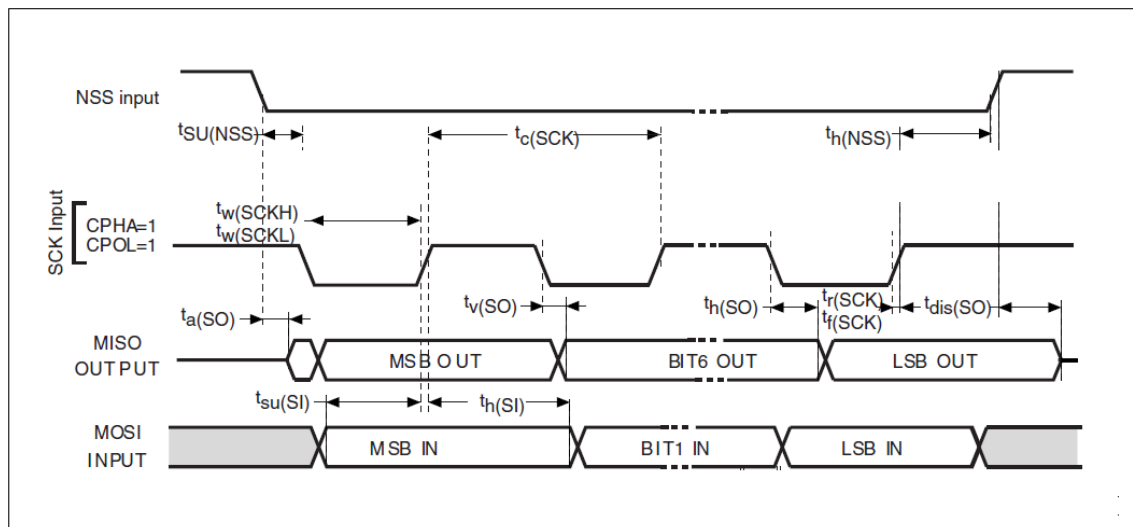
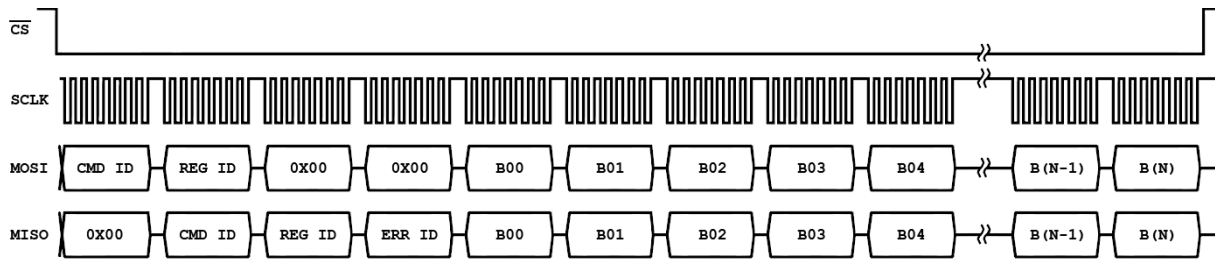


Figure 11 - SPI Data Diagram



A response for a given SPI command will be sent over the MISO line on the next SPI transaction. Thus the data received by the Master on the MISO line will always be the response to the previous transaction. So for example if Yaw, Pitch, Roll and angular rates are desired, then the necessary SPI transactions would proceed as shown below.

SPI Transaction 1		
Line	Bytes	Description
SCK	8 bytes	
MOSI	01 08 00 00 00 00 00 00 (shown as hex)	Read register 8 (Yaw, Pitch, Roll)
MISO	00 00 00 00 00 00 00 00 (shown as hex)	No response

SPI Transaction 2		
Line	Bytes	Description
SCK	16 bytes	
MOSI	01 13 00 00 00 00 00 00 00 00 00 00 00 00 00 00 (shown as hex)	Read register 13 (Angular Rates)
MISO	00 01 08 00 39 8A 02 43 FD 43 97 C1 CD 9D 67 42 (shown as hex)	Yaw, Pitch, Roll = -130.54, -18.91, +57.90

SPI Transaction 3		
Line	Bytes	Description
SCK	16 bytes	
MOSI	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 (shown as hex)	No command
MISO	00 01 13 00 00 F5 BF BA 00 80 12 38 B8 CC 8D 3B (shown as hex)	Rates = -0.001465, +0.000035, +0.004327

During the first transaction the master sends the command to read register 8. The available registers which can be read or written to are listed in Table 26. At the same time zeros are received by the master, assuming no previous SPI command was sent to the chip since reboot. On the second transaction the master sends the command to read register 13. At the same time the response from the previously requested register 8 is received by the master on the MISO line. It consists of four 32-bit words. The first byte of the first word will always be zero. The second byte of the first word is the type of command that this transaction is in response to. In this case it is a 0x01 which means that on the previous transaction a read register command was issued. The third byte of the first word is the register that was requested on the previous transaction. In this case it shows to be 0x08 which is the yaw, pitch, roll register. The fourth byte of the first word is the error code for the previous transaction. Possible



error codes are listed in Table 25. The remaining three 4-byte words are the yaw, pitch, and roll respectively given as single precision floating point numbers. The floating point numbers are consistent with the IEEE 754 standard. On the third SPI transaction 16 bytes are clocked on the SCK line, during which zeros are sent by the master since no further data is required from the sensor. These 16 bytes are clocked out the SPI for the sole purpose of reading the response from the previous read register 13 command. The response consists of 4 32-bit words, starting with the zero byte, the requested command byte, register ID, error code, and three single precision floating point numbers. If only one register is required on a regular basis then this can be accomplished by sending the same command twice to the VN-100. The response received on the second transaction will contain the most up to date values for the desired register.

SPI Transaction 1		
Line	Bytes	Description
SCK	16 bytes	
MOSI	01 08 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 (shown as hex)	Read register 8 (Yaw, Pitch, Roll)
MISO	00 01 08 00 39 8A 02 43 FD 43 97 C1 CD 9D 67 42 (shown as hex)	Yaw, Pitch, Roll = +130.54, -18.91, +57.90

SPI Transaction 2		
Line	Bytes	Description
SCK	16 bytes	
MOSI	01 08 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 (shown as hex)	Read Register 8 (Yaw, Pitch, Roll)
MISO	00 01 08 00 C5 9A 02 43 51 50 97 C1 32 9A 67 42 (shown as hex)	Yaw, Pitch, Roll = +130.60, -18.91, +57.90

At first the device would be initialized by sending the eight bytes 01 08 00 00 00 00 00 00, requesting a read of the yaw, pitch, roll register. The response from the second transaction would be the response to the requested yaw, pitch, roll from the first transaction. The minimum time required between SPI transactions is 50  $\mu$ s.





## 6 Communication Protocol

The following sections describe the serial and SPI data protocol used by the VN-100.

### 6.1 Numeric Formats

Floating point numbers displayed as ASCII text are presented in two formats: single precision floating point and single precision fixed point. In order to conserve bandwidth each variable in the register has associated with it either a floating or fixed point representation. Any time this variable is accessed using a read/write register command or as Async output, the variable will always use its associated data format.

### 6.2 Single Precision Floating Points

Single precision floating point numbers are represented with 7 significant digits and a 2 digit exponent. Both the sign of the number and exponent are provided. The decimal point will always follow the first significant digit. An 'E' will separate the significant digits from the exponential digits. Below are some samples of correct single precision floating point numbers.

#### Single Precision Floating Point Number Examples

```
+9.999999E+99      -7.344409E-05
-1.234567E+01      +4.893203E+00
```

### 6.3 Fixed-Point Numbers

The fixed-point representation consists of a specified number of digits to the left and right of a fixed decimal point. The registers that use fixed point representation and their associated formatting are listed below. It is important to note that all numeric calculations onboard the VN-100 are performed with 32-bit IEEE floating point numbers. For the sake of simplifying the output stream some of these numbers are displayed in ASCII as fixed point as described below.

Table 14 – Floating Point Representation

Variable Type	Fixed/Floating	Register ID(s)	Printf/Scanf	Example
Yaw, Pitch, Roll	Fixed	8, 27	%+08.3f	+082.763
Quaternion	Fixed	9,10,11,12,13,14,15	%+09.6f	+0.053362
Magnetic	Fixed	10,13,15,17,20,27	%+07.4f	-0.3647
Acceleration	Fixed	11,13,14,18,20,27	%+07.3f	-09.091
Angular Rate	Fixed	12,14,15,19,20,27	%+09.6f	+00.001786

### 6.4 System Commands

This section describes the list of commands available on the VN-100 module. All commands are available in both ASCII text (UART) and binary (SPI) command formats.

The table below lists the commands available along with some quick information about the commands. The Text ID is used to specify the command when using the text command format and the Binary ID is



used to specify the command when using the binary command format. More details about the individual commands can be found in the referenced section.

**Table 15 – List of Available Commands**

Command Name	Text ID	Binary ID	Section
Read Register	VNRRG	0x01	6.4.1
Write Register	VNWRG	0x02	6.4.2
Write Settings	VNWNV	0x03	6.4.3
Restore Factory Settings	VNRFS	0x04	0
Tare	VNTAR	0x05	6.4.5
Reset	VNRST	0x06	6.4.6
Known Magnetic Disturbance	VNKMD	0x08	6.4.7
Known Acceleration Disturbance	VNKAD	0x09	6.4.8
Set Gyro Bias	VNSGB	0x0C	6.4.9

### 6.4.1 Read Register Command

This command allows the user to read any of the registers on the VN-100 module (see Section 7 for the list of available registers). 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 7 for details on this formatting. If an invalid register is requested, an error code will be returned. The error code format is described in Section 6.5.

**Table 16 - Example Read Register Command**

Example Command	Message
UART Command	\$VNRRG,5*46
UART Response	\$VNRRG,5,9600*65
SPI Command (8 bytes)	01 05 00 00 80 25 00 00 (shown as hex)
SPI Response (8 bytes)	00 01 05 00 80 25 00 00 (shown as hex)

### 6.4.2 Write Register Command

This command is used to write data values to a specified register on the VN-100 module (see Section 7 for the list of available registers). 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 section in Section 6 for this formatting. If an invalid register is requested, an error code will be returned. The error code format is described in Section 6.5.



Table 17 - Example Write Register Command

Example Command	Message
UART Command	\$VNWRG,5,9600*60
UART Response	\$VNWRG,5,9600*60
SPI Command (8 bytes)	02 05 00 00 80 25 00 00 (shown as hex)
SPI Response (8 bytes)	00 02 05 00 80 25 00 00 (shown as hex)

### 6.4.3 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-100 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 (Section 0) or by pulling pin 15 high during reset.

Table 18 - Example Write Settings Command

Example Command	Message
UART Command	\$VNWNV*57
UART Response	\$VNWNV*57
SPI Command (8 bytes)	03 00 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 03 00 00 00 00 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.*

### 6.4.4 Restore Factory Settings Command

This command will restore the VN-100 module's factory default settings (see Section 8) and reset the module. There are no parameters for this command. The module will respond to this command before restoring the factory settings.

Table 19 - Example Restore Factory Settings Command

Example Command	Message
UART Command	\$VNRFS*5F
UART Response	\$VNRFS*5F
SPI Command (8 bytes)	04 00 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 04 00 00 00 00 00 00 (shown as hex)

### 6.4.5 Tare Command

The Tare command will have the module zero out its current orientation. The effect of this command in 2D magnetic mode will be to set only the yaw angle to zero. In 3D heading mode the VN-100 will set the yaw, pitch, and roll angles to zero. In 3D heading mode the VN-100 will also now measure yaw, pitch, and roll relative to the alignment of the respective Z, Y, and X axis in 3D space when the tare command was received. For more information on how to change the magnetic mode see Section 7.35.



Table 20 - Example Tare Command

Example Command	Message
UART Command	\$VNNTAR*5F
UART Response	\$VNNTAR*5F
SPI Command (8 bytes)	05 00 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 05 00 00 00 00 00 00 (shown as hex)



Avoid switching magnetic modes after issuing a tare command as this can lead to unpredictable behavior. If you need to issue a tare command, first set the magnetic mode, next issue a write settings command, and then reset the device. After reset you can issue a tare command.

### 6.4.6 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 then the device will default to factory settings. Also upon reset the VN-100 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 low.

Table 21 - Example Reset Command

Example Command	Message
UART Command	\$VNRST*4D
UART Response	\$VNRST*4D
SPI Command (8 bytes)	06 00 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 06 00 00 00 00 00 00 (shown as hex)

### 6.4.7 Known Magnetic Disturbance Command

This command is used to notify the VN-100 that a magnetic disturbance is present. When the VN-100 receives this command it will tune out the magnetometer and will pause the current hard/soft iron calibration if it is enabled. A single parameter is provided to tell the VN-100 whether the disturbance is present or not.

- 0 – No Disturbance is present
- 1 – Disturbance is present

Table 22 - Example Magnetic Disturbance Command

Example Command	Message
UART Command	\$VNKMD,1*47
UART Response	\$VNKMD,1*47
SPI Command (8 bytes)	08 01 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 08 01 00 00 00 00 00 (shown as hex)



### 6.4.8 Known Acceleration Disturbance Command

This command is used to notify the VN-100 that an acceleration disturbance is present. When the VN-100 receives this command it will tune out the accelerometer. A single parameter is provided to tell the VN-100 whether the disturbance is present or not.

- 0 – No Disturbance is present
- 1 – Disturbance is present

**Table 23 - Example Acceleration Disturbance Command**

Example Command	Message
UART Command	\$VNKAD, 1*4B
UART Response	\$VNKAD, 1*4B
SPI Command (8 bytes)	09 01 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 09 01 00 00 00 00 00 (shown as hex)

### 6.4.9 Set Gyro Bias Command

This command is used to save the current gyro bias estimate to memory for use at startup. Make sure that the device remains perfectly still when you send this command. If this command is sent along with a write settings command, after startup the VPE will use the saved gyro bias as opposed to assuming that it is zero. This will reduce the time required to output a stable attitude and angular rate estimate.

**Table 24 - Example Gyro Bias Command**

Example Command	Message
UART Command	\$VNSGB*4E
UART Response	\$VNSGB*4E
SPI Command (8 bytes)	0B 00 00 00 00 00 00 00 (shown as hex)
SPI Response (8 bytes)	00 0B 00 00 00 00 00 00 (shown as hex)

## 6.5 System Error Codes

In the event of an error, the chip 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 25 – Error Codes**

Error Name	Code	Description
Hard Fault	1	If this error occurs, then the firmware on the chip 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 50ms 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 50ms 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.

## 7 System Registers

The VN-100 module contains a collection of registers used for configuring the module and accessing the data it produces. These registers may be read or written to using the Read Register and Write Register commands (Sections 6.4.1 and 6.4.2). When the module is rebooted or power-cycled, values written to the registers will revert back to their previous values unless a Write Settings command has been issued (Section 6.4.3) to save the registers to non-volatile memory.

Table 26 provides a quick reference for all of the registers and their associated properties. The second column lists the Access ID, which is used to identify a specific register. The third column indicates the width of the register in bytes (relevant only in SPI mode) and the last column provides the section number where a more detailed explanation of the register may be found.

Each register may be read or written to using either serial or SPI communication modes. The specific register sections that follow describe the format used by each communication mode.



Table 26 –System Registers

Register Name	Access ID	Width (bytes)	Section
User Tag	0	20	7.1
Model Number	1	24	7.2
Hardware Revision	2	4	7.3
Serial Number	3	12	7.4
Firmware Version	4	4	7.5
Serial Baud Rate	5	4	7.6
Asynchronous Data Output Type	6	4	7.7
Asynchronous Data Output Frequency	7	4	7.8
Attitude (Yaw, Pitch, Roll)	8	3 x 4	7.9
Attitude (Quaternion)	9	4 x 4	7.10
Quaternion and Magnetic	10	7 x 4	7.11
Quaternion and Acceleration	11	7 x 4	7.12
Quaternion and Angular Rates	12	7 x 4	7.13
Quaternion, Magnetic and Acceleration	13	10 x 4	7.14
Quaternion, Acceleration and Angular Rates	14	10 x 4	7.15
Quaternion, Magnetic, Acceleration, and Angular Rates	15	13 x 4	7.16
Attitude (Directional Cosine Matrix)	16	9 x 4	7.17
Magnetic Measurements	17	3 x 4	7.18
Acceleration Measurements	18	3 x 4	7.19
Angular Rate Measurements	19	3 x 4	7.20
Magnetic, Acceleration, and Angular Rate Measurements	20	9 x 4	7.21
Magnetic and Gravity Reference Vectors	21	6 x 4	7.22
Filter Measurements Variance Parameters	22	10 x 4	7.23
Magnetic Hard/Soft Iron Compensation Parameters	23	12 x 4	7.24
Disturbance Tuning Parameters	24	4 x 4	7.25
Accelerometer Compensation	25	12 x 4	7.26
Reference Frame Rotation	26	9 x 4	7.27
Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rates	27	12 x 4	7.28
Accelerometer Gain	28	4	7.29
Yaw, Pitch, Roll, and Calibrated Measurements	29	13 x 4	7.30
Communication Protocol Control	30	7	7.31
Communication Protocol Status	31	44	7.32
Synchronization Control	32	20	7.33
Synchronization Status	33	12	7.34
Filter Basic Control	34	16	7.35
VPE Control	35	4	7.36
Magnetometer Basic Tuning	36	9 x 4	0
Magnetometer Advanced Tuning	37	9 x 4	7.38
Accelerometer Basic Tuning	38	9 x 4	7.39
Accelerometer Advanced Tuning	39	9 x 4	7.40
Gyroscope Basic Tuning	40	9 x 4	7.41
Filter Simple Status	42	28	7.42
Gyro Startup Bias	43	3 x 4	7.43
Magnetometer Vector Calibration Control	44	4	7.44
Magnetometer Vector Calibration Status	46	28	7.45
Calculated Magnetometer Calibration	47	12 x 4	7.46
Indoor Heading Mode Control Register	48	8	7.47



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Register Name	Access ID	Width (bytes)	Section
Yaw, Pitch, Roll, True Body Acceleration, & Angular Rate	239	9 x 4	7.48
Yaw, Pitch, Roll, True Inertial Acceleration, & Angular Rate	240	9 x 4	7.49
Yaw, Pitch, Roll, & Inertial Calibrated Measurements	241	12 x 4	7.50
Raw Voltage Measurements	251	10 x 4	7.51
Calibrated Unfiltered Measurements	252	10 x 4	7.52
Kalman Filter State Vector	253	7 x 4	7.53
Kalman Filter Covariance Matrix Diagonal	254	6 x 4	7.54





## 7.1 User Tag Register

User Tag					
<b>Register ID :</b>		0		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		User assigned tag register. Any values can be assigned to this register. They will be stored to flash upon issuing a write settings command.			
<b>Size (Bytes):</b>		20			
<b>Example Serial Read Register Response:</b>		\$VNRRG,00,SENSOR_A14*52			
Byte Offset	Name	Number Format	Unit	Description	
0	Tag	C20	-	User defined tag register. Up to 20 bytes or characters.	



## 7.2 Model Number Register

Model Number					
<b>Register ID :</b>		1		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Model Number			
<b>Size (Bytes):</b>		24			
<b>Example Serial Read Register Response:</b>		\$VNRRG,01,VN-100*5A			
Byte Offset	Name	Number Format	Unit	Description	
0	Product Name	C24	-	Product name. 24 characters.	



## 7.3 Hardware Revision Register

Hardware Revision Register					
<b>Register ID :</b>		2		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Hardware revision.			
<b>Size (Bytes):</b>		4			
<b>Example Serial Read Register Response:</b>		\$VNRRG,02,4*69			
Byte Offset	Name	Number Format	Unit	Description	
0	Revision	U4	-	Hardware revision.	



## 7.4 Serial Number Register

Serial Number					
<b>Register ID :</b>		3		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Serial Number			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,03,0672FF574957824887212839*58			
Byte Offset	Name	Number Format	Unit	Description	
0	SN[0]	X4	-	SN Section 1. 8 hexadecimal digits (4 bytes).	
4	SN[1]	X4	-	SN Section 2. 8 hexadecimal digits (4 bytes).	
8	SN[2]	X4	-	SN Section 3. 8 hexadecimal digits (4 bytes).	



## 7.5 Firmware Version Register

Firmware Version Register					
<b>Register ID :</b>		4		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Firmware version.			
<b>Size (Bytes):</b>		4			
<b>Example Serial Read Register Response:</b>		\$VNRRG,04,1.1.98.0*44			
Byte Offset	Name	Number Format	Unit	Description	
0	Major Version	U1	-	Major release version of firmware.	
1	Minor Version	U1	-	Minor release version of firmware	
2	Build	U1	-	Build number.	
3	HotFix	U1	-	Hot fix number.	



## 7.6 Serial Baud Rate Register

Serial Baud Rate					
Register ID :		5		Firmware : v0.1 and up	Access : Read / Write
Comment :		Serial baud rate.			
Size (Bytes):		4			
Example Serial Read Register Response:		\$VNRRG,05,115200*5D			
Byte Offset	Name	Number Format	Unit	Description	
0	Baud Rate	U4	-	Serial baud rate.	
4	Serial Port	U1	-	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.	

This register specifies the baud rate of the serial data bus. The table below specifies the associated baud rate achieved when the register is set to one of the values listed in Table 27. The response for this command will be sent after the baud rate is changed.

**Table 27 – 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 then 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-100 will send the response prior to changing the baud rate.*



## 7.7 Async Data Output Type Register

Asynchronous Data Output Type				
<b>Register ID :</b>		6	<b>Firmware :</b> v0.1 and up	
<b>Access :</b>		Read / Write		
<b>Comment :</b>		Asynchronous data output type.		
<b>Size (Bytes):</b>		4		
<b>Example Serial Read Register Response:</b>		\$VNRRG,06,0*69		
Byte Offset	Name	Number Format	Unit	Description
0	ADOR	U4	-	Output register.
4	Serial Port	U1	-	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.

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 28 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 7.8).



*The serial port parameter in this register is optional. If it is not provided then the ADOR 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.*

Table 28 – Asynchronous Solution Output Settings

Setting	Asynchronous Solution Output Type	Header	Formatting Section
0	Asynchronous output turned off	N/A	N/A
1	Yaw, Pitch, Roll	VNYPR	7.9
2	Quaternion	VNQTN	7.10
3	Quaternion and Magnetic	VNQTM	7.11
4	Quaternion and Acceleration	VNQTA	7.12
5	Quaternion and Angular Rates	VNQTR	7.13
6	Quaternion, Magnetic and Acceleration	VNQMA	7.14
7	Quaternion, Acceleration and Angular Rates	VNQAR	7.15
8	Quaternion, Magnetic, Acceleration and Angular Rates	VNQMR	7.16
9	Directional Cosine Orientation Matrix	VNDCM	7.17
10	Magnetic Measurements	VNMAG	7.18
11	Acceleration Measurements	VNACC	7.19
12	Angular Rate Measurements	VNGYR	7.20
13	Magnetic, Acceleration, and Angular Rate Measurements	VNMAR	7.21
14	Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rate Measurements	VNYMR	7.28
15	Yaw, Pitch, Roll, & Calibrated Measurements	VNYCM	7.30
16	Yaw, Pitch, Roll, Body True Acceleration, and Angular Rates	VNYBA	7.48
17	Yaw, Pitch, Roll, Inertial True Acceleration, and Angular Rates	VNYIA	7.49
18	Yaw, Pitch, Roll, Inertial Magnetic/Acceleration, and Angular Rate Measurements	VNICM	7.50
252	Raw Voltage Measurements	VNRAW	7.51
253	Calibrated Measurements	VNCMV	7.52
254	Kalman Filter State Vector	VNSTV	7.53
255	Kalman Filter Covariance Matrix Diagonal	VNCOV	7.54





## 7.8 Async Data Output Frequency Register

Asynchronous Data Output Frequency				
Register ID :		7	Firmware : v0.1 and up	
Access :		Read / Write		
Comment :		Asynchronous data output frequency.		
Size (Bytes):		4		
Example Serial Read Register Response:		\$VNRRG,07,50*5D		
Byte Offset	Name	Number Format	Unit	Description
0	ADOF	U4	Hz	Output frequency.
4	Serial Port	U1	-	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.

Table 29 - 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 then 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 then the response will not include this parameter.*

## 7.9 Attitude (Yaw, Pitch, Roll Format)

Yaw, Pitch, and Roll					
<b>Register ID :</b>		8		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution as yaw, pitch, and roll in degrees.			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,8,+006.271,+000.031,-002.000*66			
Byte Offset	Name	Number Format	Unit	Description	
0	Yaw	F4	deg	Yaw angle (heading).	
4	Pitch	F4	deg	Pitch angle.	
8	Roll	F4	deg	Roll angle.	



## 7.10 Attitude Quaternion

Quaternion					
<b>Register ID :</b>		9		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution as a quaternion.			
<b>Size (Bytes):</b>		16			
<b>Example Serial Read Register Response:</b>		\$VNRRG,9,-0.017386,-0.000303,+0.055490,+0.998308*4F			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	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-100 are performed using quaternions. The quaternion used by the VN-100 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  $\vartheta$  is the principal angle.



## 7.11 Quaternion and Magnetic

Quaternion and Magnetic					
<b>Register ID :</b>		10		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, and magnetic.			
<b>Size (Bytes):</b>		28			
<b>Example Serial Read Register Response:</b>		\$VNRRG,10,-0.017285,-0.000569,+0.053088,+0.998440,+1.0641,-0.2576,+3.0696*6E			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
20	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
24	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	



## 7.12 Quaternion and Acceleration

Quaternion and Acceleration					
<b>Register ID :</b>		11		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution and acceleration.			
<b>Size (Bytes):</b>		28			
<b>Example Serial Read Register Response:</b>		\$VNRRG,11,-0.017348,-0.000265,+0.053568,+0.998414,-00.003,+00.344,-09.841*62			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[2]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
20	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
24	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	



## 7.13 Quaternion and Angular Rates

Quaternion, Acceleration, and Angular Rates					
<b>Register ID :</b>		12		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, and compensated angular rates.			
<b>Size (Bytes):</b>		28			
<b>Example Serial Read Register Response:</b>		\$VNRRG,12,-0.017030,-0.000634,+0.055279,+0.998326,-0.000748,+0.001867,-0.001236*6B			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
20	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
24	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	



## 7.14 Quaternion, Magnetic and Acceleration

Quaternion, Magnetic, and Acceleration					
<b>Register ID :</b>		13		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, magnetic, and acceleration.			
<b>Size (Bytes):</b>		40			
<b>Example Serial Read Register Response:</b>		\$VNRRG,13,-0.017198,-0.000737,+0.054042,+0.998390,+1.0670,-0.2502,+3.0567,+00.041,+00.313,-09.867*77			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
20	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
24	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	
28	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
32	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
36	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	



## 7.15 Quaternion, Acceleration and Angular Rates

Quaternion, Acceleration, and Angular Rates					
<b>Register ID :</b>		14		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, acceleration, and compensated angular rates.			
<b>Size (Bytes):</b>		40			
<b>Example Serial Read Register Response:</b>		\$VNRRG,14,-0.017270,-0.000926,+0.056119,+0.998274,+00.005,+00.332,-09.822,-0.000738,+0.000312,+0.002216*76			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
20	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
24	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	
28	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
32	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
36	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	





## 7.16 Quaternion, Magnetic, Acceleration and Angular Rates

Quaternion, Magnetic, Acceleration, and Angular Rates					
<b>Register ID :</b>		15		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, magnetic, acceleration, and compensated angular rates.			
<b>Size (Bytes):</b>		52			
<b>Example Serial Read Register Response:</b>		\$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			
Byte Offset	Name	Number Format	Unit	Description	
0	Quat[0]	F4	-	Calculated attitude as quaternion.	
4	Quat[1]	F4	-	Calculated attitude as quaternion.	
8	Quat[2]	F4	-	Calculated attitude as quaternion.	
12	Quat[3]	F4	-	Calculated attitude as quaternion. Scalar component.	
16	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
20	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
24	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	
28	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
32	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
36	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	
40	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
44	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
48	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	



## 7.17 Attitude (Directional Cosine Orientation Matrix)

Attitude Directional Cosine Matrix				
<b>Register ID :</b> 16		<b>Firmware :</b> v0.1 and up		<b>Access :</b> Read Only
<b>Comment :</b>		The calculated attitude as a directional cosine matrix.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,16,+9.941386E-01,-1.080712E-01,-3.024663E-03,+1.081114E-01,+9.935566E-01,+3.401868E-02,-6.712652E-04,-3.414628E-02,+9.994167E-01*0F		
Byte Offset	Name	Number Format	Unit	Description
0	C[0,0]	F4	-	
4	C[0,1]	F4	-	
8	C[0,2]	F4	-	
12	C[1,0]	F4	-	
16	C[1,1]	F4	-	
20	C[1,2]	F4	-	
24	C[2,0]	F4	-	
28	C[2,1]	F4	-	
32	C[2,2]	F4	-	

This register contains the attitude directional cosine matrix. This matrix is a valid 3x3 rotation matrix. Nine parameters are returned from this command, and the terms are mapped to a 3x3 matrix as follows,

$$DCM = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix}$$

The ordering of this register's nine values is shown below. All nine numbers are represented as floating point.



## 7.18 Magnetic Measurements

Magnetic Measurements					
<b>Register ID :</b>		17		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Magnetometer measurements.			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,17,+1.0647,-0.2498,+3.0628*66			
Byte Offset	Name	Number Format	Unit	Description	
0	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
4	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
8	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	



## 7.19 Acceleration Measurements

Acceleration Measurements					
<b>Register ID :</b>		18		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Acceleration measurements.			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,18,+00.013,+00.354,-09.801*65			
Byte Offset	Name	Number Format	Unit	Description	
0	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
4	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
8	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	



## 7.20 Angular Rate Measurements

Angular Rate Measurements					
<b>Register ID :</b>		19		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Compensated angular rates.			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,19,+0.002112,-0.000362,-0.000876*6C			
Byte Offset	Name	Number Format	Unit	Description	
0	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
4	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
8	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	



## 7.21 Magnetic, Acceleration and Angular Rates

Magnetic, Acceleration, and Angular Rates					
<b>Register ID :</b>		20		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Magnetic, acceleration, and compensated angular rates.			
<b>Size (Bytes):</b>		36			
<b>Example Serial Read Register Response:</b>		\$VNRRG,20,+1.0684,-0.2578,+3.0649,-00.005,+00.341,-09.780,-0.000963,+0.000840,-0.000466*64			
Byte Offset	Name	Number Format	Unit	Description	
0	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
4	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
8	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	
12	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
16	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
20	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	
24	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
28	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
32	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	



## 7.22 Magnetic and Gravity Reference Vectors

Magnetic and Gravity Reference Vectors					
<b>Register ID :</b>		21		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Magnetic and gravity reference vectors.			
<b>Size (Bytes):</b>		24			
<b>Example Serial Read Register Response:</b>		\$VNRRG,21,1,0,1.8,0,0,-9.79375*53			
Byte Offset	Name	Number Format	Unit	Description	
0	MagRefX	F4	N/A	X-Axis Magnetic Reference	
4	MagRefY	F4	N/A	Y-Axis Magnetic Reference	
8	MagRefZ	F4	N/A	Z-Axis Magnetic Reference	
12	AccRefX	F4	m/s <sup>2</sup>	X-Axis Gravity Reference	
16	AccRefY	F4	m/s <sup>2</sup>	Y-Axis Gravity Reference	
20	AccRefZ	F4	m/s <sup>2</sup>	Z-Axis Gravity Reference	



## 7.23 Filter Measurements Variance Parameters

Filter Measurement Variance Parameters				
<b>Register ID :</b> 22		<b>Firmware :</b> v0.1 and up		<b>Access :</b> Read / Write
<b>Comment :</b>		Attitude Kalman Filter measurement uncertainty variances.		
<b>Size (Bytes):</b>		40		
<b>Example Serial Read Register Response:</b>		\$VNRRG,22,5E-08,3E-06,3E-06,3E-06,0.5,0.5,0.5,0.001,0.001,0.001*7F		
Byte Offset	Name	Number Format	Unit	Description
0	RRW	F4	$\frac{rad^2}{s^3}$	Variance - Angular Walk
4	ARWX	F4	$\frac{rad^2}{s}$	Variance – X Axis Angular Rate
8	ARWY	F4	$\frac{rad^2}{s}$	Variance – Y Axis Angular Rate
12	ARWZ	F4	$\frac{rad^2}{s}$	Variance – Z Axis Angular Rate
16	VMAGX	F4	N/A	Variance – X Axis Magnetic
20	VMAGY	F4	N/A	Variance – Y Axis Magnetic
24	VMAGZ	F4	N/A	Variance – Z Axis Magnetic
28	VACCX	F4	$\left(\frac{m}{s^2}\right)^2$	Variance – X Axis Acceleration
32	VACCY	F4	$\left(\frac{m}{s^2}\right)^2$	Variance – Y Axis Acceleration
36	VACCZ	F4	$\left(\frac{m}{s^2}\right)^2$	Variance – Z Axis Acceleration



*This register is not used when VPE is enabled.*



## 7.24 Magnetic Hard/Soft Iron Compensation Parameters

Magnetic Hard/Soft Iron Compensation Parameters				
<b>Register ID :</b> 23		<b>Firmware :</b> v0.1 and up		<b>Access :</b> Read / Write
<b>Comment :</b>		Allows the magnetometer to be compensated for hard/soft iron effects.		
<b>Size (Bytes):</b>		48		
<b>Example Serial Read Register Response:</b>		\$VNRRG,23,1,0,0,0,1,0,0,0,1,0,0,0*73		
Byte Offset	Name	Number Format	Unit	Description
0	C[0,0]	F4	-	
4	C[0,1]	F4	-	
8	C[0,2]	F4	-	
12	C[1,0]	F4	-	
16	C[1,1]	F4	-	
20	C[1,2]	F4	-	
24	C[2,0]	F4	-	
28	C[2,1]	F4	-	
32	C[2,2]	F4	-	
36	B[0]	F4	-	
40	B[1]	F4	-	
44	B[2]	F4	-	

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.



## 7.25 Filter Active Tuning Parameters

Filter Active Tuning Parameters					
<b>Register ID :</b>		24		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Legacy active tuning parameters. Supported for reverse compatibility. For new designs it is recommended to use the adaptive tuning feature in VPE Magnetometer Basic Tuning Register (Section 0) and the VPE Accelerometer Basic Tuning Register (Section 7.39).			
<b>Size (Bytes):</b>		16			
<b>Example Serial Read Register Response:</b>		\$VNRRG,24,0,0,0.99,0.9*4C			
Byte Offset	Name	Number Format	Unit	Description	
0	MagGain	F4	-	Magnetic Disturbance Gain [0 to 10].	
4	AccGain	F4	-	Acceleration Disturbance Gain [0 to 10].	
8	MagMemory	F4	-	Magnetic Disturbance Memory [0 to 1].	
12	AccMemory	F4	-	Acceleration Disturbance Memory [0 to 1].	



## 7.26 Accelerometer Compensation

Accelerometer Compensation				
<b>Register ID :</b> 25		<b>Firmware :</b> v0.1 and up		<b>Access :</b> Read / Write
<b>Comment :</b>		Allows the accelerometer to be further compensated for scale factor, misalignment, and bias errors.		
<b>Size (Bytes):</b>		48		
<b>Example Serial Read Register Response:</b>		\$VNRRG,25,1,0,0,0,1,0,0,0,1,0,0,0*75		
Byte Offset	Name	Number Format	Unit	Description
0	C[0,0]	F4	-	
4	C[0,1]	F4	-	
8	C[0,2]	F4	-	
12	C[1,0]	F4	-	
16	C[1,1]	F4	-	
20	C[1,2]	F4	-	
24	C[2,0]	F4	-	
28	C[2,1]	F4	-	
32	C[2,2]	F4	-	
36	B[0]	F4	-	
40	B[1]	F4	-	
44	B[2]	F4	-	

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.



## 7.27 Reference Frame Rotation

Reference Frame Rotation				
<b>Register ID :</b>		26	<b>Firmware :</b> v0.1 and up	
<b>Comment :</b>		Allows the measurements of the VN-100 to be rotated into a different reference frame.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,26,1,0,0,0,1,0,0,0,1*6A		
Byte Offset	Name	Number Format	Unit	Description
0	C[0,0]	F4	-	
4	C[0,1]	F4	-	
8	C[0,2]	F4	-	
12	C[1,0]	F4	-	
16	C[1,1]	F4	-	
20	C[1,2]	F4	-	
24	C[2,0]	F4	-	
28	C[2,1]	F4	-	
32	C[2,2]	F4	-	

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-100 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-100 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-100. 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-100 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 attitude filter. As such changing this register while the attitude filter is running may lead to unexpected behavior in the attitude output. After setting the reference frame rotation register to its new value send a write settings command and then reset the VN-100. This will allow the attitude filter to startup with the newly set reference frame rotation.*

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

Yaw, Pitch, Roll, Magnetic, Acceleration, and Angular Rates					
<b>Register ID :</b>		27		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution, magnetic, acceleration, and compensated angular rates.			
<b>Size (Bytes):</b>		48			
<b>Example Serial Read Register Response:</b>		\$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			
Byte Offset	Name	Number Format	Unit	Description	
0	Yaw	F4	deg	Calculated attitude heading angle in degrees.	
4	Pitch	F4	deg	Calculated attitude pitch angle in degrees.	
8	Roll	F4	deg	Calculated attitude roll angle in degrees.	
12	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
16	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
20	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	
24	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
28	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
32	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	
36	GyroX	F4	rad/s	Calibrated & filter bias compensated angular rate in x-axis.	
40	GyroY	F4	rad/s	Calibrated & filter bias compensated angular rate in y-axis.	
44	GyroZ	F4	rad/s	Calibrated & filter bias compensated angular rate in z-axis.	



## 7.29 Accelerometer Gain

Accelerometer Gain				
<b>Register ID :</b>		28	<b>Firmware :</b> v0.1 to v0.8	
<b>Comment :</b>		Controls the accelerometer gain.		
<b>Size (Bytes):</b>		4		
<b>Example Serial Read Register Response:</b>		\$VNRRG, 28, 0*65		
Byte Offset	Name	Number Format	Unit	Description
0	AccelGain	U4	-	Accelerometer Gain

Table 30 – Accelerometer Gain

Register Value	Accelerometer Gain
0	±2g
1	±5g



Hardware version 4 and higher uses the ADXL325 which does not support the selectable gain. For this hardware version the devices will always operate at ±5g regardless of the value of this register.

## 7.30 Yaw, Pitch, Roll, & Calibrated Measurements

Yaw, Pitch, Roll, & Calibrated Measurements					
<b>Register ID :</b>		29		<b>Firmware :</b> v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution as yaw, pitch, roll and IMU calibrated measurements.			
<b>Size (Bytes):</b>		52			
<b>Example Serial Read Register Response:</b>		\$VNRRG,29,+006.536,+000.031,-001.968,+1.0662,-0.2537,+3.0664,+00.018,+00.323,-09.839,-0.017771,+0.032381,+0.004126,+25.5*5B			
Byte Offset	Name	Number Format	Unit	Description	
0	Yaw	F4	deg	Calculated attitude heading angle in degrees.	
4	Pitch	F4	deg	Calculated attitude pitch angle in degrees.	
8	Roll	F4	deg	Calculated attitude roll angle in degrees.	
12	MagX	F4	-	Calibrated magnetometer measurement in x-axis.	
16	MagY	F4	-	Calibrated magnetometer measurement in y-axis.	
20	MagZ	F4	-	Calibrated magnetometer measurement in z-axis.	
24	AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in x-axis.	
28	AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in y-axis.	
32	AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in z-axis.	
36	GyroX	F4	rad/s	Calibrated un-compensated angular rate in x-axis.	
40	GyroY	F4	rad/s	Calibrated un-compensated angular rate in y-axis.	
44	GyroZ	F4	rad/s	Calibrated un-compensated angular rate in z-axis.	
48	Temp	F4	C	Calibrated temperature in degrees Celsius.	



## 7.31 Communication Protocol Control

Communication Protocol Control				
Register ID :		30	Firmware : v1.1 and up	
Access :		Read / Write		
Comment :		Contains parameters that control settings relating to the communication protocol used to communicate with the VN-100.		
Size (Bytes):		7		
Example Serial Read Register Response:		\$VNRRG,30,0,0,0,0,1,0,1*6C		
Byte Offset	Name	Number Format	Unit	Description
0	SerialCount	U1	-	Provides the ability to append a counter to the end of the serial asynchronous messages.
1	SerialStatus	U1	-	Provides the ability to append the status to the end of the serial asynchronous messages.
2	SPICount	U1	-	Provides the ability to append a counter to the end of the SPI packets.
3	SPIStatus	U1	-	Provides the ability to append the status to the end of the SPI packets.
4	SerialChecksum	U1	-	Choose the type of checksum used for serial communications.
5	SPIChecksum	U1	-	Choose the type of checksum used for the SPI communications.
6	ErrorMode	U1	-	Choose the action taken when errors are generated.

### 7.31.1 SerialCount

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.

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 31 – SerialCount Field**

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





### 7.31.2 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. 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. 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 32 – AsyncStatus**

Value	Description
0	OFF
1	ON

### 7.31.3 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 33 – SPICount Field**

Mode	Value	Description
NONE	0	OFF
SYNCIN_COUNT	1	SyncIn Counter
SYNCIN_TIME	2	SyncIn Time
SYNCOU_COUNT	3	SyncOut Counter

### 7.31.4 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 34 – SPIStatus**

Value	Description
0	OFF
1	ON



### 7.31.5 SerialChecksum

This field controls the type of checksum used for the serial communications. Normally the VN-100 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 35 – SerialChecksum**

Value	Description
0	OFF
1	8-Bit Checksum
2	16-Bit CRC

### 7.31.6 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 36 – SPIChecksum**

Value	Description
0	OFF
1	8-Bit Checksum
2	16-Bit CRC

### 7.31.7 ErrorMode

This field controls the type of action taken by the VN-100 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 37 – ErrorMode**

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

### 7.31.8 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



## 7.32 Communication Protocol Status

Communication Protocol Status				
Register ID :		31	Firmware : v1.1 and up	
			Access : Read / Write	
Comment :		Contains parameters which allow the timing of the VN-100 to be synchronized with external devices.		
Size (Bytes):		44		
Example Serial Read Register Response:		\$VNRRG,31,25,0,6,11,0,0,0,0,0,0,0,0,0,0,0,0,0,0*70		
Byte Offset	Name	Number Format	Unit	Description
0	NumParsedSerialMessages	U4	-	Number of successfully parsed serial messages received
4	NumParsedSPIMessages	U4	-	Number of successfully parsed SPI messages received
8	MaxUsageSerialRXBuffer	U1	%	Maximum percent usage of serial incoming buffer
9	MaxUsageSerialTXBuffer	U1	%	Maximum percent usage of serial outgoing buffer
10	MaxUsageSPIRXBuffer	U1	%	Maximum percent usage of SPI incoming buffer
11	MaxUsageSPITXBuffer	U1	%	Maximum percent usage of SPI outgoing buffer
12	SysErrors	U2[16]	-	Total number of each type of system error received



*Writing zero to any field will reset the status counter. Writing any other value other than zero will not have an effect.*

## 7.33 Synchronization Control

Synchronization Control				
Register ID :		32	Firmware : v1.1 and up	
Access :		Read / Write		
Comment :		Contains parameters which allow the timing of the VN-100 to be synchronized with external devices.		
Size (Bytes):		20		
Example Serial Read Register Response:		\$VNRRG,32,0,0,0,0,3,0,0,500000,0*58		
Byte Offset	Name	Number Format	Unit	Description
0	SyncInMode	U1	-	Input signal synchronization mode
1	SyncInEdge	U1	-	Input signal synchronization edge selection
2	SyncInSkipFactor	U2	-	Input signal trigger skip factor
4	RESERVED	U4	-	Reserved for future use. Defaults to 0.
8	SyncOutMode	U1	-	Output synchronization signal mode
9	SyncOutPolarity	U1	-	Output synchronization signal polarity
10	SyncOutSkipFactor	U2	-	Output synchronization signal skip factor
12	SyncOutPulseWidth	U4	ns	Output synchronization signal pulse width
16	RESERVED	U4	ns	Reserved for future use. Defaults to 0.

### 7.33.1 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 ADC timing. If SyncInMode is set to ASYNC then the ADC 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. It is very important to note that the VN-100 must always operate at an internal rate of 200Hz. If the SyncIn event is used to control the ADC sampling, then the SyncIn event must be kept always at 200Hz. If set to ASYNC then the VN-100 will output asynchronous serial messages upon each trigger event.

Table 38 – SyncIn Mode

Mode	Pin	Value	Description
COUNT2	SYNC_IN_2	0	Count number of trigger events on SYNC_IN_2 (pin 15).
ADC2	SYNC_IN_2	1	Start ADC sampling on trigger of SYNC_IN_2 (pin 15).
ASYNC2	SYNC_IN_2	2	Output asynchronous message on trigger of SYNC_IN_2 (pin 15).
COUNT	SYNC_IN	3	Count number of trigger events on SYNC_IN (pin 22).
ADC	SYNC_IN	4	Start ADC sampling on trigger of SYNC_IN (pin 22).
ASYNC	SYNC_IN	5	Output asynchronous message on trigger of SYNC_IN (pin 22).



For firmware version 1.1.141.0 and higher the SyncIn is set by default to use pin 22. For reverse compatibility with previous firmware revisions it is possible to remap the SyncIn pin to operate on pin 15 instead. For future designs it is recommended that pin 22 is used for the SyncIn feature.



### 7.33.2 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 39 – SyncInEdge Mode**

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

### 7.33.3 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.

### 7.33.4 SyncOutMode

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

**Table 40 – SyncOutMode**

Mode	Value	Description
NONE	0	None
ADC	1	Trigger at start of ADC sampling
IMU	2	Trigger when IMU measurements are available
AHRS	3	Trigger when attitude measurements are available

### 7.33.5 SyncOutPolarity

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

**Table 41 – SyncOutPolarity**

Value	Description
0	Negative Pulse
1	Positive Pulse

### 7.33.6 SyncOutSkipFactor

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



### 7.33.7 SyncOutPulseWidth

The SyncOutPulseWidth field controls the desired width of the SyncOut pulse. The default value is 500,000 ns (0.5 ms).



## 7.34 Synchronization Status

Synchronization Status					
<b>Register ID :</b>		33		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Contains status parameters that pertaining to the communication synchronization features.			
<b>Size (Bytes):</b>		12			
<b>Example Serial Read Register Response:</b>		\$VNRRG,33,2552498,0,0*6A			
Byte Offset	Name	Number Format	Unit	Description	
0	SyncInCount	U4	-	Keeps track of the number of times that the SyncIn trigger even has occurred. 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. This field is writable to allow for initialization or clearing.	
4	SyncInTime	U4	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	U4	-	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. This field is writable to allow for initialization or clearing.	



*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.*



## 7.35 Filter Basic Control

Filter Basic Control					
<b>Register ID :</b>		34		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Provides control over various features relating to the onboard attitude filtering algorithm.			
<b>Size (Bytes):</b>		16			
<b>Example Serial Read Register Response:</b>		\$VNRRG,34,0,0,0,0,0,0,0*68			
Byte Offset	Name	Number Format	Unit	Description	
0	MagMode	U1	-	Selects whether the onboard magnetometer is used in 2D or 3D mode. In 2D mode the magnetometer will only affect the heading.	
1	ExtMagMode	U1	-	Selects what type of magnetometer is used by the onboard attitude filter. Either the internal or an external magnetic sensor can be used. For information see Section 3.6.	
2	ExtAccMode	U1	-	Selects what type of accelerometer is used by the onboard attitude filter. Either the internal or an external accelerometer sensor can be used. For information see Section 3.6.	
3	ExtGyroMode	U1	-	Selects what type of gyro is used by the onboard attitude filter. Either the internal or an external gyro sensor can be used. For information see Section 3.6.	
4	GyroLimitX	F4	rad/s	Gyro angular rate saturation limit for the X-Axis. Filter will enter gyro saturation recovery mode if the rate.	
8	GyroLimitY	F4	rad/s	Gyro angular rate saturation limit for the Y-Axis. Filter will enter gyro saturation recovery mode if the rate.	
12	GyroLimitZ	F4	rad/s	Gyro angular rate saturation limit for the Z-Axis. Filter will enter gyro saturation recovery mode if the rate.	

**Table 42 – MagMode**

Mode	Value	Description
2D	0	Magnetometer will only affect heading.
3D	1	Magnetometer will affect heading, pitch, and roll.

**Table 43 - ExtMagMode**

Mode	Value	Description
INTERNAL	0	Use Internal Magnetometer.
EXTERNAL_200HZ	1	Use External Magnetometer. Will use measurement at every new time step.
EXTERNAL_ON_UPDATE	2	Use External Magnetometer. Will only use when the measurement is updated. For other time steps the measurement will be tuned out.

**Table 44 - ExtAccMode**

Mode	Value	Description
INTERNAL	0	Use Internal Accelerometer.
EXTERNAL_200HZ	1	Use External Accelerometer. Will use measurement at every new time step.
EXTERNAL_ON_UPDATE	2	Use External Accelerometer. Will only use when the measurement is updated. For other time steps the measurement will be tuned out.

**Table 45 - ExtGyroMode**

Mode	Value	Description
INTERNAL	0	Use Internal Gyroscope.
EXTERNAL_200HZ	1	Use External Gyroscope. Will use measurement at every new time step.



## 7.36 VPE Basic Control

VPE Basic Control					
<b>Register ID :</b>		35		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Provides control over various features relating to the onboard attitude filtering algorithm.			
<b>Size (Bytes):</b>		4			
<b>Example Serial Read Register Response:</b>		\$VNRRG,35,1,3,1,1*77			
Byte Offset	Name	Number Format	Unit	Description	
0	Enable	U1	-	Enable / Disable the Vector Processing Engine (VPE).	
1	HeadingMode	U1	-	Heading mode used by the VPE.	
2	FilteringMode	U1	-	Filtering Mode used by the VPE.	
3	TuningMode	U1	-	Tuning Mode used by the VPE.	

**Table 46 – Enable**

Value	State
0	DISABLE
1	ENABLE

**Table 47 – HeadingMode**

Value	Mode
0	Absolute Heading
1	Relative Heading
2	Indoor Heading

**Table 48 - Filtering Mode**

Value	Mode
0	OFF
1	MODE 1

**Table 49 - Tuning Mode**

Value	Mode
0	OFF
1	MODE 1



For firmware version 1.1.140.0 or earlier, if the VPE is disabled, then the heading mode must also be set to Absolute Heading for correct operation. Using the sensor with the VPE turned off and the heading mode set to anything other than absolute heading mode, may result in abnormal behavior.

## 7.37 VPE Magnetometer Basic Tuning

VPE Magnetometer Basic Tuning				
<b>Register ID :</b> 36		<b>Firmware :</b> v1.1 and up		<b>Access :</b> Read / Write
<b>Comment :</b>		Provides basic control of the adaptive filtering and tuning for the magnetometer.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,36,5,5,5,3,3,3,4,4,4*68		
Byte Offset	Name	Number Format	Min/Max	Description
0	BaseTuningX	F4	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	F4	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	F4	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	F4	0 / 10	Level of adaptive tuning for X-Axis.
16	AdaptiveTuningY	F4	0 / 10	Level of adaptive tuning for Y-Axis.
20	AdaptiveTuningZ	F4	0 / 10	Level of adaptive tuning for Z-Axis.
24	AdaptiveFilteringX	F4	0 / 10	Level of adaptive filtering for X-Axis.
28	AdaptiveFilteringY	F4	0 / 10	Level of adaptive filtering for Y-Axis.
32	AdaptiveFilteringZ	F4	0 / 10	Level of adaptive filtering for Z-Axis.



## 7.38 VPE Magnetometer Advanced Tuning

VPE Magnetometer Advanced Simple Tuning					
<b>Register ID :</b>		37		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Provides advanced control of the adaptive filtering and tuning for the magnetometer.			
<b>Size (Bytes):</b>		36			
<b>Example Serial Read Register Response:</b>		\$VNRRG,37,0,10,0,10,0,10,1,2,1000*68			
Byte Offset	Name	Number Format	Min/Max	Description	
0	MinFilteringX	F4	0 / 10	Minimum allowed level of filtering for X-Axis.	
4	MinFilteringY	F4	0 / 10	Minimum allowed level of filtering for Y-Axis.	
8	MinFilteringZ	F4	0 / 10	Minimum allowed level of filtering for Z-Axis.	
12	MaxFilteringX	F4	0 / 10	Maximum allowed level of filtering for X-Axis.	
16	MaxFilteringY	F4	0 / 10	Maximum allowed level of filtering for Y-Axis.	
20	MaxFilteringZ	F4	0 / 10	Maximum allowed level of filtering for Z-Axis.	
24	MaxAdaptRate	F4	0 / 10	Controls the rate the filtering level is allowed to change.	
28	DisturbanceWindow	F4	0 / 10	Width of disturbance tuning window.	
32	MaxTuning	F4	-	Maximum allowed estimated measurement variance.	



## 7.39 VPE Accelerometer Basic Tuning

VPE Accelerometer Basic Tuning				
<b>Register ID :</b> 38		<b>Firmware :</b> v1.1 and up		<b>Access :</b> Read / Write
<b>Comment :</b>		Provides basic control of the adaptive filtering and tuning for the accelerometer.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,38,5,5,5,3,3,3,4,4,4*66		
Byte Offset	Name	Number Format	Min/Max	Description
0	BaseTuningX	F4	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	F4	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	F4	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	F4	0 / 10	Level of adaptive tuning for X-Axis.
16	AdaptiveTuningY	F4	0 / 10	Level of adaptive tuning for Y-Axis.
20	AdaptiveTuningZ	F4	0 / 10	Level of adaptive tuning for Z-Axis.
24	AdaptiveFilteringX	F4	0 / 10	Level of adaptive filtering for X-Axis.
28	AdaptiveFilteringY	F4	0 / 10	Level of adaptive filtering for Y-Axis.
32	AdaptiveFilteringZ	F4	0 / 10	Level of adaptive filtering for Z-Axis.



## 7.40 VPE Accelerometer Advanced Tuning

VPE Accelerometer Advanced Tuning				
<b>Register ID :</b>		39	<b>Firmware :</b> v1.1 and up	
<b>Comment :</b>		Provides advanced control of the adaptive filtering and tuning for the accelerometer.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,39,0,10,0,10,0,10,1,2,1000*66		
Byte Offset	Name	Number Format	Range	Description
0	MinFilteringX	F4	0 / 10	Minimum allowed level of filtering for X-Axis.
4	MinFilteringY	F4	0 / 10	Minimum allowed level of filtering for Y-Axis.
8	MinFilteringZ	F4	0 / 10	Minimum allowed level of filtering for Z-Axis.
12	MaxFilteringX	F4	0 / 10	Maximum allowed level of filtering for X-Axis.
16	MaxFilteringY	F4	0 / 10	Maximum allowed level of filtering for Y-Axis.
20	MaxFilteringZ	F4	0 / 10	Maximum allowed level of filtering for Z-Axis.
24	MaxAdaptRate	F4	0 / 10	Controls the rate the filtering level is allowed to change.
28	DisturbanceWindow	F4	0 / 10	Width of disturbance tuning window.
32	MaxTuning	F4	-	Maximum allowed estimated measurement variance.



## 7.41 VPE Gyro Basic Tuning

VPE Gyro Basic Tuning					
<b>Register ID :</b>		40		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Provides basic control of the adaptive filtering and tuning for the gyro.			
<b>Size (Bytes):</b>		36			
<b>Example Serial Read Register Response:</b>		\$VNRRG,40,5,5,5,3,3,3,4,4,4*69			
Byte Offset	Name	Number Format	Min/Max	Description	
0	VAngularWalkX	F4	1e-15 / 1e-2	Variance - Angular Walk X-Axis	
4	VAngularWalkY	F4	1e-15 / 1e-2	Variance - Angular Walk Y-Axis	
8	VAngularWalkZ	F4	1e-15 / 1e-2	Variance - Angular Walk Z-Axis	
12	BaseTuningX	F4	0 / 10	Base Gyro Tuning X-Axis [0 - 10]. This sets the level of confidence placed in the gyro X-Axis.	
16	BaseTuningY	F4	0 / 10	Base Gyro Tuning Y-Axis [0 - 10]. This sets the level of confidence placed in the gyro Y-Axis.	
20	BaseTuningZ	F4	0 / 10	Base Gyro Tuning Z-Axis [0 - 10]. This sets the level of confidence placed in the gyro Z-Axis.	
24	AdaptiveTuningX	F4	0 / 10	Level of adaptive tuning for X-Axis.	
28	AdaptiveTuningY	F4	0 / 10	Level of adaptive tuning for Y-Axis.	
32	AdaptiveTuningZ	F4	0 / 10	Level of adaptive tuning for Z-Axis.	



## 7.42 Filter Status

Filter Status					
Register ID :	42	Firmware :	v1.1 and up	Access :	Read Only
Comment :	Provides overall status of the onboard Kalman Filter.				
Size (Bytes):	28				
Example Serial Read Register Response:	\$VNRRG,42,0004,0.188461,0.0283489,0.0277957,0.120018,0.0112458,0.00154995*6E				
Byte Offset	Name	Number Format	Unit	Description	
0	SolutionStatus	X2	-	Solution status bitfield. See description below. On serial interface this will be given in hexadecimal representation.	
4	YawUncertainty	F4	deg	Standard deviation of uncertainty in yaw estimate.	
8	PitchUncertainty	F4	deg	Standard deviation of uncertainty in pitch estimate.	
12	RollUncertainty	F4	deg	Standard deviation of uncertainty in roll estimate.	
16	GyroBiasUncertainty	F4	rad/s	Maximum uncertainty in the current gyro bias estimate.	
20	MagUncertainty	F4	-	Maximum uncertainty in the current magnetic measurement.	
24	AccelUncertainty	F4	m/s <sup>2</sup>	Maximum uncertainty in the current acceleration measurement.	

**Table 50 - SolutionStatus Field (2 bytes)**

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.
MagDCDisturbance	4	1 bit	-	A strong magnetic DC disturbance has been detected.
MagACDisturbance	5	1 bit	-	A strong magnetic AC disturbance has been detected.
MagSaturation	6	1 bit	-	At least one magnetometer axis is currently saturated.
AccDCDisturbance	7	1 bit	-	A strong acceleration DC disturbance has been detected.
AccACDisturbance	8	1 bit	-	A strong acceleration AC disturbance has been detected.
AccSaturation	9	1 bit	-	At least one magnetometer axis is currently saturated.
UsingAutoHSISolution	10	1 bit	-	The automatic hard/soft iron calibration is being used.
KnownMagDisturbancePresent	11	1 bit	-	A known magnetic disturbance is present.
KnownAccDisturbancePresent	12	1 bit	-	A known acceleration disturbance is present.
RESERVED	11	3 bits	-	

**Table 51 – AttitudeQuality Field**

Value	Description
0	EXCELLENT
1	GOOD
2	BAD
3	NOT TRACKING





## 7.43 Filter Startup Gyro Bias

Filter Startup Gyro Bias				
<b>Register ID :</b>	43	<b>Firmware :</b>	v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>	The filter gyro bias estimate used at startup.			
<b>Size (Bytes):</b>	12			
<b>Example Serial Read Register Response:</b>	\$VNRRG,43,+00.000000,+00.000000,+00.000000*5D			
Byte Offset	Name	Number Format	Unit	Description
0	X-Axis Gyro Bias Estimate	F4	rad/s	Filter initial gyro bias estimate X-Axis.
4	Y-Axis Gyro Bias Estimate	F4	rad/s	Filter initial gyro bias estimate Y-Axis.
8	Z-Axis Gyro Bias Estimate	F4	rad/s	Filter initial gyro bias estimate Z-Axis.



## 7.44 Magnetometer Basic Calibration Control

Filter Tuning Status					
<b>Register ID :</b>	44	<b>Firmware :</b>	v1.1 and up	<b>Access :</b>	Read / Write
<b>Comment :</b>	Controls the magnetometer real-time calibration algorithm.				
<b>Size (Bytes):</b>	4				
<b>Example Serial Read Register Response:</b>	\$VNRRG,44,1,2,5*69				
Byte Offset	Name	Number Format	Unit	Description	
0	HSIMode	U1	-	Controls the mode of operation for the onboard real-time magnetometer hard/soft iron compensation algorithm.	
1	HSIOutput	U1	-	Controls the type of measurements that are provided as outputs from the magnetometer sensor and also subsequently used in the attitude filter.	
2	ConvergeRate	U1	-	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 52 – 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 53 – HSI\_Output Field

Mode	Value	Description
CAL_OFF	0	The raw un-processed magnetic measurements.
CAL_MANUAL	1	The magnetometer measurements are compensated for hard/soft iron using the user register (Section 7.24).
CAL_AUTO	2	The magnetometer measurements are compensated for hard/soft iron using the calculated register (Section 0).



*The VN-100 ships with the real-time hard/soft iron calibration turned ON. If the hard/soft iron will not be changing during normal operation, it is recommended that the real-time hard/soft iron calibration is turned OFF after a valid solution is reached.*



## 7.45 Magnetometer Calibration Status

Filter Tuning Status				
<b>Register ID :</b> 46		<b>Firmware :</b> v1.1 and up		<b>Access :</b> Read Only
<b>Comment :</b>		Status of the magnetometer real-time calibration algorithm.		
<b>Size (Bytes):</b>		28		
<b>Example Serial Read Register Response:</b>		\$VNRRG,45,2,1,0.00566713,-0.424594,-0.587841,1.80009,0,0,1,0,0,0,0*4D		
Byte Offset	Name	Number Format	Unit	Description
0	LastBin	U1	-	The bin for the most recently collected magnetic measurement.
1	NumMeas	U2	-	The number of measurements currently used in the solution.
4	AvgResidual	F4	-	The average residual error for magnetic measurements.
8	LastMeasX	F4	-	The most recently collected magnetic measurement X-axis.
12	LastMeasY	F4	-	The most recently collected magnetic measurement Y-axis.
16	LastMeasZ	F4	-	The most recently collected magnetic measurement Z-axis.
20	Bins[0]	U1	-	The number of measurements collected in Bin 1.
21	Bins[1]	U1	-	The number of measurements collected in Bin 2.
22	Bins[2]	U1	-	The number of measurements collected in Bin 3.
23	Bins[3]	U1	-	The number of measurements collected in Bin 4.
24	Bins[4]	U1	-	The number of measurements collected in Bin 5.
25	Bins[5]	U1	-	The number of measurements collected in Bin 6.
26	Bins[6]	U1	-	The number of measurements collected in Bin 7.
27	Bins[7]	U1	-	The number of measurements collected in Bin 8.



## 7.46 Calculated Magnetometer Calibration

Calculated Magnetometer Calibration				
<b>Register ID :</b>	47	<b>Firmware :</b>	v1.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>	Calculated magnetometer calibration values.			
<b>Size (Bytes):</b>	48			
<b>Example Serial Read Register Response:</b>	\$VNRRG,46,1,0,0,0,1,0,0,0,1,0,0,0*70			
Byte Offset	Name	Number Format	Unit	Description
0	C[0,0]	F4	-	
4	C[0,1]	F4	-	
8	C[0,2]	F4	-	
12	C[1,0]	F4	-	
16	C[1,1]	F4	-	
20	C[1,2]	F4	-	
24	C[2,0]	F4	-	
28	C[2,1]	F4	-	
32	C[2,2]	F4	-	
36	B[0]	F4	-	
40	B[1]	F4	-	
44	B[2]	F4	-	

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.



## 7.47 Indoor Heading Mode Control

Filter Control					
<b>Register ID :</b>		48		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read / Write
<b>Comment :</b>		Provides control over various features relating to the indoor heading mode.			
<b>Size (Bytes):</b>		8			
<b>Example Serial Read Register Response:</b>		\$VNRRG,47,1,0*71			
Byte Offset	Name	Number Format	Unit	Description	
0	MaxRateError	F4	%	The maximum allowable error in the estimated heading rate. Controls how quickly the VPE will recover a known heading error while in motion.	
4	RESERVED	F4	-	Reserved for future use. Value should remain 0.	



## 7.48 Yaw, Pitch, Roll, True Body Acceleration, and Angular Rates

Yaw, Pitch, Roll, True Body Acceleration, and Angular Rates					
<b>Register ID :</b>		239		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution as yaw, pitch, roll and the inertial acceleration.			
<b>Size (Bytes):</b>		36			
<b>Example Serial Read Register Response:</b>		\$VNRRG,239,-124.743,+001.019,-000.203,+00.019,-00.001,+00.039,+00.001665,-00.000785,+00.000647*55			
Byte Offset	Name	Number Format	Unit	Description	
0	Yaw	F4	deg	Calculated attitude heading angle in degrees.	
4	Pitch	F4	deg	Calculated attitude pitch angle in degrees.	
8	Roll	F4	deg	Calculated attitude roll angle in degrees.	
12	BodyAccelX	F4	m/s <sup>2</sup>	Acceleration estimate in the body X-axis.	
16	BodyAccelY	F4	m/s <sup>2</sup>	Acceleration estimate in the body Y-axis.	
20	BodyAccelZ	F4	m/s <sup>2</sup>	Acceleration estimate in the body Z-axis.	
24	GyroX	F4	rad/s	Calibrated un-compensated angular rate in the body X-axis.	
28	GyroY	F4	rad/s	Calibrated un-compensated angular rate in the body Y-axis.	
32	GyroZ	F4	rad/s	Calibrated un-compensated angular rate in the body Z-axis.	



*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.*

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

Yaw, Pitch, Roll, True Inertial Acceleration, and Angular Rates				
<b>Register ID :</b>		240		<b>Firmware :</b> v1.1 and up
<b>Comment :</b>		Attitude solution as yaw, pitch, roll and the inertial acceleration.		
<b>Size (Bytes):</b>		36		
<b>Example Serial Read Register Response:</b>		\$VNRRG,240,-124.642,+000.993,-000.203,+00.009,-00.027,+00.084,-00.000479,-00.000522,+00.000076*5F		
Byte Offset	Name	Number Format	Unit	Description
0	Yaw	F4	deg	Calculated attitude heading angle in degrees.
4	Pitch	F4	deg	Calculated attitude pitch angle in degrees.
8	Roll	F4	deg	Calculated attitude roll angle in degrees.
12	InertialAccelX	F4	m/s <sup>2</sup>	Acceleration estimate in the inertial X-axis.
16	InertialAccelY	F4	m/s <sup>2</sup>	Acceleration estimate in the inertial Y-axis.
20	InertialAccelZ	F4	m/s <sup>2</sup>	Acceleration estimate in the inertial Z-axis.
24	GyroX	F4	rad/s	Calibrated un-compensated angular rate in the body X-axis.
28	GyroY	F4	rad/s	Calibrated un-compensated angular rate in the body Y-axis.
32	GyroZ	F4	rad/s	Calibrated un-compensated angular rate in the body Z-axis.



*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-100.*

## 7.50 Yaw, Pitch, Roll, & Inertial Calibrated Measurements

Yaw, Pitch, Roll, & Inertial Calibrated Measurements					
<b>Register ID :</b>		241		<b>Firmware :</b> v1.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>		Attitude solution as yaw, pitch, roll and IMU calibrated measurements mapped into the inertial coordinate frame using the current attitude solution.			
<b>Size (Bytes):</b>		48			
<b>Example Serial Read Register Response:</b>		\$VNRRG,241,-124.717,+000.988,-000.216,+01.1964,-00.2585,+02.9721,+00.020,-00.018,-09.743,+00.002349,-00.002240,+00.000445*7F			
Byte Offset	Name	Number Format	Unit	Description	
0	Yaw	F4	deg	Calculated attitude heading angle in degrees.	
4	Pitch	F4	deg	Calculated attitude pitch angle in degrees.	
8	Roll	F4	deg	Calculated attitude roll angle in degrees.	
12	Inertial_MagX	F4	-	Calibrated magnetometer measurement in the inertial X-axis.	
16	Inertial_MagY	F4	-	Calibrated magnetometer measurement in the inertial Y-axis.	
20	Inertial_MagZ	F4	-	Calibrated magnetometer measurement in the inertial Z-axis.	
24	Inertial_AccelX	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in the inertial X-axis.	
28	Inertial_AccelY	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in the inertial Y-axis.	
32	Inertial_AccelZ	F4	m/s <sup>2</sup>	Calibrated accelerometer measurement in the inertial Z-axis.	
36	GyroX	F4	rad/s	Calibrated un-compensated angular rate in the body X-axis.	
40	GyroY	F4	rad/s	Calibrated un-compensated angular rate in the body Y-axis.	
44	GyroZ	F4	rad/s	Calibrated un-compensated angular rate in the body Z-axis.	



*The magnetic and acceleration measurements provided in this register are measured in the inertial reference frame. The calculated attitude from the VN-100 is used to rotate the magnetic and acceleration measurements from the body to the inertial frame.*



## 7.51 Raw Voltage Measurements

Raw Voltage Measurements				
<b>Register ID :</b>	251	<b>Firmware :</b>	v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>	Provides the raw voltage measurements from each of the onboard sensors.			
<b>Size (Bytes):</b>	40			
<b>Example Serial Read Register Response:</b>	\$VNRRG,251,+1.349903,+1.487589,+1.681984,+1.434724,+1.450579,+1.591674,+1.284848,+1.276317,+1.294371,+1.334271*42			
Byte Offset	Name	Number Format	Unit	Description
0	MagX	F4	volt	Raw voltage measured on X-axis magnetometer.
4	MagY	F4	volt	Raw voltage measured on Y-axis magnetometer.
8	MagZ	F4	volt	Raw voltage measured on Z-axis magnetometer.
12	AccelX	F4	volt	Raw voltage measured on X-axis accelerometer.
16	AccelY	F4	volt	Raw voltage measured on Y-axis accelerometer.
20	AccelZ	F4	volt	Raw voltage measured on Z-axis accelerometer.
24	GyroX	F4	volt	Raw voltage measured on X-axis gyro.
28	GyroY	F4	volt	Raw voltage measured on Y-axis gyro.
32	GyroZ	F4	volt	Raw voltage measured on Z-axis gyro.
36	Temperature Sensor	F4	volt	Raw voltage measured on temperature sensor.



## 7.52 Calibrated IMU Measurements

Calibrated IMU Measurements				
<b>Register ID :</b>	252	<b>Firmware :</b>	v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>	Provides the calibrated IMU measurements			
<b>Size (Bytes):</b>	40			
<b>Example Serial Read Register Response:</b>	\$VNRRG,252,+1.0678,-0.2539,+3.0652,-00.017,+00.341,-09.820,-0.019193,+0.031246,+0.005292,+25.8*40			
Byte Offset	Name	Number Format	Unit	Description
0	MagX	F4	-	Calibrated magnetic X-axis measurement.
4	MagY	F4	-	Calibrated magnetic Y-axis measurement.
8	MagZ	F4	-	Calibrated magnetic Z-axis measurement.
12	AccelX	F4	m/s <sup>2</sup>	Calibrated acceleration X-axis measurement.
16	AccelY	F4	m/s <sup>2</sup>	Calibrated acceleration Y-axis measurement.
20	AccelZ	F4	m/s <sup>2</sup>	Calibrated acceleration Z-axis measurement.
24	GyroX	F4	rad/s	Calibrated X-axis angular rate.
28	GyroY	F4	rad/s	Calibrated Y-axis angular rate.
32	GyroZ	F4	rad/s	Calibrated Z-axis angular rate.
36	Temperature Sensor	F4	C	Calibrated temperature sensor.



## 7.53 Kalman Filter State Vector

Kalman Filter State Vector				
<b>Register ID :</b>	253	<b>Firmware :</b>	v0.1 and up	<b>Access :</b> Read Only
<b>Comment :</b>	The state vector for the Kalman Filter.			
<b>Size (Bytes):</b>	28			
<b>Example Serial Read Register Response:</b>	\$VNRRG,253,-3.239629E-01,-4.725538E-01,+4.936326E-01,+6.542690E-01,+7.909242E-02,+9.193795E-02,+1.185605E-02*39			
Byte Offset	Name	Number Format	Unit	Description
0	q[0] of quaternion	F4	-	Calculated attitude as quaternion.
4	q[1] of quaternion	F4	-	Calculated attitude as quaternion.
8	q[2] of quaternion	F4	-	Calculated attitude as quaternion.
12	q[3] of quaternion (scalar term)	F4	-	Calculated attitude as quaternion. Scalar component.
16	X-Axis Gyro Bias Estimate	F4	rad/s	Estimated X-axis gyro bias.
20	Y-Axis Gyro Bias Estimate	F4	rad/s	Estimated Y-axis gyro bias.
24	Z-Axis Gyro Bias Estimate	F4	rad/s	Estimated Z-axis gyro bias.



## 7.54 Kalman Filter Covariance Matrix Diagonal

Kalman Filter Covariance Matrix Diagonal				
<b>Register ID :</b>		254	<b>Firmware :</b> v0.1 and up	
<b>Comment :</b>		The diagonal of the covariance matrix for the Kalman Filter.		
<b>Size (Bytes):</b>		24		
<b>Example Serial Read Register Response:</b>		\$VNRRG,254,+4.462022E-06,+4.669347E-06,+1.912999E-04,+4.470797E-07,+4.477159E-07,+1.033085E-06*46		
Byte Offset	Name	Number Format	Unit	Description
0	P[0,0]	F4	-	Variance for X-axis vector component of attitude quaternion.
4	P[1,1]	F4	-	Variance for Y-axis vector component of attitude quaternion
8	P[2,2]	F4	-	Variance for Z-axis vector component of attitude quaternion.
12	P[3,3]	F4	-	Variance for X-axis gyro bias estimate.
16	P[4,4]	F4	-	Variance for Y-axis gyro bias estimate.
20	P[5,5]	F4	-	Variance for Z-axis gyro bias estimate.



## 8 System Registers - Default Factory State

The following table details the VN-100 module's settings as it is delivered from the factory. These settings may be restored by issuing a Restore Factory Settings command (Section 0) or by using the Restore Factory Settings signal pins.

**Table 54 – Factory Default Register Values**

Settings Name	Default Factory Value
Serial Baud Rate	115200
Async Data Output Frequency	40 Hz
Async Data Output Type	YMR : Yaw, Pitch, Roll, Magnetic, Acceleration, & Angular Rates
Magnetic and Gravity Reference Vectors	+1.0e+0, +0.0e+0, +1.8e+0 +0.0e+0, +0.0e+0, -9.793746e+0
Filter Measurement Variance Parameters	+1.0e-10,+1.0e-6, +1.0e-6, +1.0e-6 +1.0e-2, +1.0e-2, +1.0e-2 +1.0e-2, +1.0e-2, +1.0e-2
Magnetic Hard/Soft Iron Compensation Parameters	1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0
Filter Active Tuning Parameters	0.0, 0.0,0.99, 0.9
Acceleration Compensation Parameters	1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0
Reference Frame Rotation	1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0
Accelerometer Gain	0
Communication Protocol Control	0,0,0,1,0,1
Synchronization Control	3,0,0,3,0,0,500000,0
Filter Basic Control	0,0,0,0,16.581,16.581,16.581
VPE Basic Control	1,2,1,1
VPE Magnetometer Basic Tuning	5,5,5,5,5,5,5,5,5,5,5
VPE Magnetometer Advanced Tuning	0,0,0,6,6,6,0.4,8.0,1000
VPE Accelerometer Basic Tuning	6,6,6,3,3,3,5,5,5
VPE Accelerometer Advanced Tuning	0,0,0,6,6,6,0.4,5.0,1000
VPE Gyro Basic Tuning	7,7,7,3,3,3,0,0,0
Filter Startup Gyro Bias	0,0,0
Magnetometer Basic Calibration Control	1,2,5
Calculated Magnetometer Calibration	1,0,0,0,1,0,0,0,1,0,0,0
Indoor Heading Mode Control	0.5,0



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