Navigation, Guidance and Sensors

440 Series User Manual

Installation   Configuration   Reference

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Preface

This document provides information about the 440 Series Inertial Systems, including operational functions and configuration options.

Intended Audience

This document is intended for those who install, configure, extract data and use inertial systems. It is assumed the reader is familiar with the technology of navigation. For advanced use of the 440 Series, knowledge of C programming is required.

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Text Conventions

Table 2 Text Conventions

Convention	Definition
Italics	Emphasizes important information, or indicates the title of a document.
Bold	Stronger emphasis of important information.
`System items`	Indicates a sample of screen output, a command in the body of the document or an example of a command to enter.
`Command`	A software command that must be entered as shown.
NOTE:	Additional information.
CAUTION:	The information provided should be followed to prevent damage to the equipment.
WARNING:	The information provided must be followed to prevent physical injury.

Glossary

Table 3 Glossary

Term	Definition
6DOF	Six Degree of Freedom
ACL	Accelerometer
AHRS	Attitude Heading Reference
BIT	Built In Test
DMU	Dynamic Measurement Unit
DSP	Digital Signal Processor
ECEF	Earth-Centered Earth-Fixed
ESS	Environmental Stress Screening
EKF	Extended Kalman Filter
FIR	Finite Impulse Response
GB-GRAM	Ground-Based GPS Receiver Application Module
GPS	Global Positioning System
Hard failure	Fatal condition, non-operational
Hard iron	Magnetism is retained (*permanent*)

Term	Definition
IMU	Inertial Measurement Unit
LLA	Latitude Longitude and Altitude
LSB	Least Significant Byte
MEMS	Micro-Electro-Mechanical Systems
MSB	Most Significant Byte
MTBF	Mean Time Between Failure
PPS	Precise Positioning Service
QTP	Qualification Test Plan
SAASM	Selective Availability / Anti-Spoofing Module
SDGPS	Satellite Differential GPS
Soft error	Persistent error, repeated many times within a period of time
Soft iron	Magnetism is not retained; magnetism only occurs while the material exposed to a magnetic field
VDC	Voltage Direct Current
VG	Vertical Gyroscope
WAGE	Wide Area GPS Enhancement

Chapter 1. 440 Series Overview

This chapter provides a high level summary of the 440 Series:

- Software Compatibility, page 17
- 440 Series Inertial System Functions, page 17
- Summary of Major Changes from the 300/400 Series and the 420 Series, page 18

Software Compatibility

Moog Crossbow 's 440 Series Inertial Systems are *not* software compatible with any previous Moog Crossbow products. The 440 Series units utilize a new extensible communication protocol which is documented in *Chapter 9. Communicating with the 440 Series Units*. Additionally, the 440 Series includes numerous enhancements and features that allow for better performance in many applications than the comparable 400 or 420 Series products.

Series Inertial System Functions

This manual provides a comprehensive introduction to the use of Moog Crossbow 's 440 Series Inertial System functions listed in Table 4 below. This manual is intended to be used as a detailed technical reference and operating guide for the 440 Series . Moog Crossbow 's 440 Series units combine the latest in high-performance commercial MEMS (Micro-Electromechanical Systems) sensors and digital signal processing techniques to provide a small, cost-effective alternative to existing IMU systems and mechanical gyros.

Table 4 440 Series Functional Description

Function	Features
IMU440	6- DOF Digital IMU
VG440	6-DOF IMU, plus Dynamic Roll/Pitch
AHRS440	6-DOF IMU with 3-Axis Internal Magnetometer Dynamic Roll, Pitch, and Heading
NAV440	6-DOF IMU with 3-Axis Internal Magnetometer, and Internal WAAS Capable GPS Receiver Position, Dynamic Velocity, and Dynamic Roll, Pitch, Heading

The 440 Series is Moog Crossbow 's third generation of MEMS-based Inertial Systems, building on over a decade of field experience, and encompassing thousands of deployed units and millions of operational hours in a wide range of land, marine, airborne, and instrumentation applications.

- At the core of the 440 Series is a rugged 6-DOF (Degrees of Freedom) MEMS inertial sensor cluster that is common across all members of the 440 Series . The 6-DOF MEMS inertial sensor cluster includes three axes of MEMS angular rate sensing and three axes of MEMS linear acceleration sensing. These sensors are based on rugged, field proven silicon bulk micromachining technology. Each sensor within the cluster is individually factory calibrated for temperature and non-linearity effects during Moog Crossbow 's manufacturing and test process using automated thermal chambers and rate tables.

- Coupled to the 6-DOF MEMS inertial sensor cluster is a high performance Digital Signal Processor (DSP) that utilizes the inertial sensor measurements to accurately compute navigation information including attitude, heading, and linear velocity thru dynamic maneuvers (actual measurements are a function of the 440 Series unit as shown in Table 2).

  The DSP processor makes use of internal and external magnetic sensor and/or GPS data to aid the performance of the inertial algorithms and help correct long term drift and estimate errors from the inertial sensors and computations. The navigation algorithm utilizes a multi-state configurable Extended Kalman Filter (EKF) to correct for drift errors and estimate sensor bias values. This algorithm runs on a 150MHz 32-bit DSP that has approximately four times the computational power of Moog Crossbow 's earlier generation Inertial Systems.

- Another unique feature of the 440 Series is the extensive field configurability of the units. This field configurability allows the 440 Series of Inertial Systems to satisfy a wide range of applications and performance requirements with a single mass produced hardware platform. The basic configurability includes parameters such as baud rate, packet type, and update rate, and the advanced configurability includes the defining of custom axes and how the sensor feedback is utilized in the Kalman filter during the navigation process.

The 440 Series is packaged in a fully sealed lightweight housing which provides EMI, vibration, and moisture resistance to levels consistent with most land, marine, and airborne environments. The 440 Series utilizes an RS-232 serial link for data communication, and each data transmission includes a BIT (Built-In-Test) message providing system health status. The 440 Series is supported by Moog Crossbow 's NAV-VIEW 2.X, a powerful PC-based operating tool that provides complete field configuration, diagnostics, charting of sensor performance, and data logging with playback.

Summary of Major Changes from the 300/400 Series and the 420 Series

Mechanical Size and Footprint

The mechanical footprint of Moog Crossbow 's new 440 Series Inertial Systems is compatible with prior generation Inertial Systems including Moog Crossbow 's 400 Series (IMU400, VG400, AHRS400) and the NAV420 Series products. The mounting plate foot print is the same and the connector location is identical. The 440 Series units are shorter than their equivalent 400 Series product (i.e. the AHRS440 is shorter than the AHRS400, etc). The 440 Series unit is dimensionally equivalent to the NAV420. For detailed mechanical and installation drawings, refer to *Appendix E. Mechanical Specifications*.

Connector Pin Out & Operating Voltage, Current

The DB-15 male connector on Moog Crossbow 's 440 Series Inertial Systems has a backward compatible pin out with the 400 Series and 420 Series. However, the 440 Series has a secondary optional-use communications port for internal or external GPS.

Operating Performance and Accuracy

The 440 Series has been characterized in a wide range of land and airborne applications. In the qualification testing, the dynamic accuracy of the 440 Series has shown superior performance when compared to the equivalent model of 400 and 420 Series, reducing attitude estimation errors in half during certain critical dynamic maneuvers without the use of GPS aiding. With GPS aiding in the NAV440, attitude estimation is improved by an order of magnitude compared with 400 series products. Recommended configuration settings are discussed in *Appendix B. Application Examples*. The 440 Series functions are discussed in *Chapter 2. 440 Series Functions.*

Chapter 2. 440 Series Functions

This chapter provides an overview of the hardware and software systems of the 440 Series unit, and the functions provided.

440 Series System

The 440 Series is a compact MEMS based GPS/inertial navigation system. It delivers continuous GPS position, true heading and vehicle attitude tracking information for ground tactical vehicles. The system integrates advanced MEMS inertial gyros and accelerometers, embedded or optional remote 3-axis magnetometer, a SAASM or C/A code GPS receiver, and 10/100 Ethernet interface in a fully sealed enclosure for tactical vehicle operating in combat or homeland security environments.

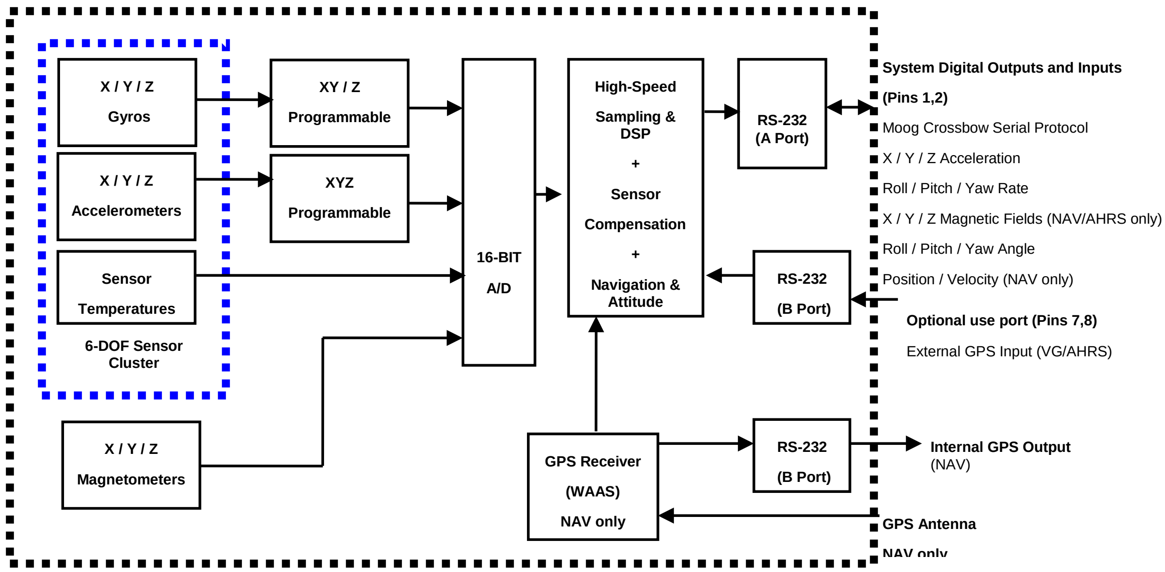
Figure 1 below shows the 440 Series hardware block diagram. At the core of the 440 Series is a rugged 6-DOF (Degrees of Freedom) MEMS inertial sensor cluster that is common across all members of the 440 Series . The 6-DOF MEMS inertial sensor cluster includes three axes of MEMS angular rate sensing and three axes of MEMS linear acceleration sensing. These sensors are based on rugged, field proven silicon bulk micromachining technology. Each sensor within the cluster is individually factory calibrated using Moog Crossbow 's automated manufacturing process.

Configuring NAV440 Functions

Based on the User Behavior settings, the 440 Series unit can be configured to fulfill various functions.

1. Using only the calibrated sensor data, the 440 Series unit functions as an Inertial Measurement Unit (IMU) to output angular rates and accelerations.
2. Incorporating the gyroscope and accelerometer data with the EKF, the 440 Series unit can output roll and pitch attitude information, functioning as a Vertical Gyroscope (VG) unit.
3. Building on the VG function and combining magnetic field measurement, the 440 unit can function as an Attitude Heading Reference System (AHRS): provide a heading angle estimate in addition to the (VG) roll and pitch. The 440 Series unit is provided with an internal magnetometer; an external magnetometer can be integrated with the unit and configured to override the internal magnetometer.
4. Combining GPS sensor data into the EKF, the 440 Series unit can provide a complete attitude system, as well as outputting 3D velocity and position measurements, thereby functioning as a Navigation unit (NAV). An internal C/A code GPS receiver is provided; an external WAAS GPS receiver can be integrated with the unit and configured to override the internal receiver.

Figure 1 440 Series Hardware Block Diagram

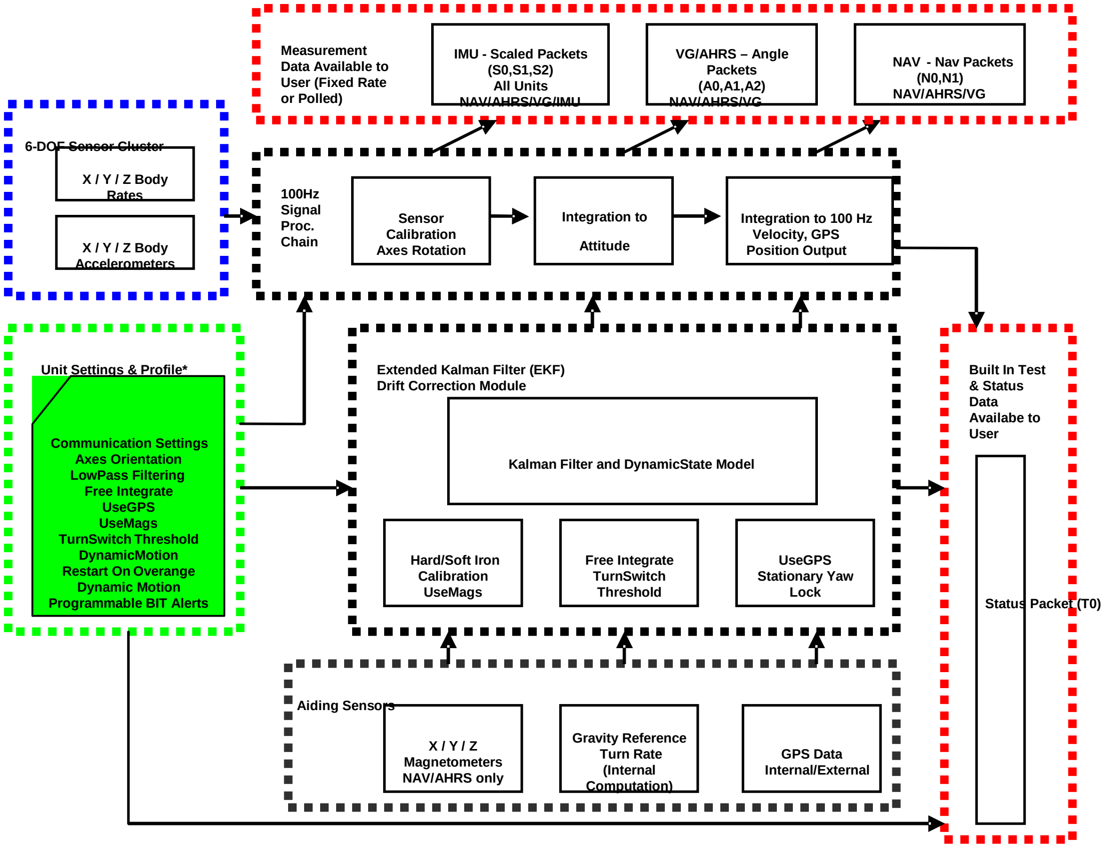


Software Structure

Figure 2 below shows the software block diagram. The 6-DOF inertial sensor cluster data is fed into a high speed 100Hz signal processing chain. These 6-DOF signals pass through one or more of the processing blocks and these signals are converted into output measurement data as shown. Measurement data packets are available at fixed continuous output rates or on a polled basis. The type of measurement data packets available depends on the unit type according to the software block diagram and. Aiding sensor data is used by an Extended Kalman Filter (EKF) for drift correction. Built-In-Test and Status data is available in the measurement packet or via the special Status Packet T0.

As shown in *Figure 2*, the 440 Series has a unit setting and profile block which configures the algorithm to user and application specific needs. This feature is one of the more powerful features in the 440 Series architecture as it allows the 440 Series to work in a wide range of commercial applications by setting specific functions of the 440 Series .

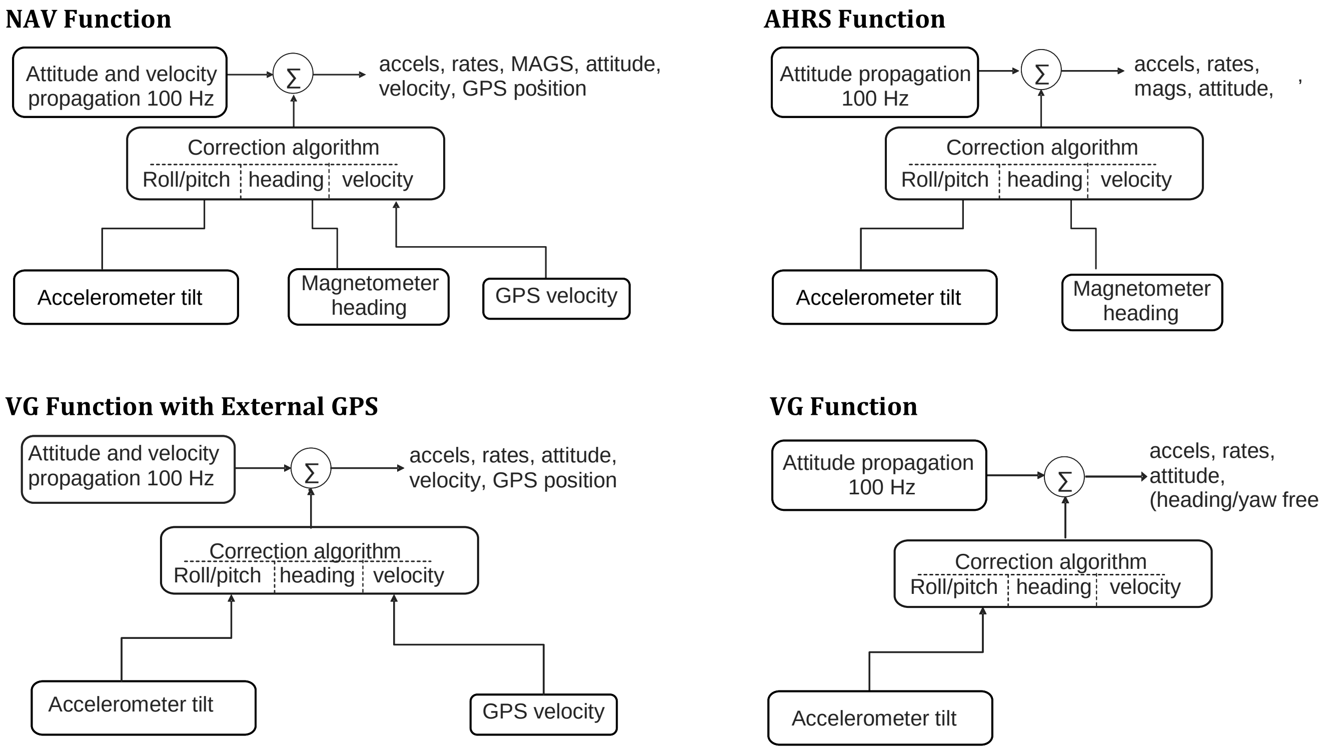
Figure 2 440 Series Software Block Diagram



Functional Block Diagram

Figure 3 below illustrates the unit setting and profile block, which configures the algorithm to user and application specific needs. This feature is one of the more powerful features in the 440 architecture; it allows the 440 Series to work in a wide range of commercial applications by setting specific functions.

Figure 3 440 Series Functions

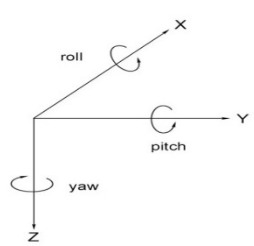


440 Series Default Coordinate System

The 440 Series Inertial System default coordinate system is shown in *Figure 4* below. The coordinate system is configurable with either NAV-VIEW 2.2 or by sending the appropriate serial commands. This section of the manual describes the default coordinate system settings of the unit when it leaves the factory. For information about configuring the 440 Series unit, refer to *Chapter 7. Configuring the 440 Series with* NAV-VIEW 2.2 and *Chapter 10. Programming Guidelines*.

With the 440 Series connector facing you and the mounting plate down, the axes are defined as shown below:

Figure 4 440 Series Default Coordinate System



X-axis: from face with connector through the unit

Y-axis: along the face with connector from left to right

Z-axis: along the face with the connector from top to bottom

The axes form an orthogonal SAE right-handed coordinate system. Acceleration is positive when it is oriented towards the positive side of the coordinate axis. For example, with a 440 Series unit sitting on a level table, it will measure zero g along the x and y-axes and -1 g along the z-axis. Normal Force acceleration is directed upward, which would be defined as negative for the 440 Series z-axis.

The angular rate sensors are aligned with the same axes. The rate sensors measure angular rotation rate around a given axis. The rate measurements are labeled by the appropriate axis. The direction of a positive rotation is defined by the right-hand rule.

With the thumb of your right hand pointing along the axis in a positive direction, your fingers curl around in the positive rotation direction. For example, if the 440 Series unit is sitting on a level surface and you rotate it clockwise on that surface, this will be a positive rotation around the z-axis. The x and y-axis rate sensors would measure zero angular rates, and the z-axis sensor would measure a positive angular rate.

The magnetic sensors are aligned with the same axes definitions and sign as the linear accelerometers. For example, when oriented towards magnetic North, you will read approximately +0.25 Gauss along X, 0.0 Gauss along Y, and +0.35 Gauss along Z direction (North America). Magnetic values at other geographic locations are available at http://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml.

Pitch is defined positive for a positive rotation around the y-axis (pitch up). Roll is defined as positive for a positive rotation around the x-axis (roll right). Yaw is defined as positive for a positive rotation around the z-axis (turn right).The angles are defined as standard Euler angles using a 3-2-1 system. To rotate from the body frame to an earth-level frame, roll first, then pitch, and then yaw.

The position output from GPS is represented in Latitude, Longitude, and Altitude (LLA) convention on the WGS84 Ellipsoid. This is the most commonly used spherical coordinate system. The GPS velocity is defined in North, East and Down reference frame, which can be converted to the Cartesian coordinate system: Earth-Centered, Earth-Fixed (ECEF). ECEF uses three-dimensional XYZ coordinates (in meters) to describe the location of a GPS user or satellite. Several online resources are available to help users with this transformation. Application notes are available on the Moog Crossbow website: http://www.moog-crossbow.com.

Advanced Settings

The 440 Series Inertial Systems have a number of advanced settings that can be changed. The specific settings available vary from unit to unit, and a detailed description of each unit is found in the subsequent sections of this manual. All units support baud rate, power-up output packet type, output rate, sensor low pass filtering, and custom axes configuration. The units can be configured via two methods:

- NAV-VIEW 2.2, a GUI application, (*Chapter 7. Configuring the 440 Series with* NAV-VIEW 2.2*)*
- Program commands, *Chapter 10. Programming Guidelines)*

IMU440 Function

IMU440 (Inertial Measurement Unit) provides the inertial measurement unit functionality that the unit provides by outputting inertial rate and acceleration data in 6-DOF (six degrees of freedom). The IMU440 signal processing chain consists of the 6-DOF sensor cluster, programmable low-pass filters , analog to digital conversion, and the DSP signal processor for sensor error compensation. The rate and acceleration analog sensor signals are sampled and converted to digital data at 1 kHz.

The sensor data is filtered and down-sampled to 100Hz by the DSP using FIR (finite impulse response) filters. The factory calibration data, stored in EEPROM, is used by the DSP to remove temperature bias, misalignment, scale factor errors, and non-linearities from the sensor data. Additionally any advanced user settings such as axes rotation are applied to the IMU440 data. The 100Hz IMU440 data is continuously being maintained inside the unit. Digital IMU440 data is output over the RS-422 at a selectable fixed rate (100, 50, 25, 20, 10, 5 or 2 Hz) or as requested using the GP (Get Packet) command.

The digital IMU440 data is available in one of several measurement packet formats including Scaled Sensor Data (S1 Packet) and Delta-Theta, Delta-V (S2 Packet). In the Scaled Sensor Data (S1 Packet) data is output in scaled engineering units. In the Delta-Theta, Delta-V format (S2 Packet) scaled sensor data is integrated with respect to the time of the last output packet and the data is reported in units of accumulated (i.e., delta) degrees and meters/second. For details about full packets, refer to *Chapter 9. Communicating with the 440* and *Chapter 10. Programming Guidelines.*

NOTE: The Delta-Theta, Delta-V packet is only recommended for use in continuous output mode at 5Hz or greater. Polled requests for this packet will produce values accumulated since the last poll request; they are subject to overflow (data type wrap around).

IMU440 Advanced Settings

The IMU440 advanced settings are described in *Table 5*below. All of the advanced settings are accessible thru NAV-VIEW 2.2 under the Configuration Menu→Unit Configuration settings. For information about using NAV-VIEW 2.2, refer to *Chapter 7. Configuring the 440 Series with* NAV-VIEW 2.2*.*

Table 5 IMU440 Function Advanced Settings

Setting	Default Value	Comments
Baud Rate	38,400	9600, 19200, 57600 also available
Packet Type	S1	S2 also available
Packet Rate	100Hz	This sets the rate at which the selected *Packet Type* packets are output. If polled mode is desired, then select Quiet. If Quiet is selected, the unit will only send measurement packets in response to GP commands.
Orientation	See *Figure 4* on page 22.	To configure the axis orientation, select the desired measurement for each axis: NAV-VIEW 2.2 will show the corresponding image of the unit, so it easy to visualize the mode of operation. Refer to *Orientation Field* on page *83* for the twenty four possible orientation settings. The default setting points the connector AFT.
Analog Filter Clocks 1,2, 3	25 Hz	The low pass filters are set to a default of 25 Hz for the accelerometers, and 25 Hz for the angular rate sensors. There is one filter setting for all three angular rate sensors. There are two settings for the accelerometers, one for the X and Y axes, and a separate setting for the Z axis. In many installations, the Z-axis vibration level is much higher than in the X and Y axes; in such cases it can prove helpful to filter the Z-axis at a lower cutoff than the X and Y axes. For more information, *Analog Filter Clocks* below.

Analog Filter Clocks

Typically, there is no reason to change the low-pass filter settings on the IMU440 or other 440 Series Inertial Systems. However, when a 440 Series unit is installed in an environment with a lot of vibration, it can be helpful to reduce the vibration-based signal energy and noise prior to further processing on the signal. Installing the IMU440 in the target environment and reviewing the data with NAV-VIEW 2.X can be helpful to determine if changing the filter settings is needed. Although the filter settings can be helpful in reducing vibration based noise in the signal, low filter settings (e.g., 1Hz) also reduce the bandwidth of the signal, i.e. can wash out the signals containing the dynamics of a target. The analog filter clock settings are shown in default IMU440 coordinate system.

Treat the filter settings with caution.

NOTE: If the coordinate system is configured to a non-standard or custom configuration, apply the appropriate rotation and configure the filter settings accordingly.

VG440 (Vertical Gyroscope) Function

The VG440 provides dynamic roll and pitch measurements, as well as all IMU440 data functions. The dynamic roll and pitch measurements are stabilized by the using the accelerometers as a long-term gravity reference. The VG440 can also output a free integrating yaw angle measurement that is not stabilized by a magnetometer or compass heading).

At a fixed 100Hz rate, the VG440 continuously maintains both the digital IMU440 data as well as the dynamic roll and pitch data. As shown in the software block diagram (*Figure 2* on page 21), after the *Sensor Calibration* block, the IMU440 data is passed into an *Integration to Orientation* block. (If using external GPS, refer to Figure 4on page22.)The *Integration to Orientation* block integrates body frame sensed angular rate to orientation at a fixed 100 times per second. For improved accuracy and to avoid singularities when dealing with the cosine rotation matrix, a quaternion formulation is used in the algorithm to provide attitude propagation.

Also shown in the software block diagram (*Figure 2*, page 21) the *Integration to Orientation* block receives drift corrections from the *Extended Kalman Filter* or *Drift Correction Module*. In general, rate sensors and accelerometers suffer from bias drift, misalignment errors, acceleration errors (g-sensitivity), nonlinearity (square terms), and scale factor errors.

The largest error in the orientation propagation is associated with the rate sensor bias terms. The Extended Kalman Filter (EKF) module provides an on-the-fly calibration for drift errors, including the rate sensor bias, by providing corrections to the Integration to Orientation block and a characterization of the gyroscope bias state. In the VG440, the internally computed gravity reference vector provides a reference measurement for the EKF when the unit is in quasi-static motion to correct roll and pitch angle drift and to estimate the X and Y gyroscope rate bias. Because the gravity vector has no horizontal component, the EKF has no ability to estimate either the yaw angle error or the Z gyroscope rate bias.

VG440 adaptively tunes the EKF feedback in order to best balance the bias estimation and attitude correction with distortion free performance during dynamics when the object is accelerating either linearly (speed changes) or centripetally (false gravity forces from turns). Because centripetal and other dynamic accelerations are often associated with yaw rate, the unit maintains a low-pass filtered yaw rate signal and compares it to the turnSwitch threshold field (user adjustable).

When the platform the unit is attached to exceeds the *turnSwitch* threshold yaw rate, the unit lowers the feedback gains from the accelerometers to allow the attitude estimate to coast through the dynamic situation with primary reliance on angular rate sensors. This situation is indicated by the softwareStatus→turnSwitch status flag. Using the turnSwitch maintains better attitude accuracy during short-term dynamic situations, but care must be taken to ensure that the duty cycle of the turnSwitch generally stays below 10% during the vehicle mission. A high turnSwitch duty cycle does not allow the system to apply enough rate sensor bias correction and could allow the attitude estimate to become unstable.

The VG440 algorithm has two major phases of operation. The first phase of operation is the initialization phase. During the initialization phase, the unit is expected to be stationary or quasi-static so the EKF weights the accelerometer gravity reference heavily in order to rapidly estimate the roll and pitch angles, and X, Y rate sensor bias. The initialization phase lasts approximately 60 seconds, and the initialization phase can be monitored in the software Status BIT transmitted by default in each measurement packet. After the initialization phase, the unit operates with lower levels of feedback (also referred to as EKF gain) from the accelerometers to continuously estimate and correct for roll and pitch errors, as well as to estimate X and Y rate sensor bias. To reset the algorithm or re-enter the initialization phase, sending the algorithm reset command, AR, will force the algorithm into the reset phase.

In addition to the scaled sensor packets described in the IMU440 section, the VG440 has additional measurement output packets including the default A2 Angle Packet which outputs the roll angle, pitch angle, and digital IMU440 data. N0 and N1 packets are also available for use with an external GPS receiver. Refer to *Chapter 9. Communicating with the 440* and *Chapter 10. Guidelines* for full packet descriptions.

VG440 Advanced Settings

In addition to the configurable baud rate, packet rate, axis orientation, and sensor low-pass filter settings, VG440 provides additional advanced settings that are selectable for tailoring the unit to a specific application requirements. The settings are listed in *Table 6* below.

Table 6 VG440 Advanced Settings

Setting	Default Value	Comments
Baud Rate	38,400 baud	9600, 19200, 57600 also available
Packet Type	A2	S1, S2, N0, N1 also available
Packet Rate	25Hz	This setting sets the rate at which selected Packet Type, packets are output. If polled mode is desired, then select *Quiet*. If *Quiet* is selected, the unit will only send measurement packets in response to GP commands.
Orientation	See *Figure 4* on page 22.	To configure the axis orientation, select the desired measurement for each axis: NAV-VIEW 2.2 will show the corresponding image of the unit, so it easy to visualize the mode of operation. Refer to *Orientation Field* on page *83* for the twenty four possible orientation settings. The default setting points the connector AFT.
Freely Integrate	OFF	The *Freely Integrate* setting allows configuring the unit into a *free gyroscope*. In free gyroscope mode, the roll, pitch and yaw are computed exclusively from angular rate with no Kalman filter based corrections of roll, pitch, or yaw. When turned on, there is no coupling of acceleration based signals into the roll and pitch. As a result, the roll, pitch, and yaw outputs will drift roughly linearly with time due to sensor bias. For best performance, the Freely Integrate mode should be used after the algorithm has initialized. This allows the Kalman Filter to estimate the roll and pitch rate sensor bias prior to entering the free gyroscope mode. Exiting the free *gyroscope* mode (OFF), causes one of the following behaviors to occur: • If the unit has been in freely integrate mode for less than sixty seconds, the algorithm will resume operation at normal gain settings. • If the unit has been in freely integrate mode for greater than sixty seconds, the algorithm will force a reset and reinitialize with high gains automatically.

Setting	Default Value	Comments
Restart On Over Range	OFF	This setting forces an algorithm reset when a sensor over range occurs i.e., a rotational rate on any of the three axes exceeds the maximum range. The default setting is OFF. Algorithm reset returns the unit to a high gain state, where the unit rapidly estimates the gyroscope bias and uses the accelerometer feedback heavily. This setting is recommended when the source of over-range is likely to be sustained and potentially much greater than the rate sensor operating limit. Large and sustained angular rate over-ranges result in unrecoverable errors in roll and pitch outputs. An unrecoverable error is one where the EKF cannot stabilize the resulting roll and pitch reading. If the over-ranges are expected to be of short duration (<1 sec) and a modest percentage over the maximum operating range, it is recommended that the restart on over range setting be turned off. Handling an inertial rate sensor over-range is controlled with the *restartOnOverRange* switch. • If *restartOnOverRange* is off, the system will flag the overRange status flag and continue to operate through it. • If *restartOnOverRange*is on, the system will flag a master Fail error during an over-range condition and continue to operate with this flag until a quasi-static condition is met to allow for an algorithm restart. The quasi-static condition required is that the absolute value of each low-pass rate sensor falls below 3 deg/sec to begin initialization. The system will then attempt a normal algorithm start.
Dynamic Motion	ON	The default setting is ON. Turning off the dynamic motion setting results in a higher gain state that uses the accelerometer feedback heavily. During periods of time when there is known low dynamic acceleration, this switch can be turned off to allow the attitude estimate to quickly stabilize.
Turn Switch threshold	10.0 deg/sec	With respect to centripetal or false gravity forces from turning dynamics (or coordinated turn), the unit monitors the yaw-rate. If the yaw rate exceeds a given turnSwitch threshold, the feedback gains from the accelerometer signals for attitude correction are reduced because they are likely corrupted.

AHRS440 Function

The AHRS440 (Attitude Heading Reference System) unit includes an additional internal 3-axis magnetometer and associated software running on the DSP processor. This enables the computation of dynamic heading, as well as dynamic roll and pitch. AHRS440 data provides dynamic heading, roll, and pitch measurements, in addition to the VG440 and IMU440 data. The dynamic heading measurement is stabilized using the 3-axis magnetometer as a magnetic north reference. The dynamic roll and pitch measurements are stabilized using the accelerometers as a long-term gravity reference. The unit can be configured to turn on and off the magnetic reference for user defined periods of time.

This function utilizes data from calibrated sensors, the gyroscopes, the accelerometers and a magnetometer (internal or external). For details of the IMU functions, refer to *IMU440 Function* on page 23. For details of the VG functions, refer to *VG440 (Vertical Gyroscope) Function*, on page 25. In addition to those features, the AHRS440 algorithm has two major phases of operation.

The first phase of operation is the high-gain initialization phase. During the initialization phase, the unit is expected to be stationary or quasi-static so the EKF weights the accelerometer gravity reference and Earth's magnetic field reference heavily in order to rapidly estimate the X, Y, and Z rate sensor bias, and the initial attitude and heading of the unit. The initialization phase lasts approximately 60 seconds, and the initialization phase can be monitored in the software Status BIT transmitted by default in each measurement packet. After the initialization phase, the unit operates with lower levels of feedback (also referred to as EKF gain) from the accelerometers and magnetometers to continuously estimate and correct for roll, pitch, and heading (yaw) errors, as well as to estimate X, Y, and Z rate sensor bias.

The AHRS440 provides the same scaled sensor and angle mode packets of the VG440. The AHRS440 defaults to the *A1* Angle Packet, which outputs the roll angle, pitch angle, yaw angle, and digital IMU440 data. In the AHRS440, the `A0` and `A1` packets contain accurate magnetometer readings. Refer to *Chapter 9. Communicating with the 440* and *Chapter 10. Programming Guidelines* for full packet descriptions.

NOTE: For proper operation, the unit relies on magnetic field readings from its internal 3-axis magnetometer. The unit must be installed correctly and calibrated for hard-iron and soft iron effects to avoid any system performance degradation. Refer to *Chapter 4. Magnetometer Calibration and Alignment Guidelines* for information about magnetic calibration; review that information before using the AHRS440.

NOTE: The unit must be mounted at least 24" away from large ferrous objects and fluctuating magnetic fields. Failure to locate the unit in a clean magnetic environment will affect the attitude solution.

AHRS440 Advanced Settings

In addition to the configurable baud rate, packet rate, axis orientation, and sensor low-pass filter settings, the unit provides additional advanced settings which are selectable for tailoring the unit to specific application requirements. The AHRS440 advanced settings are listed in *Table 7* below:

Table 7 AHRS 440 Series Advanced Settings

Setting	Default Value	Comments
Baud Rate	38400	9600, 19200, 57600 also available
Packet Type	A1	S0, S1, S2, A0, A2, N0, N1 also available
Packet Rate	25 Hz	This setting sets the rate at which selected Packet Type, packets are output. If polled mode is desired, then select Quiet.
Orientation	See *Figure 4* on page 22.	To configure the axis orientation, select the desired measurement for each axis: NAV-VIEW 2.2 will show the corresponding image of the unit, so it easy to visualize the mode of operation. Refer to *Orientation Field* on page *83* for the twenty four possible orientation settings. The default setting points the connector AFT.

Setting	Default Value	Comments
Freely Integrate	OFF	The Freely Integrate setting allows a user to turn the unit into a *free gyroscope*. In free gyroscope mode, the roll, pitch and yaw are computed exclusively from angular rate with no Kalman filter based corrections of roll, pitch, or yaw. When turned on, there is no coupling of acceleration based signals into the roll and pitch or magnetometer based signals to the yaw. Due to sensor bias., the roll, pitch, and yaw outputs will drift roughly linearly with time. For best performance, the Freely Integrate mode should be used after the algorithm has initialized. This allows the Kalman Filter to estimate the roll and pitch rate sensor bias prior to entering the free gyroscope mode. Upon exiting the free gyroscope mode (OFF), one of two behaviors will occur: • If the unit has been in freely integrate mode for less than sixty seconds, the algorithm will resume operation at normal gain settings • If the unit has been in freely integrate mode for greater than sixty seconds, the algorithm will force a reset and reinitialize with high gains automatically.
Use Mags	ON	The Use Mags setting allows users to turn on and off the magnetometer feedback for yaw/heading stabilization. • The default setting is ON. When Use Mags is turned ON, the 440 Series unit uses the magnetic field sensor readings to stabilize the drift in yaw, and it slaves the yaw to the compass reading provided from the magnetic field sensor readings. • When Use Mags is turned OFF, the heading (yaw) angle measurement of the unit will drift and freely integrate. In effect, this setting converts the functionality to VG. However, unlike a unit in the VG440, this can be done on a selectable basis and changed in real time during a mission. The reason for this setting is to give the user an ability to turn off the magnetometer stabilization when severe magnetic distortion may be occurring. This setting is desirable when the user system temporarily moves in close proximity to a large ferrous object. When the Use Mags switch is turned from OFF to ON, the unit will reinitialize the yaw/heading angle with the compass reading provided from the magnetic field sensor readings.

Setting	Default Value	Comments
Restart On Over Range	OFF	This setting forces an algorithm reset when a sensor over range occurs i.e., a rotational rate on any of the three axes exceeds the maximum range. The default setting is OFF. Algorithm reset returns the unit to a high gain state, where the unit rapidly estimates the gyroscope bias and uses the accelerometer feedback heavily. This setting is recommended when the source of over-range is likely to be sustained and potentially much greater than the rate sensor operating limit. Large and sustained angular rate over-ranges result in unrecoverable errors in roll and pitch outputs. An unrecoverable error is one where the EKF cannot stabilize the resulting roll and pitch reading. If the over-ranges are expected to be of short duration (<1 sec) and a modest percentage over the maximum operating range, it is recommended that the restart on over range setting be turned off. Handling of an inertial rate sensor over-range is controlled using the restartOnOverRange switch. If this switch is off, the system will flag the overRange status flag and continue to operate through it. If this switch is on, the system will flag a masterFail error during an over-range condition and continue to operate with this flag until a quasi-static condition is met to allow for an algorithm restart. The quasi-static condition required is that the absolute value of each low-pass rate sensor falls below 3 deg/sec to begin initialization. The system will then attempt a normal algorithm start.
Dynamic Motion	ON	The default setting is ON. Turning off the dynamic motion setting results in a higher gain state that uses the accelerometer feedback heavily. During periods of time when there is known low dynamic acceleration, this switch can be turned off to allow the attitude estimate to quickly stabilize.
Turn Switch threshold	0.5 deg/sec	With respect to centripetal or false gravity forces from turning dynamics (or coordinated turn), the unit monitors the yaw-rate. If the yaw rate exceeds a given TurnSwitch threshold, the feedback gains from the accelerometer signals for attitude correction are reduced because they are likely corrupted.

NAV440 Function

The NAV440 Function supports all the features of the IMU440, VG440 and AHRS440 functions. In addition, the NAV function provides an internal GPS receiver, which includes software running on the DSP processor for computing navigation and orientation information. In this function, the unit outputs GPS information (Latitude, Longitude, and Altitude), inertial-aided 3-axis velocity information, as well as heading, roll, and pitch measurements, in addition to digital IMU440 data.

At a fixed 100Hz rate, the unit continuously maintains the digital IMU440 data; the dynamic roll, pitch, and heading data; as well as the navigation data. As shown in *Figure 2* on page 21, after the Sensor Calibration block, the IMU440 data is passed into an Integration to Orientation block. The Integration to Orientation block integrates body frame sensed angular rate to orientation at a fixed 100 times per second. For improved accuracy and to avoid singularities when dealing with the cosine rotation matrix, a quaternion formulation is used in the algorithm to provide attitude propagation. Following the integration to orientation block, the body frame accelerometer signals are rotated into the NED level frame and are integrated to velocity. At this point, the data is blended with GPS position data, and output as a complete navigation solution.

As shown in *Figure 2* on page 21, the Integration to Orientation and the Integration to Velocity signal processing blocks receive drift corrections from the Extended Kalman Filter (EKF) drift correction module. The drift correction module uses data from the aiding sensors, when they are available, to correct the errors in the velocity, attitude, and heading outputs. Additionally, when aiding sensors are available corrections to the rate gyroscope and accelerometers are performed.

The NAV Function blends GPS derived heading and accelerometer measurements into the EKF update depending on the health and status of the associated sensors. If the GPS link is lost or poor, the Kalman Filter solution stops tracking accelerometer bias, but the algorithm continues to apply gyroscope bias correction and provides stabilized angle outputs. The EKF tracking states are reduced to angles and gyroscope bias only. The accelerometers will continue to integrate velocity, however, accelerometer noise, bias, and attitude error will cause the velocity estimates to start drifting within a few seconds. The attitude tracking performance will degrade, the heading will freely drift, and the filter will revert toVG440 functions: the EKF formulation will continue without GPS velocity. The UTC packet synchronization will drift due to internal clock drift.

The status of GPS signal acquisition can be monitored from the hardware Status BIT (refer to *Chapter 11. Built In Test (BIT))*. From a cold start, it typically takes 40 seconds for GPS to lock. The actual lock time depends on the antenna's view of the sky and the number of satellites in view. The DSP performs time-triggered trajectory propagation at 100Hz and synchronizes the sensor sampling with the GPS UTC (Universal Coordinated Time) second boundary when available.

As with the AHRS440 and VG440, the algorithm has two major phases of operation. Immediately after power-up, the unit uses the accelerometers and magnetometers to compute the initial roll, pitch and yaw angles. The roll and pitch attitude will be initialized using the accelerometer's reference of gravity, and yaw will be initialized using the leveled magnetometers X and Y axis reference of the earth's magnetic field. During the first 60 seconds of startup, the unit should remain approximately motionless in order to properly initialize the rate sensor bias. The initialization phase lasts approximately 60 seconds, and the initialization phase can be monitored in the software Status BIT transmitted by default in each measurement packet. After the initialization phase, the unit operates with lower levels of feedback (also referred to as EKF gain) from the GPS, accelerometers, and magnetometers.

The NAV Function provides additional output measurement packets including the default *N1* Navigation Packet, which outputs the Latitude, Longitude, Altitude, X,Y,Z velocities, accelerations, and roll angle, pitch angle, yaw angle, and digital IMU440 data. Refer to *Chapter 9. Communicating with the 440* and*Chapter 10. Programming Guidelines* for full packet descriptions.

NAV440 Advanced Settings

In addition to the configurable baud rate, packet rate, axis orientation, and sensor low-pass filter settings, the NAV Function provides additional advanced settings, which are selectable for tailoring the unit to a specific application requirements. The advanced settings are listed in *Table 8 NAV440 Advanced Settings* below:

Table 8 NAV440 Advanced Settings

Setting	Default Value	Comments
Baud Rate	38400	9600, 19200, 57600 also available
Packet Type	N1	S0, S1, S2, A0, A1, A2, N0 also available
Packet Rate	25 Hz	This setting sets the rate at which selected Packet Type, packets are output. If polled mode is desired, then select Quiet.

Setting	Default Value	Comments
Orientation	See *Figure 4* on page 22.	To configure the axis orientation, select the desired measurement for each axis: NAV-VIEW 2.2 will show the corresponding image of the unit, so it easy to visualize the mode of operation. Refer to *Orientation Field* on page *83* for the twenty four possible orientation settings. The default setting points the connector AFT.
Freely Integrate	OFF	The Freely Integrate setting allows a user to turn the unit into a *free gyroscope*. In free gyroscope mode, the roll, pitch and yaw are computed exclusively from angular rate with no Kalman filter based corrections of roll, pitch, and yaw. When turned on, there is no coupling of acceleration based signals into the roll and pitch or magnetometer based signal to the yaw. As a result, the roll, pitch, and yaw outputs will drift roughly linearly with time due to sensor bias. For best performance, the Freely Integrate mode should be used after the algorithm has initialized. This allows the Kalman Filter to estimate the roll and pitch rate sensor bias prior to entering the free gyroscope mode. Upon exiting the *free gyroscope* mode (OFF), one of two behaviors will occur ▪ If the unit has been in freely integrate mode for less than sixty seconds, the algorithm will resume operation at normal gain settings ▪ If the unit has been in freely integrate mode for greater than sixty seconds, the algorithm will force a reset and reinitialize with high gains automatically.
Use GPS	ON	The Use GPS setting allows users to turn on and off the GPS feedback. The default setting is ON. When Use GPS is turned OFF, the units behavior will revert to AHRS440.
Stationary Yaw Lock	OFF	This setting defaults to OFF; it is recommended to be OFF for NAV Function. The stationary yaw lock is only recommended for consideration when the unit is operating with GPS (Use GPS = ON) and WITHOUT magnetometer feedback (*UseMags* = OFF). Stationary yaw lock may be appropriate if the user platform is a ground vehicle.
Use Mags	ON	The Use Mags setting allows users to turn on and off the magnetometer feedback for yaw/heading stabilization. The default setting is ON.. When Use Mags is turned ON, the unit uses the magnetic field sensor readings to stabilize the drift in yaw, and it slaves the yaw to the compass reading provided from the magnetic field sensor readings. When *UseMags* is turned OFF, the heading (yaw) angle measurement of the unit will be slaved to the GPS heading if GPS is available, otherwise the heading will drift feely. The reason for this setting is to give the user an ability to turn off the magnetometer stabilization when severe magnetic distortion may be occurring. This setting is desirable when the user vehicle temporarily moves in close proximity to a large ferrous object. When the *UseMags* switch is turned from OFF to ON, the unit will reinitialize the yaw/heading angle with the compass reading provided from the magnetic field sensor readings.

Setting	Default Value	Comments
Restart On Over Range	OFF	This setting forces an algorithm reset when a sensor over range occurs i.e., a rotational rate on any of the three axes exceeds the maximum range. The default setting is OFF.. Algorithm reset returns the unit to a high gain state, where the unit rapidly estimates the gyroscope bias and uses the accelerometer feedback heavily. This setting is recommended when the source of over-range is likely to be sustained and potentially much greater than the rate sensor operating limit. Large and sustained angular rate over-ranges result in unrecoverable errors in roll and pitch outputs. An unrecoverable error is one where the EKF cannot stabilize the resulting roll and pitch reading. If the over-ranges are expected to be of short duration (<1 sec) and a modest percentage over the maximum operating range, it is recommended that the restart on over range setting be turned off. Handling of an inertial rate sensor over-range is controlled using the restartOnOverRange switch. ▪ If this switch is off, the system will flag the overRange status flag and continue to operate through it. ▪ If this switch is on, the system will flag a masterFail error during an over-range condition and continue to operate with this flag until a quasi-static condition is met to allow for an algorithm restart. The quasi-static condition required is that the absolute value of each low-pass rate sensor falls below 3 deg/sec to begin initialization. The system will then attempt a normal algorithm start.
Dynamic Motion	ON	The default setting is ON. Turning off the dynamic motion setting results in a higher gain state that uses the accelerometer feedback heavily. During periods of time when there is known low dynamic acceleration, this switch can be turned off to allow the attitude estimate to quickly stabilize.
Turn Switch threshold	0.5 deg/sec	With respect to centripetal or false gravity forces from turning dynamics (or coordinated turn), the NAV440 monitors the yaw-rate. If the yaw rate exceeds a given Turnswitch threshold, the feedback gains from the accelerometer signals for attitude correction are reduced because they are likely corrupted.

Chapter 3. Hardware Interface

This chapter provides information about the power and signal interface connectors.

I/O Connector

NOTE: During the normal operation of the 440 Series , do not connect to the factory test pins: 6, 12 14, 15. These pins have internal pull-up mechanisms and must have no connections for the 440 Series to operate properly.

The 440 Series has a male DB-15 connector. The signals are as shown in Table 3 below.

Figure 5 DB15 Connector

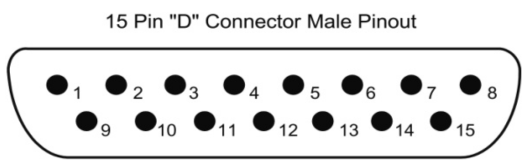


Table 3 DB-15 Connector Pin Assignments

Pin	Signal	Pin	Signal
1	RS-232 Transmit Data (A Port)	9	Signal Ground
2	RS-232 Receive Data (A Port)	10	1 PPS OUT
3	Positive Power Input (+Vcc)	11	1 PPS (IMU440/VG440/AHRS440 only)
4	Power Ground	12	NC – factory use only
5	Chassis Ground	13	Hardware BIT Error
6	NC – Factory use only	14	NC – factory use only
7	RS-232 GPS Tx (B Port)	15	NC – factory use only
8	RS-232 GPS Rx (B Port)		

For a standard DB-9 COM port connector, connect the signals as listed below in Table 10.

Table 9 DB-9 COM Port Pin Assignments

COM Port Connector		440 Series Connector	
Pin #	***Signal***	***Pin #***	***Signal***
2	RxD	1	TxD
3	TxD	2	RxD
5	GND	9	GND

J2—GPS Antenna Connector

The GPS receiver needs to receive signals from as many satellites as possible. A GPS receiver does not work properly in narrow streets and underground parking lots or if objects or human beings cover the antenna. Poor visibility may result in position drift or a prolonged Time-To-First-Fix (TTFF). A good sky visibility is therefore a prerequisite. Even the best receiver cannot compensate for signal loss due to a poor antenna, in-band jamming or a poor RF cable.

The unit ships with an external active antenna that must be connected properly to SMA jack on the unit case. Placing the antenna on a 16 square inch or larger ground plane is highly recommended.

I/O Port Interface

Port A: User (computer), RS232 serial data interface

The serial interface is standard RS-232, 9600, 19200, 38400, or 57600 baud, 8 data bits, 1 start bit, 1 stop bit, no parity, and no flow control and will output at a user configurable output rate. These settings allow interaction via a standard PC serial port.

Port B: GPS Interface, RS232 serial interface

Port B can be applied to internal or external GPS interface.

Internal GPS

The internal GPS receiver of the NAV440 outputs data in NMEA-0183 format as defined by the National Marine Electronics Association (NMEA), Standard For Interfacing Marine Electronic Devices, Version 2.20, January 1, 1997. The packets are sent at 9600 Baud, 8 data bits, 1 start bit, 1 stop bit, no parity bit, and no flow control.

GPS messages are delivered in NMEA message format. For more information, refer to *Appendix A. NMEA Message Format* on page 101.

External GPS

External GPS is supported via VG440 and AHRS440 functions. For the 440 Series unit to interface with an external GPS receiver, the GPS receiver must be configured to output data in a format compatible with the 440 Series unit. Formats are described in the next section: *External GPS Aiding (Port B, VG440 and AHRS440)* on page 37.

Cable Field Requirements

The 440 Series is shipped with an EMI filter attached to the DB-15 Connector. This connector must remain in place to ensure proper shielding from EMI interference.

CAUTION: The cable sent with the unit is intended to provide the user with the ability to test the unit right out of the box, and will not provide adequate shielding for all environments. Case ground must be used to provide full EMI protection, and ensure the cable shield is grounded on only one end of the cable.

Case Grounding

The case is electrically connected to Pin 5 of the DB-15 connector. The Pin 5 should be electrically connected to the user’s cable shield, especially if the chassis does not make good ground contact. The case should be bolted to a good conducting surface that is grounded.

Signals

External GPS Aiding (Port B, VG440 and AHRS440)

NOTE: This feature only applies to VG440 and AHRS440.

NOTE: The GPS serial communication port should be configured to 8 data bits, 1 start bit, 1 stop bit, no parity bit, and no flow control.

The VG440/AHRS440 allows using an external GPS receiver. To do so, the following actions are required:

- The external GPS receiver must be configured to output the GPS messages to be compatible with the 440 Series . *Table 10* below shows the supported GPS protocols and guidelines for configuration. The details of the GPS messages can be found in the respective GPS protocol documents.
- The VG/AHRS440 must be configured to accept external GPS information. Refer to *Table 10* below and *Chapter 7. Configuring the 440 Series with NAV-VIEW 2.2*.

Table 10 Configuration for External GPS Receiver for VG440/AHRS440

Protocols	Required Messages	Required Message Rate	Baud rate
Ublox binary	NAV-LLH, NAV-VELNED, NAV-STATUS	4 Hz	9600, 19200, 38400, 57600$
NovAtel OEM4 and OEMV Binary	BestPosB, BestVelB	4Hz	9600, 19200, 38400, 57600$
NovAtel OEM4 ASCII	PosVelNavDopA	4Hz	19200, 38400, 57600$
NMEA*	GPGGA, GPVTG	4Hz	9600, 19200, 38400, 57600$

*Not recommended for airborne applications.

$57600 is the preferred baud rate for optimum performance

If the VG/AHRS440 is parsing valid external GPS data and the GPS receiver has 3D lock, then the comStatus→noExternalGPS flag will be zero, otherwise it will be one. Refer to *Chapter 11. Built In Test (BIT)* on page 91 for details about system status indications.

As the NMEA protocol does not provide vertical velocity, the vertical velocity the 440 Series estimates (based upon GPS altitude changes) may not be sufficient for airborne applications.

NOTE: The NMEA protocol is not recommended for airborne applications

Hardware BIT Error Output

The hardware BIT error output pin is the ultimate indication of system failure. This indication is available in most software output packets as the master Fail flag. It is the logical AND of the hardware Error, com Error, and software Error flags monitored by the system. In the event of a communication failure, the hardware BIT error pin may be used to detect a master Fail assertion. This pin is open-collector and requires a 1k to 10k ohm pull-up resister. The system will drive this pin low to assert a system failure.

1 PPS Input Interface

The 1PPS input signal allows the user of the 440 Series unit to force synchronization of sensor data collection to a 1Hz rising-edge signal. The signal must maintain 0.0-0.2 V zero logic and 3.0-5.0 volts high logic and stay within 100ms of the internal system 1 second timing. Sending this signal to the system will align the sensor data collection and algorithm processing to its rising edge and 10ms boundaries thereafter. When the system is synchronized to 1PPS, the hardwareStatus→unlocked1PPS flag will be *zero*; otherwise, the flag will be *one*.

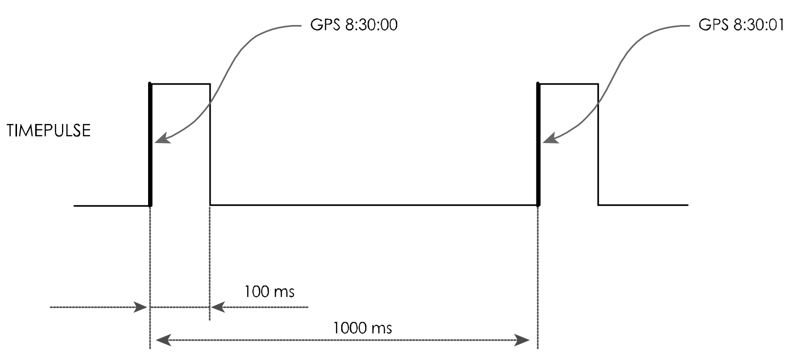
1 PPS Output Interface

The 1PPS output signal is provided by the internal GPS receiver (when GPS timing is known) on the 440 Series unit. The 1PPS output signal is open-collector and should be interfaced to a rising-edge trigger with pull up resistor between 1k and 10k ohms. The 440 Series unit synchronizes sensor data collection to this 1PPS signal internally when available. Therefore, the 100Hz navigation algorithm will run exactly 100 times each second with no slip when locked to 1PPS.

Packet data is valid on the rising edge of 1PPS and 10ms boundaries thereafter. There is, however, up to 500µs of additional latency in sensor data collection. If 1PPS is provided by the internal GPS receiver in 440 units, then the rising edge of 1PPS will correspond to the UTC second boundary. When the system is synchronized to 1PPS, the hardware Status→unlocked1PPS flag will be *zero*; otherwise, the flag will be *one*.

Figure 6 below shows the sequential order of the signal present at 1 PPS OUT pin. The one PPS signal is aligned to the sampling clock of 23.104 MHz, which results in the timing resolution of 43 ns.

Figure 6 1PPS Output Signal



Chapter 4. Magnetometer Calibration and Alignment Guidelines

This chapter provides information for calibrating and aligning the magnetometer with the 440 Series unit.

This section provides guidelines to calibrate and align the magnetometer. This information applies when implementing AHRS Function or NAV Function (*AHRS440 Function* on page 27, *NAV440 Function* on page 30).

NOTE: For effective calibration results, the 440 Series unit must be installed in the system during the alignment process.. If calibrated outside of the system, the magnetism of the system will not be measured. Without those values, the unit will not be able to compensate magnetic readings: either heading readings will be incorrect or error messages will be displayed.

Compensation for Magnetic Fields

Magnetic sensors measure magnetic fields which are then used to compute heading. A correct heading angle is based only on the earth's magnetic field. However, the magnetic fields of the NAV440 unit and the surroundings (such as the system/vehicle in which the unit is installed) are also measured, which affect the magnetic reading. To compensate for these magnetic fields and ensure accurate heading readings, the 440 Series unit must be calibrated.

The 440 Series unit compensates for the extra magnetic field(s) by taking a series of measurements and then applying those measurements to a two-dimensional algorithm. The algorithm is used to calculate the hard iron and soft iron effects, the values of which are then stored as constants in the EEPROM of the unit. Those constants are used for correcting the magnetic readings, ensuring accurate heading output. Hard iron effects are P shifts in the magnetic fields from ferrous objects or other magnetic material in the proximity of the magnetic sensor. Soft iron effects are the change of direction of a magnetic field; this change is caused by hard iron on the input direction. Hard iron magnetic fields are permanent whereas soft iron magnetic fields are temporary: soft iron can be magnetized and then demagnetized or have varying effects during operation.

Following is an overview of the calibration process:

1. Install the 440 Series in the system (vehicle) in which it will be used
2. Select an appropriate test location, free of magnetic interference
3. Run the calibration and alignment procedure
4. Set the calibration readings in the 440 Series unit

NOTE: Ensure the test location is appropriate for magnetic calibration. The calibration process provides corrections for magnetic fields from fixed locations that are relative to the position of the unit. The calibration does not compensate for time varying fields, or fields created by magnetic material that moves relative to the 440 Series unit.

Magnetometer Alignment Using NAV-VIEW 2.2

During the calibration procedure, the unit makes a series of measurements while the user system is being turned through a complete 360 degree circle. A 360 degree rotation gives the unit visibility to hard and soft iron distortion in the horizontal plane. Using NAV-VIEW 2.2, the hard and soft iron effects can be viewed by selecting the *Misalignment* option on the *Configuration Menu*, and viewing the magnetic circle during the calibration.

For calibration instructions, refer to *Aligning the Magnetometer* on page 55.

Magnetometer Alignment Using Code

The unit provides a command interface for initiating the hard iron/soft iron calibration without using NAV-VIEW 2.2. To do so, send a `WC` command to initiate the calibration, and then rotate the user system 360 degrees. The `WC` command has two options: auto-termination and manual termination.

- With auto-termination, the unit tracks the yaw movement and after 380 degrees of rotation returns the calibration complete response, `CC`. The auto-termination sequence can falsely terminate if the 360 degree rotation is not completed within two (2) minutes of the `WC` command initiation.
- Manual termination requires sending a second `WC` command with the termination code in the payload. Manual termination is a good option when the user system moves very slowly (e.g., large marine vessel) and completing the 360 degree rotation may require more than two minutes.

The status of the magnetometer calibration is indicated by the softwareError→dataError→magAlignOutOfBounds error flag available in the `T0` packet. You can access the hardIronScaleRatio and softIronScaleRatio calibration data as configuration fields in NAV-VIEW 2.2, or by using the communication protocol. Also, the softwareError bit of the masterFail byte within the BIT word is transmitted in every measurement packet. When the unit has not been properly calibrated, this softwareError bit will be set to fail (high).

The calibration complete (`CC`) command response message contains the X and Y hard iron bias, as well as the soft iron ratio. This information can be interpreted to give an indication of the quality of the calibration. For more information on the hard iron bias and soft iron ratio, refer to *Compensation for Magnetic Fields* on page 39. Refer to *Chapter 9. Communicating with the 440* for details of the `WC` and `CC` commands.

Installation Guidelines

Field Installation

- For a proper calibration and alignment, the 440 Series unit must be installed in its operating environment, such as the land vehicle or aircraft in which it will be used.

Chapter 5. Installation Guidelines

This chapter provides information to set up the 440 Series unit and NAV-VIEW 2.2 software for laboratory test.

NOTE: Directions to install a unit in a vehicle for field use is outside the scope of this document.

Overview

The following instructions are for connecting the 440 Series unit to a computer and using NAV-VIEW 2.2 to verify basic functions of the unit in a laboratory setting.

Installation Requirements

Computer

- CPU: ≥ 1GHz
- RAM Memory: ≥ 3GB
- Hard Drive Free Memory: ≥ 60MB
- Operating System: Windows XP, 32 bit or 64 bit; Windows 7, 32 bit or 64 bit
- Microsoft .NET 4.0 or higher

Communication Port

- Determine which COM port to use

Power and Hardware

Power:

- Voltage: +9 VDC to +42 VDC
- Power: > 5 W

Hardware:

- Ensure all necessary hardware has been determined and provided.
- Optional: For laboratory test, use the cable provided with the Moog Crossbow evaluation kit. (Refer to *Figure 27* on page 122.)

  NOTE: The evaluation kit cable is only suitable for laboratory test; it is not designed for field use. Refer to *Figure 27* on page 122.

1. Install Software—NAV-VIEW 2.2

Instructions

a. Insert the CD *440 Series Inertial System* in the CD-ROM drive.

b. On the CD, navigate to the NAV-VIEW 2.2 folder and double click the **setup.exe** file.

c. Follow the wizard instructions to install NAV-VIEW 2.2 and .NET 4.0 framework.

2. Prepare the Communication Port

- The 440 Series unit communicates directly to the computer or host via serial port: determine which communication port to use.
- Setting up the port will be handled in step *4Turn on the 440 Series* .

3. Connect the GPS Antenna

NOTE: The 440 Series unit is shipped with an external active antenna.

To clearly receive signals from many satellites, a *clear view* from the antenna to the sky is required.

- Poor visibility may result in position drift or a prolonged Time-To-First-Fix (TTFF). The following setups can obstruct the signal, resulting in poor results for navigation:
- The GPS receiver will not work properly if signals are blocked, such as objects cover the antenna, or the receiver is located underground or other confined area.
- Signals can also be blocked or distorted with a poor quality antenna or RF cable, or in-band jamming.
- Placing the antenna on a 16square inch (e.g. 4" x 4") or larger ground plane is recommended.

Instructions

- Secure the antenna to the SMA jack on the enclosure.

4. Turn on the 440 Series

Instructions

a. Ensure the voltage level of the power supply is set between +9 VDC and +42 VDC, and then turn off the power supply.

b. Secure the DB-15 end of the cable to the 440 Series unit.

c. Secure the DB-9 end of the cable to the host computer.

d. Connect the input power (red and black wires) to the DC voltage power supply:

  - Connect the red plug to the positive terminal (+)
  - Connect the black plug to the ground terminal (-) ground.

CAUTION: If the input power leads are reversed, the unit may be damaged. The warranty for the unit does not cover damage cause by neglect or incorrect use; Moog Crossbow will assume no responsibility for the repair or replacement of the unit.

e. Turn on the power supply. Ensure the total power drawn does not exceed 5 watts.

f. Start NAV-VIEW 2.2—click the NAV-VIEW 2.2 icon on the computer.

NAV-VIEW 2.2 should automatically detect the 440 Series unit. If NAV-VIEW 2.2 does not show connection to the 440 Series unit, it may be necessary to set up the serial port. The instructions follow:

a. Start NAV-VIEW 2.2 on the computer: double-click the NAV-VIEW 2.2 icon on the desktop.

a. On the menu bar click **Setup** and then select **Port** from the drop menu.

b. The *Configure Serial Port* dialog window opens:

c. Select the appropriate COM port.

d. Set the baud rate: **Auto** is recommended.

e. Click **Connect** and then click **Save and Close**.

If the connections are correct and the unit is functional, information should be displayed on the screen. For guidelines to verify basic operations, refer to *Chapter 6. Viewing and Logging Data with NAV-VIEW 2.2* on page 45.

Trouble-Shooting Tips

- If the unit is connected but not working, check the following:
  - The power supply is connected and the output voltage and current levels are correct.
  - Ensure the correct COM port is being used; check the configuration and the cable connection.

Chapter 6. Viewing and Logging Data with NAV-VIEW 2.2

NOTE: It is assumed that 440 Series and NAV-VIEW 2.2 have been set up, connected and turned on. For instructions, refer to *Chapter 5. Installation Guidelines* on page 41.

Figure 8 on page 46 shows the main page of NAV-VIEW.

The functions are available from the menu bar at the top of the page.

The graphs are displayed in the main body of the page.

- Multiple graphs can be selected for viewing. Which graphs are available depends on the packet type that was selected. For details about packet types, refer to *Chapter 9. Communicating with the 440*.
- The time range (speed) of viewing the graphs can be selected: 2, 5, 10, 20, or 50 seconds per time frame.

The bottom of the page indicates information about the unit and connection to the unit

- That the unit is connected to the COM port
- The baud rate
- If the unit is connected and working properly, the following messages will be displayed:

  "Unit Connected"

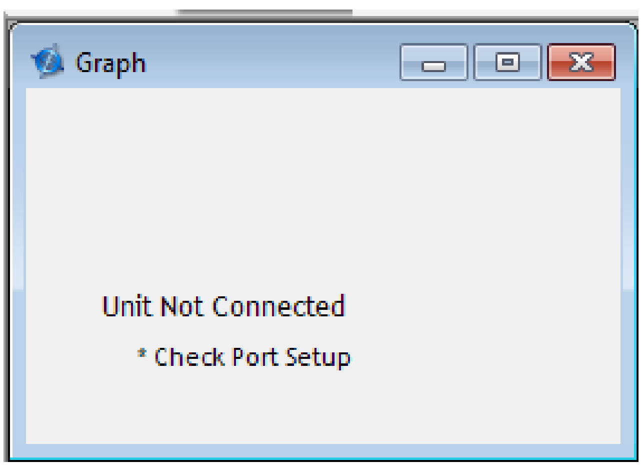
  Packet Rate

  The serial number of the 440 Series unit

  The version of NAV-VIEW 2.2

If the unit is not connected, the following message will be displayed:

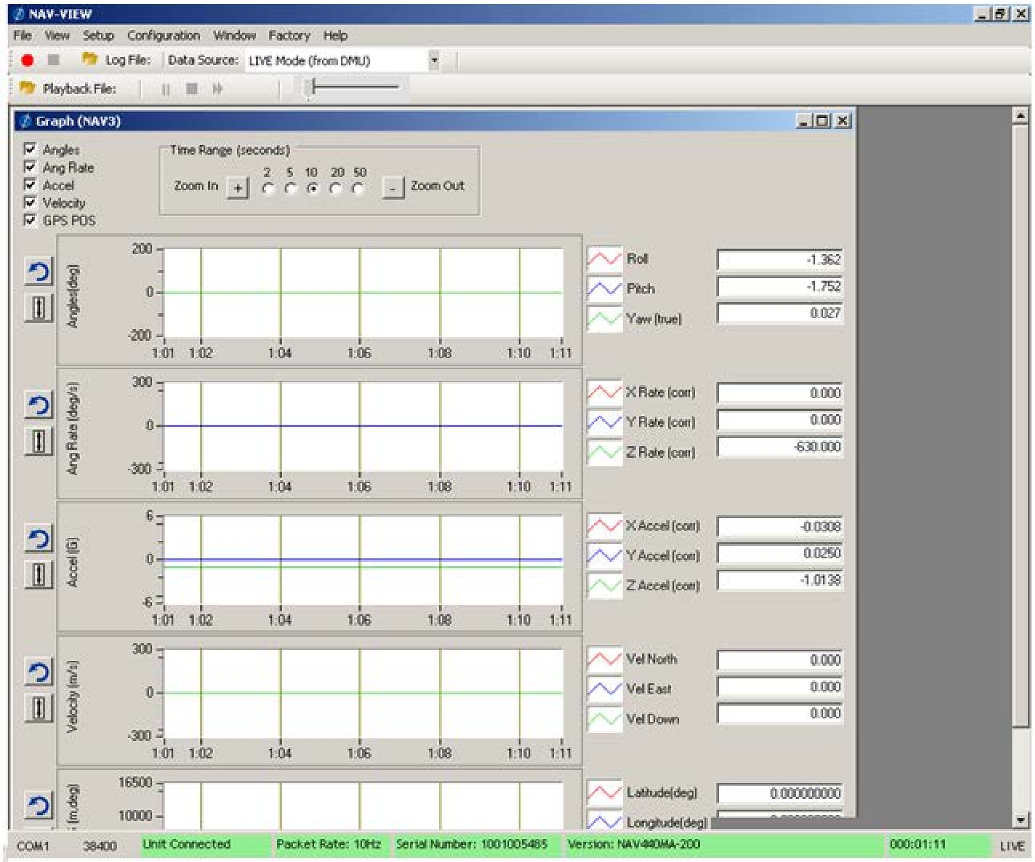
Figure 7 No Display



If *Unit Not Connected* is displayed, check the following:

- Are the power supply levels are correct.
- Verify that the setting of the serial Port.

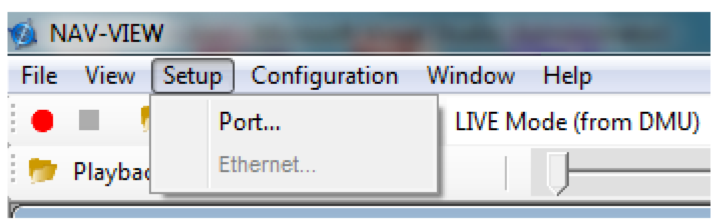
Figure 8 Main Screen



Communication Port

NOTE: The 440 Series is accessed via serial port; the 440 Series does not support Ethernet connectivity.

To select a port, click Setup and then select the desired port from the drop menu. A dialog window then opens, enabling configuration.



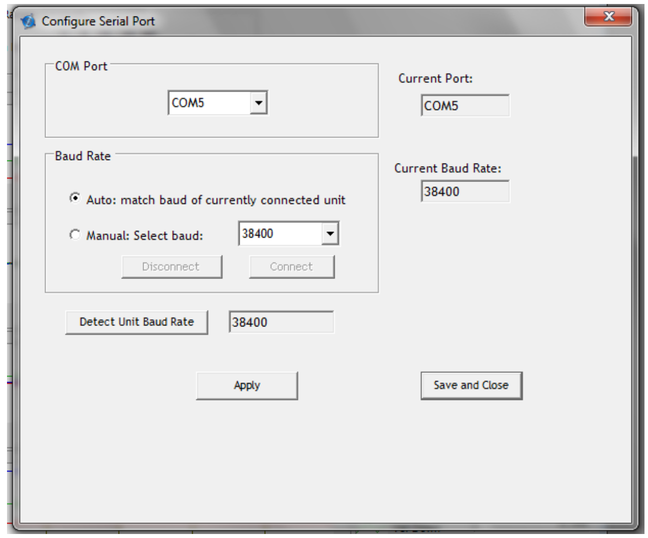
Serial Port

The *Configure Serial Port* dialog shows the current Port and Baud rate, which can both be configured. To do so:

1. Select the desired **COM Port.**

   Either manually select the desired **Baud Rate** or select **Auto.**
2. To apply the configuration, click **Apply**.
3. To ensure the configuration is saved after rebooting the unit, click **Save and Close**.

Figure 9 Configure Serial Port



Record Data

NAV-VIEW 2.2can be used to log data to a text file (.txt). How data is logged can be configured: data type; logging rate; recording length. The instructions follow:

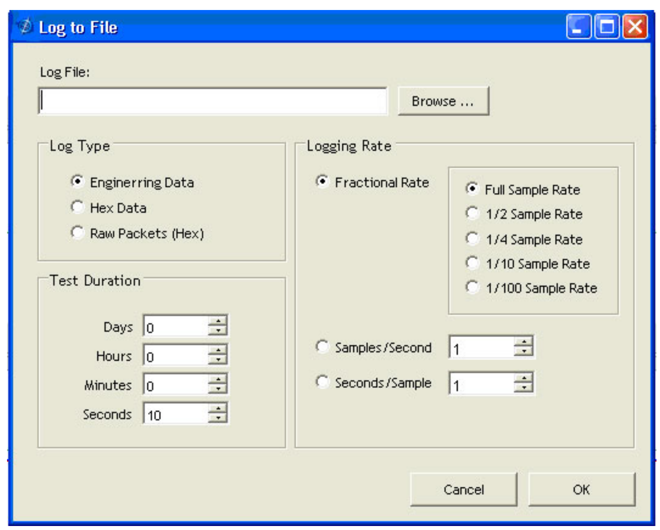
1. Locate the icon at the top of the page, or click **File** and then select **Log to File** from the drop down menu. The dialog window opens.
2. Click the **Browse** button and select the location for saving data.
3. In the **Log Type** section, select the type of data to record:

   Engineering Data records the converted values provided from the system in engineering units (default selection).

   Hex Data provides the raw hex values separated into columns displaying the value.

   Raw Packets records the hex strings as they are sent from the unit.

Figure 10 Log to File Menu



4. In the **Logging Rate** section, the following options are available:
    - Fractional Rate
    - Sample Rates
5. In the **Test Duration** section, define the desired duration of the data logging in terms of **Days**, **Hours**, **Minutes**, and/or **Seconds**. The default setting is 10 seconds.
6. After setting all the options, click the **OK** button. The display will return to the main window.

    To start the recording process, press the button at the top of the window, click **File** and then select **Start Logging** from the drop menu. Refer to *Figure 8* on page 46.

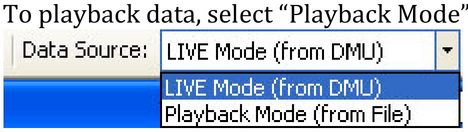
    To stop the recording the data early, press the button.

    To pause the recording, press the button.

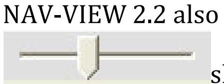
Playback Data

In addition to data recording, NAV-VIEW 2.2enables replaying data that has been stored in a log file.

1. To playback data, select "Playback Mode" from the "Data Source" drop down menu at the top.

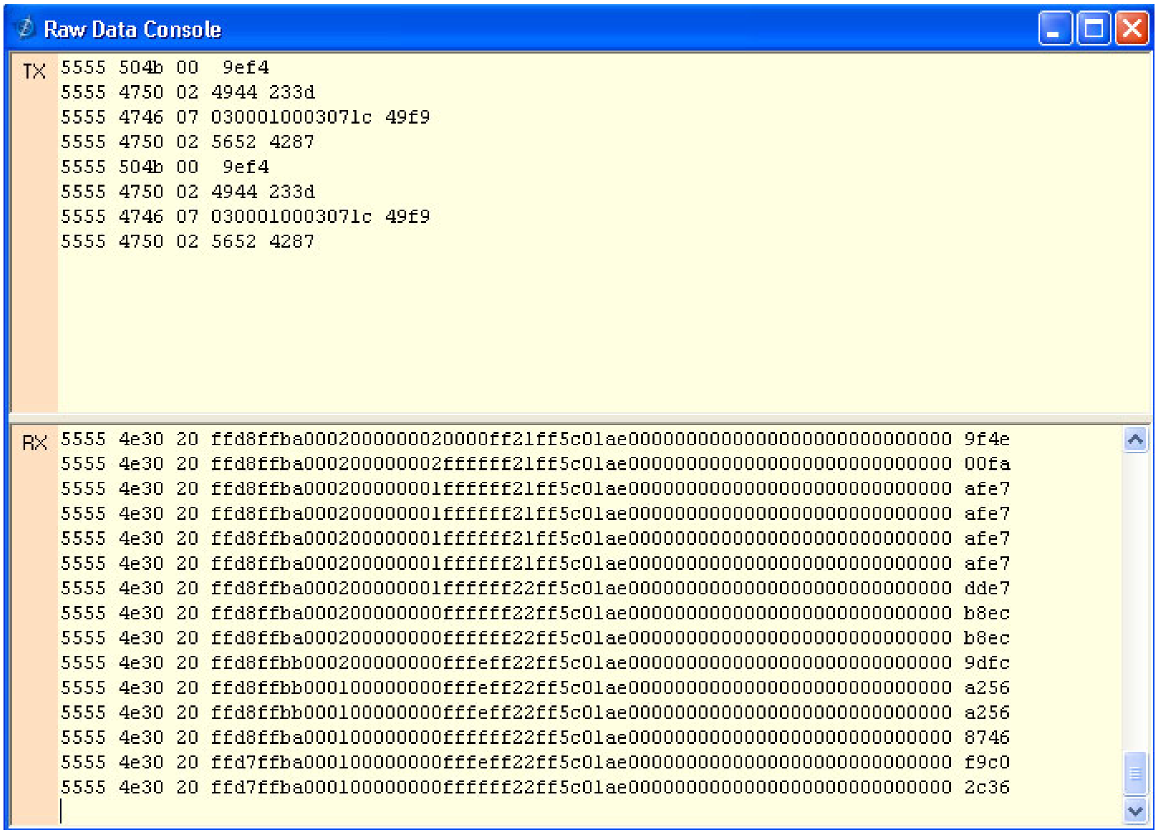
    Selecting Playback mode opens a text prompt, which allows specifying the location of the file to play back. All three file formats are supported (Engineering, Hex, and Raw) for playback. In addition, each time recording is stopped/started a new section is created. These sections can be individually played back by using the drop down menu and associated VCR controls.
2. Once the file is selected, use the VCR style controls at the top of the page to start, stop, or pause the playback of the data.

    NAV-VIEW 2.2 also provides users with the ability to alter the start time for data playback. The  slide bar at the top of the page can be used to adjust the starting time.

Raw Data Console

NAV-VIEW 2.2 offers some unique debugging tools that may assist programmers in the development process. One such tool is the Raw Data Console. From the "View" drop down menu, simply select the "Raw Data Console". This console provides users with a simple display of the packets that have been transmitted to the unit (Tx) and the messages received (Rx). An example is provided below.

Figure 11 Raw Data Console

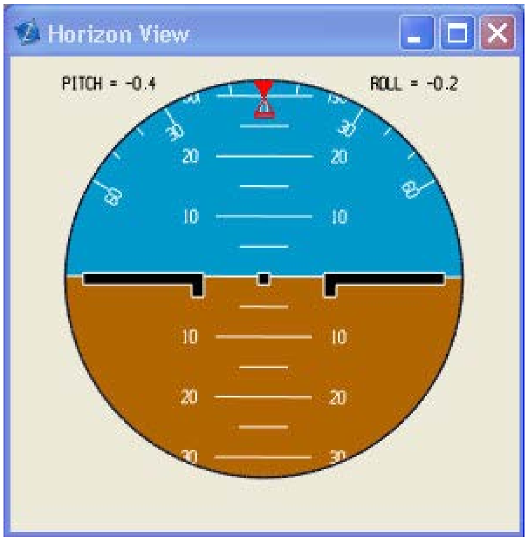


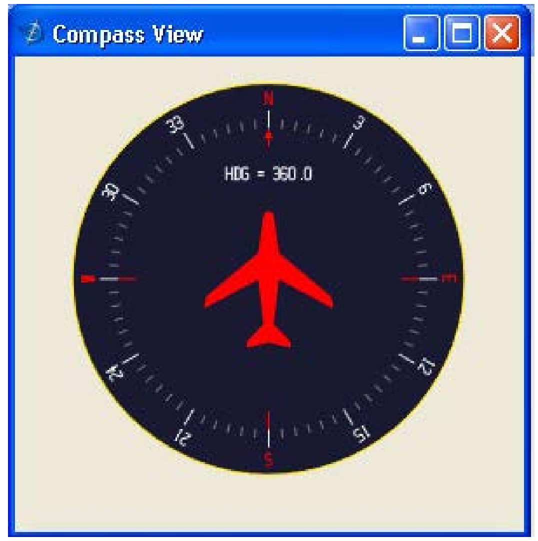
Horizon and Compass Views

NAV-VIEW 2.2provides a compass and a simulated artificial horizon view.

- To activate these views, click **View** at the menu bar, and then select **Horizon View** and/or **Compass View** from the drop down menu.

Figure 12 Horizon and Compass Views



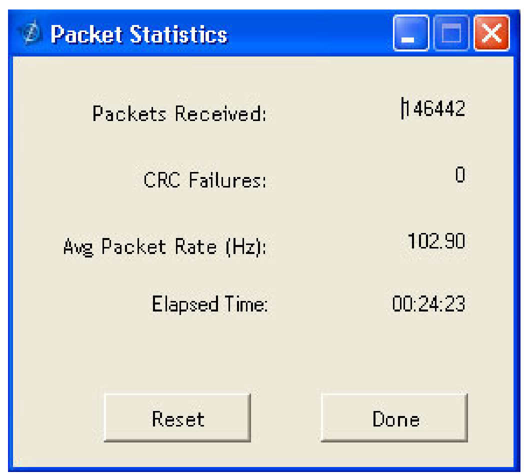


Packet Statistics View

To view packet statistics, click **View** at the menu bar and then select the **Packet Statistics**.

This view provides a short list of vital statistics (including Packet Rate, CRC Failures, and overall Elapsed Time) that are calculated over a one second window. This tool should be used to gather information regarding the overall health of the user configuration. Incorrectly configured communication settings can result in a large number of CRC failures and poor data transfer.

Figure 13 Packet Statistics



Chapter 7. Configuring the 440 Series with NAV-VIEW 2.2

It is assumed the 440 Series unit and NAV-VIEW 2.2 have been set up. For instructions to do so, refer to *Chapter 5. Installation Guidelines*.

This section provides instructions to configure the unit via NAV-VIEW 2.2, a GUI application. For information about configuring the unit via programming code, refer to *Chapter 10. Programming Guidelines*.

NOTE: It is recommended to read and thoroughly understand the affects of altering the settings in the **Advanced** tab before making changes to the unit configuration. Refer to *Chapter 2. 440 Series Functions.*

- Viewing Current Configurations, page 51.
- Configuring the Unit, page 52

  The configuration tabs:
  - General, page 52
  - Advanced, page53
  - BIT Configuration, page 54
  - Aligning the Magnetometer, page 55

Viewing Current Configurations

NAV-VIEW 2.2 allows viewing the current settings and calibration data. The displayed information can be printed.

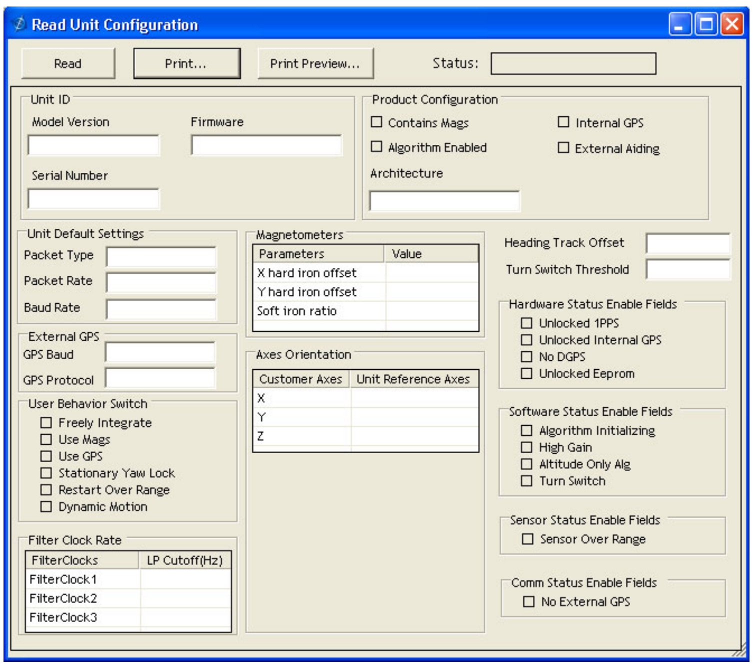
There are two methods to view current configuration.

Method 1:

- At the main screen, select **Unit Configuration** from the menu bar, then select **Print** from the drop menu.

  The dialog window opens (*Figure 14*).

Figure 14 Current Configuration



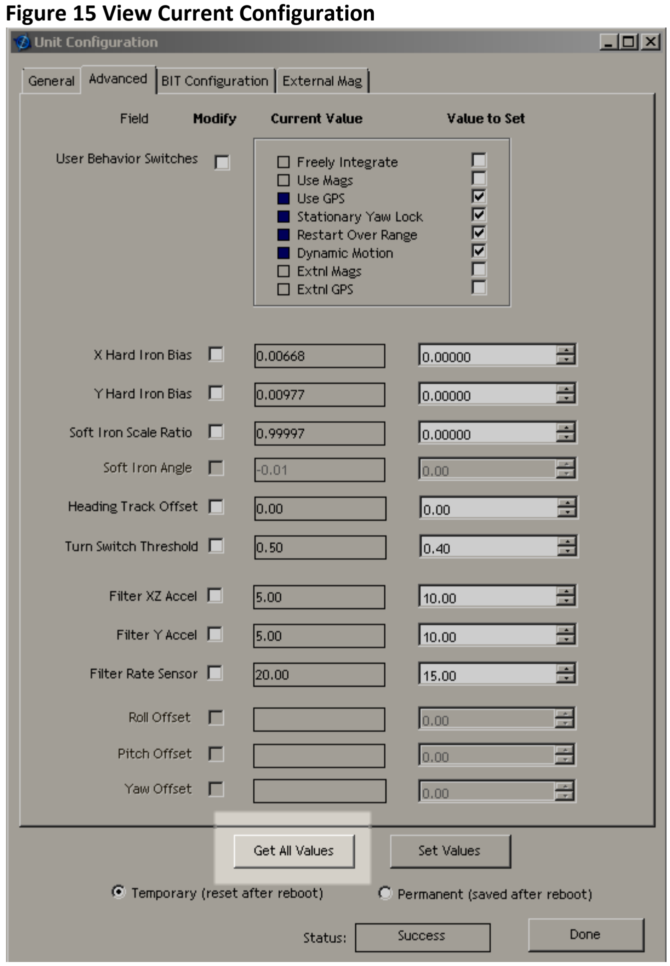
Method 2:

1. At the main screen, select **Unit Configuration** from the menu bar, then select **Configuration** from the drop menu.

   The dialog window opens *(Figure 15*).

2. Click **Get All Values** at the bottom of the screen. The current configuration values will be displayed. This applies to all tabs.

Figure 15 View Current Configuration



Configuring the Unit

The Unit Configuration window enables viewing and configuring the system configurations.

There are five tabs within the **Unit Configuration** menu;

- General, page52
- Advanced, page53
- BIT Configuration, page54

General

The **General** tab provides quick access to the most frequently used configuration features. To view *all* current configurations on one page, refer to *Viewing* Current Configuration on page 51. Additional configuration options are described in the following sections.

Viewing Current Configuration

To view the current configuration, click the **Get All Values** button. The current settings will be displayed in the text fields.

Under **Current Value**, a box filled with blue color indicates the status field is enabled. Refer to *Figure 16.*

Changing Configurations

To change a configuration setting:

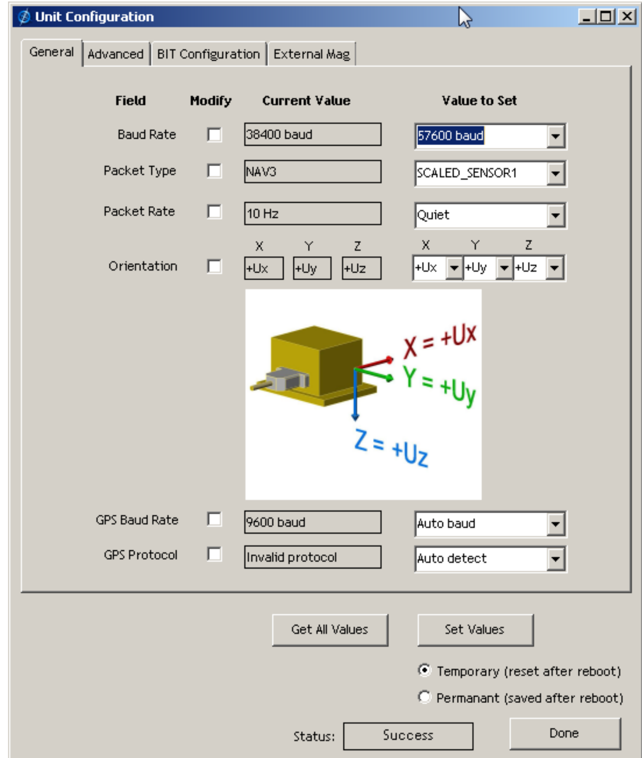
1. Checkmark the desired item(s) in the left Colum
2. Using the drop menus in the right column, select the new values.
3. Select either **Temporary** or **Permanent**.

   Temporary: The configuration will not be stored in non-volatile memory (EEPROM). The configuration will be applied, but the unit will return to the *Permanent* configuration when it is rebooted.

   Permanent: The configuration will be stored in non-volatile memory. The unit will continue to use the configuration after being rebooted.
4. Click the **Set Values** button.

   The configuration values will be saved as specified: *Temporary* or *Permanent*.

Figure 16 Unit Configuration



NOTE: Ensure that the settings selected are compatible with the system that is being configured. In most cases a **FAIL** message will appear if incompatible selections are made.

NOTE: Unit orientation selections must conform to the right hand coordinate system as noted in *440 Series Default Coordinate* System, page 22. Selecting orientations that do not conform to these criteria are not allowed.

Advanced

The **Advanced** tab provides access to more complex configurations, such as user behavior setting.

Viewing Current Configuration

To view the current configuration, click the **Get All Values** button. The current settings will be displayed in the text fields.

Under **Current Value**, a box filled with blue color indicates the status field is enabled. Refer to *Figure 17.*

Changing Configurations

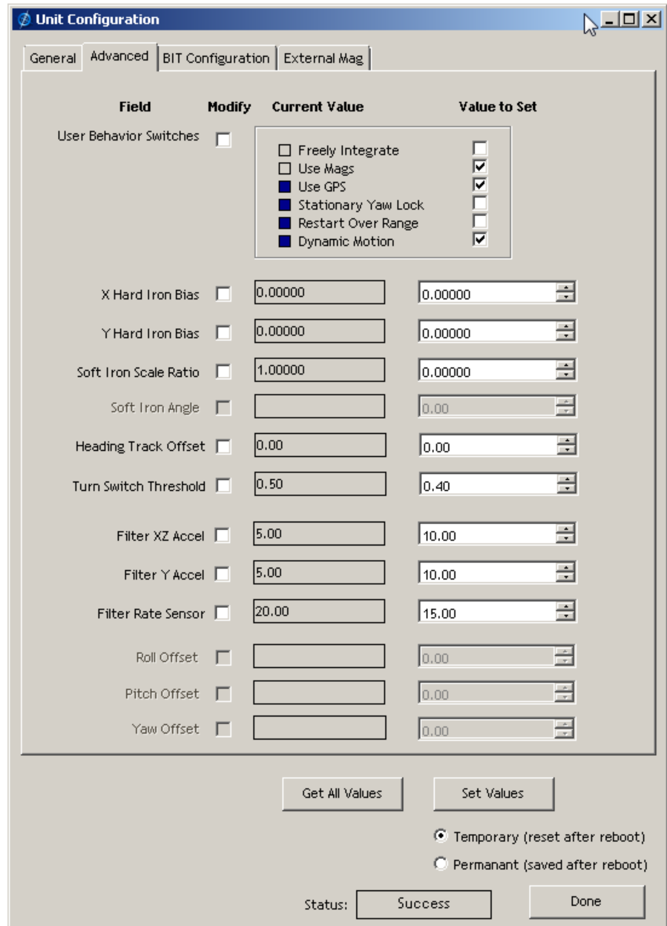
1. To enable a switch
   a. Checkmark the desired item under **Value to Set.**
2. To set a value, under **Value to Set**:
   a. checkmark the box of the desired item(s). The fields of the selected items will *ungrey*.
   b. For each item, checkmark the box under **Modify** and enter the new value under **Value to Set**.
   c. Select either **Temporary** or **Permanent**.

   Temporary: The configuration will not be stored in non-volatile memory (EEPROM). The configuration will be applied, but the unit will return to the *Permanent* configuration when it is rebooted.

   Permanent: The configuration will be stored in non-volatile memory. The unit will continue to use the configuration after being rebooted.
3. Click the **Set Values** button.

   The configuration values will be saved as specified: *Temporary* or *Permanent*.

Figure 17 Advanced Settings



BIT Configuration

BIT Configuration enables configuring the logic of individual status flags that affect the masterStatus flag in the master BIT status field. Enabling individual status flags determines which flags are logically OR'ed to generate the masterStatus flag. This provides the flexibility to listen to the indications that affect specified applications. For more information about BIT status fields, refer to *BIT Status Fields* on page 91.

Viewing Current Configuration

To view the current configuration, click the **Get All Values** button. The current settings will be displayed in the text fields.

Under **Current Value**, a box filled with blue color indicates the status field is enabled. Refer to *Figure 18.*

Changing Configurations

To view the current settings, click the **Get All Values** button.

To modify Status Field(s):

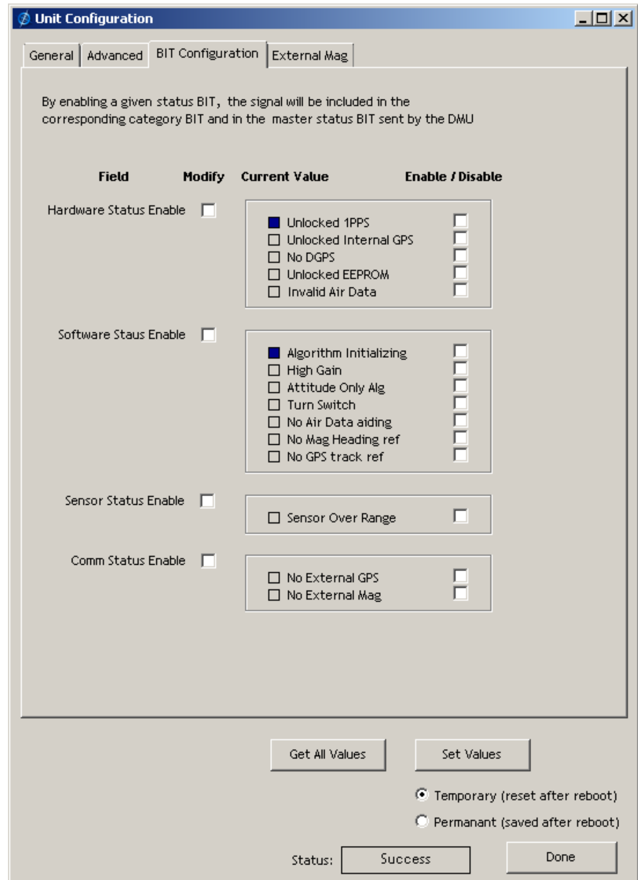
1. Checkmark the desired item(s) under **Modify.**
2. For each Status, check or uncheck the item (status bit) under **Enable/Disable**
3. Select either **Temporary** or **Permanent.**

   Temporary: The configuration will not be stored in non-volatile memory (EEPROM). The configuration will be applied, but the unit will return to the *Permanent* configuration when it is rebooted.

   Permanent: The configuration will be stored in non-volatile memory. The unit will continue to use the configuration after being rebooted.
4. Click the **Set Values** button.

   The configuration values will be saved as specified: *Temporary* or *Permanent.*

Figure 18 BIT Configuration



Aligning the Magnetometer

NOTE: This configuration only applies when using the AHRS or NAV function.

This section provides technical information about aligning the magnetometer as well as the instructions.

- Technical Overview, page 55
- Alignment Instructions, 56

Technical Overview

NOTE: Due to the effects of magnetic fields on navigation, the magnetometer must be aligned with the unit installed in the field system.

If the calibration process is run with the unit by itself, not installed in the field system, there will be no corrections for the magnetism in the field system. Afterwards, when the unit is installed in the system (such as a vehicle) and magnetic fields are present in the system, errors will occur due to the magnetism of the system.

After completing the alignment procedure, the heading accuracy should be verified with all third party systems actively using a known reference such as a compass rose, GPS track or a calibrated compass. Heading inaccuracies greater than the values specified on the data sheet or fluctuating heading performance may indicate magnetic field disturbances near the unit.

NOTE: An acceptable calibration will provide X and Y Hard Iron Offset Values of <0.1 and a Soft Iron Ratio >0.95. If this procedure generates calibration parameters significantly outside of this range, the system will assert the softwareError→dataError→magAlignOutOfBounds error flag. Refer to *Chapter 11. Built In Test (BIT)* for details about error flag handling.

For more information about magnetism, including hard iron and soft iron effects, refer to *Chapter 4. Magnetometer Calibration and Alignment Guidelines* on page 39.

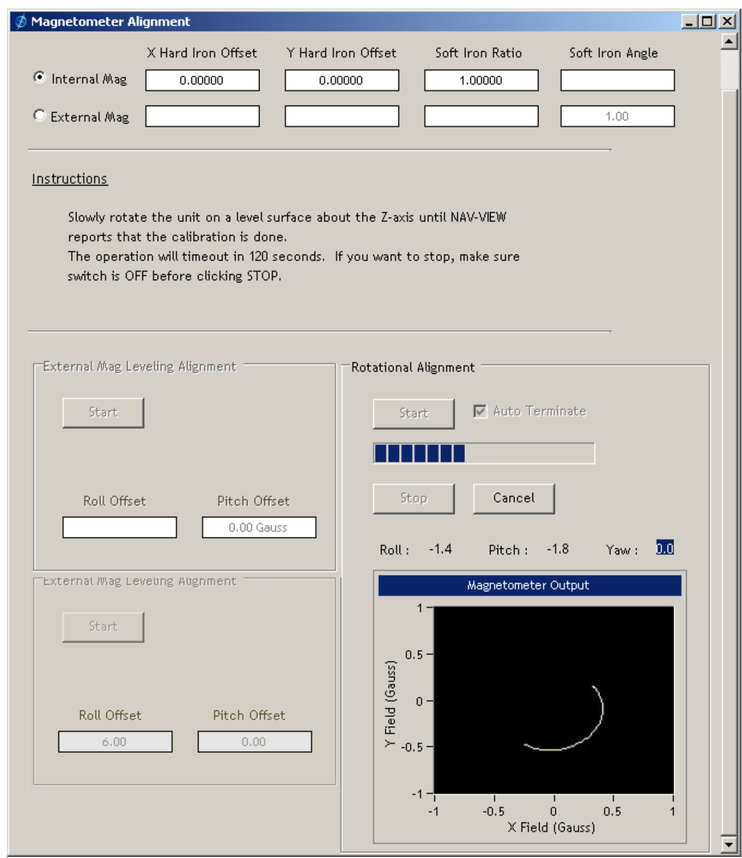
NOTE: The alignment does not correct for time varying fields, or fields created by ferrous material that moves with respect to the unit.

Alignment Instructions

NOTE: The 440 Series does not support external magnetometers; aligning or leveling an external magnetometer does not apply to a 440 Series unit.

1. Click **Configuration** and then select **Magnetometer Alignment** from the drop menu.
2. The *Magnetometer Alignment* dialog window opens. Ensure **Internal Mag** is selected.
3. If the 360 degree turn can be completed within 120 seconds, check **Auto-Terminate**.
4. Select the **Start** button to begin the alignment. Follow the instructions displayed in the screen. Refer to *Figure 19*.
5. Rotate the unit for 380 degrees of rotation or until the message is displayed that alignment is complete.

Figure 19 Magnetometer Alignment Dialog

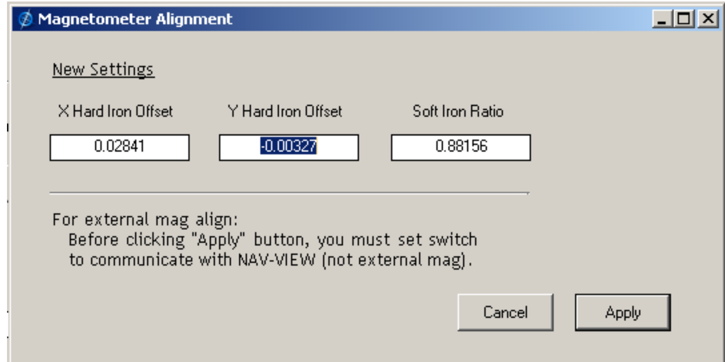


After completing the rotation, data will be displayed with the calibration accuracy. The X and Y offset values indicate how far the magnetic field has been offset due to hard iron affects from components surrounding the unit.

The soft iron ratio will also be displayed, which is the effect of soft iron on the unit.

6. The save the offset values, click the **Apply** button.

Figure 20 Magnetometer Alignment



Chapter 8. Programming Guide

NOTE: This section of the manual assumes that the user is familiar with ANSI C programming language and data type conventions.

The 440 Series support a common packet structure that includes both command or input data packets, and measurement output or response packet formats. This section of the manual explains these packet formats as well as the supported commands. NAV-VIEW 2.2 also features a number of tools to understand the packet types available and the information contained within the packets. For an example of the code required to parse input data packets, refer to *Appendix C. Sample Packet—Parser Code*.

General Settings

The serial port settings are RS232 with 1 start bit, 8 data bits, no parity bit, 1 stop bit, and no flow control. The supported baud rates are 9600, 19200, 38400, and 57600.

Common definitions include:

- A word is defined as two (2) bytes, which consists of 16 bits.
- All communications to and from the unit are packets that start with a single word alternating bit preamble 0x5555. This is the ASCII string "UU".
- All multiple byte values are transmitted Big Endian (Most Significant Byte First).
- All communication packets end with a single word CRC (2 bytes). CRC's are calculated on all packet bytes excluding the preamble and CRC itself. Input packets with incorrect CRC's will be ignored.
- Each complete communication packet must be transmitted to the 440 Series inertial system within a four (4) second period.

Number Formats

Number Format Conventions include:

- 0x as a prefix to hexadecimal values
- Single quotes ('') to delimit ASCII characters
- No prefix or delimiters to specify decimal values

The following table defines number formats:

Table 11 Number Formats

Descriptor	Description	Size (bytes)	Comment	Range
U1	Unsigned Char	1	—	0 to 255
U2	Unsigned Short	2	—	0 to 65535
U4	Unsigned Int	4	—	0 to 2^32-1
I2	Signed Short	2	2's Complement	-2^15 to 2^15-1
I2*	Signed Short	2	Shifted 2's Complement	Shifted to specified range
I4	Signed Int	4	2's Complement	-2^31 to 2^31-1

Descriptor	Description	Size (bytes)	Comment	Range
F4	Floating Point	4	IEEE754 Single Precision	-1*2^127 to 2^127
SN	String	N	ASCII	

Packet Format

All of the Input and Output packets, except the Ping command, conform to the following structure:

0x5555	<2-byte packet type (U2)>	<payload byte-length (U1)>	<variable length payload>	<2-byte CRC (U2)>

The Ping Command does not require a CRC, so a 440 Series unit can be pinged from a terminal emulator. To Ping a 440 Series unit, type the ASCII string 'UUPK'. If properly connected, the 440 Series unit will respond with 'PK'. All other communications with a 440 Series unit require the 2-byte CRC.

NOTE: A 440 Series unit will also respond to a ping command using the full packet formation with payload 0 and correctly calculated CRC. Example: 0x5555504B009ef4.

Packet Header

The packet header is always the bit pattern 0x5555.

Packet Type

The packet type is always two bytes long in unsigned short integer format. Most input and output packet types can be interpreted as a pair of ASCII characters. As a semantic aid consider the following single character acronyms:

Table 12 Character Acronyms

Acronym	Description
P	Packet
F	Fields: Refers to Fields which are settings or data contained in the unit
E	EEPROM Refers to factory data stored in EEPROM
R	Read: Reads default non-volatile fields
G	Get: Gets current volatile fields or settings
W	Write: Writes default non-volatile fields. These fields are stored in non-volatile memory and determine the unit's behavior on power up. Modifying default fields take effect on the next power up and thereafter.
S	Set: Sets current volatile fields or settings. Modifying current fields will take effect immediately by modifying internal RAM and are lost on a power cycle.

Payload Length

The payload length is always a one byte unsigned character with a range of 0-255. The payload length byte is the length (in bytes) of the *<variable length payload>* portion of the packet ONLY, and does not include the CRC.

Payload

The payload is of variable length based on the packet type.

16-Bit CRC-CCITT

Packets end with a 16-bit CRC-CCITT calculated on the entire packet excluding the 0x5555 header and the CRC field itself. A discussion of the 16-bit CRC-CCITT and sample code for implementing the computation of the CRC is included at the end of this document. This 16-bit CRC standard is maintained by the International Telecommunication Union (ITU).

Width: 16 bits

Polynomial: 0x1021

Initial value:0xFFFF

No XOR is performed on the final value.

Refer to *Appendix C.* Sample Packet—Parser Code for sample code that implements the 16-bit CRC algorithm.

Messaging Overview

The following table summarizes the messages available with a 440 Series model. Packet types are assigned mostly using the ASCII mnemonics defined above and are indicated in the summary table below and in the detailed sections for each command. The payload byte-length is often related to other data elements in the packet as defined in the table below. The referenced variables are defined in the following sections.

Output messages are sent from the 440 Series inertial system to the user system as a result of a poll request or a continuous packet output setting. Input messages are sent from the user system to the 440 Series inertial system and will result in an associated Reply Message or NAK message. Reply messages typically have the same *<2-byte packet type (U2)>* as the input message that evoked it but with a different payload.

Table 13 Message Table

ASCII Mnemonic	<2-byte packet type (U2)>	<payload byte-length (U1)>	Description	Type	Available Functions
Link Test					
PK	0x504B	0	Ping Command and Response	Input/Reply Message	ALL
CH	0x4348	N	Echo Command and Response	Input/Reply Message	ALL
Interactive Commands					
GP	0x4750	2	Get Packet Request	Input Message	ALL
AR	0x4152	0	Algorithm Reset	Input/Reply Message	VG,AHRS, NAV

ASCII Mnemonic	<2-byte packet type (U2)>	<payload byte-length (U1)>	Description	Type	Available Functions
SR	0x5352	0	Software Reset	Input/Reply Message	ALL
NAK	0x1515	2	Error Response	Reply Message	ALL
WC	0x5743	2	Calibrate Command and Response	Input/Reply Message	AHRS, NAV
CC	0x4343	8	Calibration Completed	Reply Message	AHRS, NAV
Output Messages: Status and Other, (Polled Only)					
ID	0x4944	5+N	Identification Data	Output Message	ALL
VR	0x5652	5	Version Data	Output Message	ALL
T0	0x5430	28	Test 0 (Detailed BIT and Status)	Output Message	ALL
Output Messages: Measurement Data (Continuous or Polled)					
S0	0x5330	30	Scaled Sensor 0 Data	Output Message	NAV
S1	0x5331	24	Scaled Sensor 1 Data	Output Message	ALL
S2	0x5332	28	Scaled Sensor 2 Data	Output Message	ALL
A0	0x4130	30	Angle 0 Data	Output Message	AHRS,NAV
A1	0x4131	32	Angle 1 Data	Output Message	AHRS,NAV
A2	0x4132	30	Angle 2 Data	Output Message	VG, AHRS,NAV
N0	0x4E30	32	Nav 0 Data	Output Message	VG, AHRS, NAV
N1	0x4E31	42	Nav 1 Data	Output Message	VG, AHRS, NAV
B1	0x4231	18	Short Packet Angle B1 Data	Output Message	OEM Only
B2	0x4232	10	Short Packet Angle B2 Data	Output Message	OEM Only
Advanced Commands					
WF	0x5746	numFields*4+1	Write Fields Request	Input Message	ALL
WF	0x5746	numFields*2+1	Write Fields Response	Reply Message	ALL
SF	0x5346	numFields*4+1	Set Fields Request	Input Message	ALL

ASCII Mnemonic	<2-byte packet type (U2)>	<payload byte-length (U1)>	Description	Type	Available Functions
SF	0x5346	numFields*2+1	Set Fields Response	Reply Message	ALL
RF	0x5246	numFields*2+1	Read Fields Request	Input Message	ALL
RF	0x5246	numFields*4+1	Read Fields Response	Reply Message	ALL
GF	0x4746	numFields*2+1	Get Fields Request	Input Message	ALL
GF	0x4746	numFields*4+1	Get Fields Response	Reply Message	ALL

Chapter 9. Communicating with the 440 Series Units

Communication Commands

Communication commands are used to verify a unit is present and alive.

Ping Command

Table 14 Ping Command

Ping (‘PK’ = 0x504B)			
Preamble	***Packet Type***	***Length***	***Termination***
0x5555	0x504B	-	-

The ping command has no payload. Sending the ping command will cause the unit to send a ping response. To facilitate human input from a terminal, the length and CRC fields are not required.

Example: 0x5555504B009ef4 or 0x5555504B

Ping Response

Table 15 Ping Response

Ping (‘PK’ = 0x504B)			
Preamble	***Packet Type***	***Length***	***Termination***
0x5555	0x504B	0x00	<CRC (U2)>

The unit will send this packet in response to a ping command.

Echo Command

Table 16 Echo

Echo (‘CH’ = 0x4348)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4348	N	<echo payload>	<CRC (U2)>

The echo command allows testing and verification of the communication link. The unit will respond with an echo response containing the *echo data*. The *echo data* is N bytes long.

Echo Response

Table 17 Echo Payload

Echo Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	echoData0	U1	—	—	first byte of echo data
1	echoData1	U1	—	—	Second byte of echo data
…	…	U1	—	—	Echo data

Echo Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
N-2	echoData…	U1	—	—	Second to last byte of echo data
N-1	echoData…	U1	—	—	Last byte of echo data

Interactive Commands

Interactive commands are used to interactively request data from the 440 Series unit, and to calibrate or reset the unit.

Get Packet Request

Table 18 Get Packet Request

Get Packet ('GP' = 0x4750)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4750	0x02	<GP payload>	<CRC (U2)>

This command allows the user to poll for both measurement packets and special purpose output packets including *T0*, *VR*, and *ID*.

Table 19 GP Payload

GP Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	requestedPacketType	U2	—	—	The requested packet type

Refer to the sections below for Packet Definitions sent in response to the 'GP' command

Algorithm Reset Command

Table 20 Algorithm Reset Command

Algorithm Reset ('AR' = 0x4152)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4152	0x00	—	<CRC (U2)>

This command resets the state estimation algorithm without reloading fields from EEPROM. All current field values will remain in effect. The unit will respond with an algorithm reset response.

Algorithm Reset Response

Table 21 Algorithm Reset

Algorithm Reset ('AR' = 0x4152)			
Preamble	***Packet Type***	***Length***	***Termination***

Algorithm Reset ('AR' = 0x4152)			
Preamble	***Packet Type***	***Length***	***Termination***
0x5555	0x4152	0x00	<CRC (U2)>

The unit will send this packet in response to an algorithm reset command.

Software Reset Command

Table 22 Software Reset Command

Software Reset ('SR' = 0x5352)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5352	0x00	—	<CRC (U2)>

This command performs a core CPU reset, functionally equivalent to a power cycle. All default power-up field settings will apply. The unit will respond with software reset response before the system goes down.

Software Reset Response

Table 23 Software Reset

Software Reset ('SR' = 0x5352)			
Preamble	***Packet Type***	***Length***	***Termination***
0x5555	0x5352	0x00	<CRC (U2)>

The unit will send this packet in response to a software reset command.

Calibrate Command

Table 24 Calibrate Command

Calibrate ('WC' = 0x5743)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5743	0x02	<WC payload>	<CRC (U2)>

This command allows the user to perform various calibration tasks with the 440 Series unit. See the calibration command table below for details. The unit will respond immediately with a calibrate response containing the *calibrationRequest* received or an error response if the command cannot be performed.

Table 25 WC Payload

WC Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	calibrationRequest	U2	—	—	The requested calibration task

Currently, magnetic alignment is the only function supported by the calibrate command. There are two magnetic alignment procedures supported; (1) magnetic alignment with automatic yaw tracking termination, and magnetic alignment without automatic termination.

Table 26 Calibration Request

calibrationRequest	Description
0x0009	Begin magnetic alignment without automatic termination. Rotate vehicle through >360 degrees yaw and then send 0x000B calibration request for termination.
0x000B	Terminate magnetic alignment. The unit will send a CC response containing the hard-iron and soft-iron values. To accept the parameters, store them using the write magnetic calibration command.
0x000C	Begin magnetic calibration with automatic termination. Rotate the unit through 380 degrees in yaw. The unit will send a CC response containing the hard-iron and soft-iron values upon completion of the turn. To accept the parameters, store them using the write magnetic calibration command.
0x000E	Write magnetic calibration. The unit will write the parameters to EEPROM and then send a calibration response.

Calibrate Acknowledgement Response

Table 27 Calibrate

Calibrate ('WC' = 0x5743)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5743	0x02	<WC payload>	<CRC (U2)>

The unit will send this packet in response to a calibrate request if the procedure can be performed or initiated.

Table 28 WC Payload

WC Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	calibrationRequest	U2	—	—	The requested calibration task

Calibration Completed Parameters Response

Table 29 Calibrate Completed

Calibrate Completed ('CC' = 0x4343)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4343	0x08	<CC payload>	<CRC (U2)>

The unit sends this packet after a calibration has been completed. Currently, there is only one message of this type sent after a magnetic calibration has been completed (with or without automatic termination) and the parameters have been calculated. The *calibrationRequest* field will be 0x000B or 0x000C.

Table 30 CC Payload

CC Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	calibrationRequest	U2	—	—	The requested calibration task
2	xHardIron	I2	2/2^16	G	The x hard iron bias
4	yHardIron	I2	2/2^16	G	The y hard iron bias
6	softIronScaleRatio	U2	2/2^16	—	The scaling ratio between the x and y axis

Error Response

Table 31 Error Response

Error Response (ASCII NAK, NAK = 0x1515)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x1515	0x02	<NAK payload>	<CRC (U2)>

The unit will send this packet in place of a normal response to a *failedInputPacketType* request if it could not be completed successfully.

Table 32 NAK Payload

NAK Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	failedInputPacketType	U2	—	—	the failed request

Output Packets (Polled)

The following packet formats are special informational packets which can be requested using the GP command.

Identification Data Packet

Table 33 Identification Data Packet

Identification Data ('ID' = 0x4944)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4944	5+N	<ID payload>	<CRC (U2)>

This packet contains the unit *serialNumber* and *modelString*. The model string is terminated with 0x00. The model string contains the programmed *versionString* (8-bit Ascii values) followed by the firmware part number string delimited by a whitespace.

Table 34 ID Payload

ID Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	serialNumber	U4	—	—	Unit serial number
4	modelString	SN	—	—	Unit Version String
4+N	0x00	U1	—	—	Zero Delimiter

Version Data Packet

Table 35 Version Data Packet

Version Data ('VR' = 0x5652)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5652	5	<VR payload>	<CRC (U2)>

This packet contains firmware version information. *majorVersion* changes may introduce serious incompatibilities. *minorVersion* changes may add or modify functionality, but maintain backward compatibility with previous minor versions. *patch* level changes reflect bug fixes and internal modifications with little effect on the user. The build stage is one of the following: 0=release candidate, 1=development, 2=alpha, 3=beta.

The *buildNumber* is incremented with each engineering firmware build. The *buildNumber* and *stage* for released firmware are both zero. The final beta candidate is v.w.x.3.y, which is changed to v.w.x.0.1 to create the first release candidate. The last release candidate is v.w.x.0.z, which is changed to v.w.x.0.0 for release.

Table 36 VR Payload

VR Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	majorVersion	U1	—	—	Major firmware version
1	minorVersion	U1	—	—	Minor firmware version
2	patch	U1	—	—	Patch level
3	stage	-	—	—	Development Stage (0=release candidate, 1=development, 2=alpha, 3=beta)
4	buildNumber	U1	—	—	Build number

Test 0 (Detailed BIT and Status) Packet

Table 37 Test 0 Packet

Test ('T0' = 0x5430)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
03.3x5555	0x5430	0x1C	<T0 payload>	<CRC (U2)>

This packet contains detailed BIT and status information. Full BIT Status details is described in *Chapter 11. Built In Test (BIT).*

Table 38 T0 Payload

T0 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	BITstatus	U2	—	—	Master BIT and Status Field
2	hardwareBIT	U2	—	—	Hardware BIT Field
4	hardwarePowerBIT	U2	—	—	Hardware Power BIT Field
6	hardwareEnvironmentalBIT	U2	—	—	Hardware Environmental BIT Field
8	comBIT	U2	—	—	communication BIT Field
10	comSerialABIT	U2	—	—	Communication Serial A BIT Field
12	comSerialBBIT	U2	—	—	Communication Serial B BIT Field
14	softwareBIT	U2	—	—	Software BIT Field
16	softwareAlgorithmBIT	U2	—	—	Software Algorithm BIT Field
18	softwareDataBIT	U2	—	—	Software Data BIT Field
20	hardwareStatus	U2	—	—	Hardware Status Field
22	comStatus	U2	—	—	Communication Status Field
24	softwareStatus	U2	—	—	Software Status Field
26	sensorStatus	U2	—	—	Sensor Status Field

Output Packets (Polled or Continuous)

Scaled Sensor Data Packet 0

Table 39 Scaled Sensor Data Packet 0

Scaled Sensor Data ('S0' = 0x5330)

Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5330	0x1E	<S0 payload>	<CRC (U2)>

This packet contains scaled sensor data. The scaled sensor data is fixed point, 2 bytes per sensor, MSB first, for 13 sensors in the following order: accels(x,y,z); gyros(x,y,z); mags(x,y,z); temps(x,y,z,board). Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10) g
- Magnetometers: scaled to a range of (-1,+1) Gauss
- Temperature: scaled to a range of (-100, +100)°C

Table 40 S0 Payload

S0 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	xAccel	I2	20/2^16	g	X accelerometer
2	yAccel	I2	20/2^16	g	Y accelerometer
4	zAccel	I2	20/2^16	g	Z accelerometer
6	xRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate
8	yRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate
10	zRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate
12	xMag	I2	2/2^16	Gauss	X magnetometer
14	yMag	I2	2/2^16	Gauss	Y magnetometer
16	zMag	I2	2/2^16	Gauss	Z magnetometer
18	xRateTemp	I2	200/2^16	deg. C	X rate temperature
20	yRateTemp	I2	200/2^16	deg. C	Y rate temperature
22	zRateTemp	I2	200/2^16	deg. C	Z rate temperature
24	boardTemp	I2	200/2^16	deg. C	CPU board temperature
26	GPSITOW	U2	truncated	ms	GPS ITOW (lower 2 bytes)
28	BITstatus	U2	—	—	Master BIT and Status

Scaled Sensor Data Packet 1 (Default IMU Data)

Table 41 Scaled Sensor Data Packet 1

Scaled Sensor Data ('S1' = 0x5331)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***

Scaled Sensor Data ('S1' = 0x5331)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5331	0x18	<S1 payload>	<CRC (U2)>

This packet contains scaled sensor data. Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10)g
- Temperature: scaled to a range of (-100, +100)°C

Table 42 S1 Payload

S1 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	xAccel	I2	20/2^16	g	X accelerometer
2	yAccel	I2	20/2^16	g	Y accelerometer
4	zAccel	I2	20/2^16	g	Z accelerometer
6	xRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate
8	yRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate
10	zRate	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate
12	xRateTemp	I2	200/2^16	deg. C	X rate temperature
14	yRateTemp	I2	200/2^16	deg. C	Y rate temperature
16	zRateTemp	I2	200/2^16	deg. C	Z rate temperature
18	boardTemp	I2	200/2^16	deg. C	CPU board temperature
20	Counter	U2	—	packets	Output packet counter
22	BITstatus	U2	—	—	Master BIT and Status

Scaled Sensor Data Packet 2 (Delta-Theta, Delta-V)

Table 43 Scaled Sensor Data Packet 2

Scaled Sensor Data ('S2' = 0x5332)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5332	0x1C	<S2 payload>	<CRC (U2)>

This packet contains scaled sensor data in the traditional delta-theta and delta-velocity format with integration time equivalent to the packet rate. Changes in body axis angles and velocities are accumulated during the interval between successive packets as determined by the packet rate. Polled requests for this packet will produce values accumulated since the last poll request, and thus, are subject to overflow (data type wrap around).

- Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.
- Delta Angle: scaled to range of 3.5* (-pi, +pi) Δ radians or (-630, +630) Δ degrees.
- Delta Velocity: scaled to a range of (-100, +100) Δ m/s.

Table 44 S2 Payload

S2 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	xDeltaVel	I4	200/2^32	Δ m/s	X delta velocity
4	yDeltaVel	I4	200/2^32	Δ m/s	Y delta velocity
8	zDeltaVel	I4	200/2^32	Δ m/s	Z delta velocity
12	xDeltaAngle	I4	7*pi/2^32 (1260°/2^32)	Δ rad (Δ °)	X delta angle
16	yDeltaAngle	I4	7*pi/2^32 (1260°/2^32)	Δ rad (Δ °)	Y delta angle
20	zDeltaAngle	I4	7*pi/2^32 (1260°/2^32)	Δ rad (Δ °)	Z delta angle
24	Counter	U2	—	packets	Output packet counter
26	BITstatus	U2	—	—	Master BIT and Status

Angle Data Packet 0

Table 45 Angle Data Packet

Angle Data ('A0' = 0x4130)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4130	0x1E	<A0 payload>	<CRC (U2)>

This packet contains angle data and selected sensor data scaled in most cases to a signed 2^16 2's complement number. Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angles: scaled to a range of (-pi, +pi) or (-180 deg to +180 deg).
- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10)g
- Magnetometers: scaled to a range of (-1,+1) Gauss
- Temperature: scaled to a range of (-100, +100) °C

Table 46 A0 Payload

A0 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleMag	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (magnetic north)
6	xRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular RateCorrected
8	yRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular RateCorrected
10	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular RateCorrected
12	xAccelCorrected	I2	20/2^16	g	X AccelCorrected
14	yAccelCorrected	I2	20/2^16	g	Y AccelCorrected
16	zAccelCorrected	I2	20/2^16	g	Z AccelCorrected
18	xMag	I2	2/2^16	Gauss	X magnetometer
20	yMag	I2	2/2^16	Gauss	Y magnetometer
22	zMag	I2	2/2^16	Gauss	Z magnetometer
24	xRateTemp	I2	200/2^16	deg C	X rate temperature
26	GPSITOW	U2	truncated	ms	GPS ITOW (lower 2 bytes)
28	BITstatus	U2	—	—	Master BIT and Status

Angle Data Packet 1 (Default AHRS Data)

Table 47 Angle Data Packet 1

Angle Data ('A1' = 0x4131)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4131	0x20	<A1 payload>	<CRC (U2)>

This packet contains angle data and selected sensor data scaled in most cases to a signed 2^16 2's complement number. Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angles: scaled to a range of (-pi, +pi) or (-180 deg to +180 deg).
- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10) g
- Magnetometers: scaled to a range of (-1,+1) Gauss

- Temperature: scaled to a range of (-100, +100) °C

Table 48 A1 Payload

A1 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleMag	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (magnetic north)
6	xRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate Corrected
8	yRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate Corrected
10	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate Corrected
12	xAccel	I2	20/2^16	g	X accelerometer
14	yAccel	I2	20/2^16	g	Y accelerometer
16	zAccel	I2	20/2^16	g	Z accelerometer
18	xMag	I2	2/2^16	Gauss	X magnetometer
20	yMag	I2	2/2^16	Gauss	Y magnetometer
22	zMag	I2	2/2^16	Gauss	Z magnetometer
24	xRateTemp	I2	200/2^16	Deg C	X rate temperature
26	timeITOW	U4	1	ms	DMU ITOW (sync to GPS)
30	BITstatus	U2	—	—	Master BIT and Status

Angle Data Packet 2 (Default VG Data)

Table 49 Angle Data Packet 2

Angle Data ('A2' = 0x4132)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4132	0x1E	<A2 payload>	<CRC (U2)>

This packet contains angle data and selected sensor data scaled in most cases to a signed 2^16 2's complement number. Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angles: scaled to a range of (-pi, +pi) or (-180 deg to +180 deg).
- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10) g
- Magnetometers: scaled to a range of (-1,+1) Gauss
- Temperature: scaled to a range of (-100, +100) °C

Table 50 A2 Payload

A2 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleTrue	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (free)
6	xRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate corrected
8	yRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate Corrected
10	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate Corrected
12	xAccel	I2	20/2^16	g	X accelerometer
14	yAccel	I2	20/2^16	g	Y accelerometer
16	zAccel	I2	20/2^16	g	Z accelerometer
18	x RateTemp	I2	2/2^16	deg. C	X rate temperature
20	y RateTemp	I2	2/2^16	deg. C	Y rate temperature
22	z RateTemp	I2	2/2^16	deg. C	Z rate temperature
24	timeITOW	U4	1	ms	DMU ITOW (sync to GPS)
28	BITstatus	U2	—	—	Master BIT and Status

Nav Data Packet 0

Nav Data (‘N0’ = 0x4E30)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4E30	0x20	<N0 payload>	<CRC (U2)>

This packet contains navigation data and selected sensor data scaled in most cases to a signed 2^16 2’s complement number. Data involving angular measurements include the factor pi in the scaling and can be interpreted in either radians or degrees.

- Angles: scaled to a range of (-pi, +pi) or (-180 deg to +180 deg).
- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10) g
- Temperature: scaled to a range of (-100, +100) °C
- Velocities are scaled to a range of (-256,256) m/s
- Altitude is scaled to a range of (-100, 16284) m using a shifted 2's complement representation.
- Longitude and latitude are scaled to a range of (-pi, pi) or (-180 deg to +180 deg).

Table 51 N0 Payload

N0 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleTrue	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (true north)
6	xRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate corrected
8	yRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate corrected
10	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate corrected
12	nVel	I2	512/2^16	m/s	North velocity
14	eVel	I2	512/2^16	m/s	East velocity
16	dVel	I2	512/2^16	m/s	Down velocity
18	longitudeGPS	I4	2*pi/2^32 (360°/2^32)	Radians (°)	GPS Longitude
22	latitudeGPS	I4	2*pi/2^32 (360°/2^32)	Radians (°)	GPS Latitude
26	altitudeGPS	I2*	2^14/2^16	m	GPS altitude (-100,16284)
28	GPSITOW	U2	truncated	ms	GPS ITOW (lower 2 bytes)
30	BITstatus	U2	—	—	Master BIT and Status

Nav Data Packet 1 (Default NAV)

Table 52 Nav Data Packet 1

Nav Data ('N1' = 0x4E31)

Preamble	Packet Type	Length	Payload	Termination
0x5555	0x4E31	0x2A	<N1 payload>	<CRC (U2)>

This packet contains navigation data and selected sensor data scaled in most cases to a signed 2^16 2's complement number. Data involving angular measurements include the factor **pi** in the scaling and can be interpreted in either radians or degrees.

- Angles: scaled to a range of (-pi, +pi) or (-180 deg to +180 deg).
- Angular rates: scaled to range of 3.5* (-pi,+pi) or (-630 deg/sec to +630 deg/sec)
- Accelerometers: scaled to a range of (-10,+10) g
- Temperature: scaled to a range of (-100, +100) °C
- Velocities are scaled to a range of (-256,256) m/s
- Altitude is scaled to a range of (-100, 16284) m using a shifted 2's complement representation.
- Longitude and latitude are scaled to a range of (-pi, pi) or (-180 deg to +180 deg).

Table 53 N1 Payload

N1 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleTrue	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (true north)
6	xRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	X angular rate corrected
8	yRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Y angular rate corrected
10	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate corrected
12	xAccel	I2	20/2^16	g	X accelerometer
14	yAccel	I2	20/2^16	g	Y accelerometer
16	zAccel	I2	20/2^16	g	Z accelerometer
18	nVel	I2	512/2^16	m/s	North velocity
20	eVel	I2	512/2^16	m/s	East velocity
22	dVel	I2	512/2^16	m/s	Down velocity
24	longitudeGPS	I4	2*pi/2^32 (360°/2^32)	Radians (°)	GPS Longitude

N1 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
28	latitudeGPS	I4	2*pi/2^32 (360°/2^32)	Radians (°)	GPS Latitude
32	altitudeGPS	I2*	2^14/2^16	m	GPS altitude (-100,16284)
34	xRateTemp	I2	200/2^16	deg C	X rate sensor temperature
36	timeITOW	U4	1	ms	DMU ITOW (sync to GPS)
40	BITstatus	U2	—	—	Master BIT and Status

Angle Data Packet B1 (Custom VG Data)

Table 54 Angle Data Packet B1

Angle Data (‘B1’ = 0x4231)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4231	0x12	<B1 payload>	<CRC (U2)>

This packet contains selected angle and sensor data.

Table 55 B1 Payload

B1 Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	yawAngleTrue	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Yaw angle (free)
6	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate corrected
8	xAccel	I2	20/2^16	g	X accelerometer
10	yAccel	I2	20/2^16	g	Y accelerometer
12	timeITOW	U4	1	ms	DMU ITOW (sync to GPS)
16	BITstatus	U2	—	—	Master BIT and Status

Angle Data Packet B2 (Custom VG Data)

Table 56 Angle Data Packet B2

Angle Data (‘B2’ = 0x4232)

Preamble	Packet Type	Length	Payload	Termination
0x5555	0x4232	0x0A	<B2 payload>	<CRC (U2)>

This packet contains selected angle and sensor data.

Table 57 B2 Payload

B2 Payload Contents					
Byte Offset	*Name*	*Format*	*Scaling*	*Units*	*Description*
0	rollAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Roll angle
2	pitchAngle	I2	2*pi/2^16 (360°/2^16)	Radians (°)	Pitch angle
4	zRateCorrected	I2	7*pi/2^16 (1260°/2^16)	rad/s (°/sec)	Z angular rate corrected
6	xAccel	I2	20/2^16	g	X accelerometer
8	timeITOWtruncated	U2	1	ms	DMU ITOW (sync to GPS) truncated to two bytes

Chapter 10. Programming Guidelines

The advanced commands allow users to programmatically change the 440 Series unit settings. This section of the manual documents all of the settings and options contained under the Unit Configuration tab within NAV-VIEW 2.2. Using these advanced commands, the settings of a unit can be modified without NAV-VIEW 2.2.

Configuration Fields

Configuration fields determine various behaviors of the unit that can be modified by the user. These include settings like baud rate, packet output rate and type, algorithm type, etc. These fields are stored in EEPROM and loaded on power up. These fields can be read from the EEPROM using the *RF* command. These fields can be written to the EEPROM affecting the default power up behavior using the *WF* command.

The current value of these fields (which may be different from the value stored in the EEPROM) can also be accessed using the *GF* command. All of these fields can also be modified immediately for the duration of the current power cycle using the *SF* command. The unit will always power up in the configuration stored in the EEPROM. Configuration fields can only be set or written with valid data from Table 58below.

Table 58 Configuration Fields

Index	Configuration fields	Field ID	Valid Values	Description
1	packet rate divider	0x0001	0,1,2,4,5,10, 20, 25, 50	quiet, 100Hz, 50Hz, 25Hz, 20Hz, 10Hz, 5Hz, 4Hz, 2Hz
2	Serial Port A BAUD rate	0x0002	0,1,2,3	9600, 19200, 38400, 57600

Index	Configuration fields	Field ID	Valid Values	Description
3	Continuous packet type	0x0003	Any output packet type	Not all output packets available for all unit functions. See detailed field descriptions below.
4	Reserved	0x0004		N.A.
5	Reserved	0x0005		N.A.
6	Reserved	0x0006		N.A.
7	Orientation	0x0007	See below	Determine forward, rightward, and downward facing sides
8	User Behavior Switches	0x0008	Any	Free Integrate, Use Mags, Use GPS, etc.
9	X Hard Iron Bias	0x0009	Any	I2 scaled from (-1,1)
10	Y Hard Iron Bias	0x000A	Any	I2 scaled from (-1,1)
11	Soft Iron Scale Ratio	0x000B	Any	U2 scaled from (0,2)
12	Heading Track Offset	0x000C	Any	Heading-Track Offset to use in NAV filter track update mode.

NOTE: BAUD rate SF has immediate effect. Some output data may be lost. Response will be received at new BAUD rate.

NOTE: Only configuration fields 1, 2, 3, 7, 8, 13, 16, 17, 18, 19, 22, 25, 26, 27, and 34 are applicable for “architectures 4 and 5.”

Continuous Packet Type Field

This is the packet type that is being continually output. The supported packet depends on the model number. Please refer to *Output Packets (Polled or Continuous)* on page 71 for a complete list of the available packet types.

Analog Filter Clocks 1,2,3

These three fields set hardware low pass filter cutoff frequencies. Each sensor listed is defined in the default factory orientation. Users must consider any additional rotation to their intended orientation.

Table 59 Filter Clocks

Filter Clock	Sensor
analogFilterClock1	Ux, Uz Accel
analogFilterClock2	Uy Accel
analogFilterClock3	Ux, Uy, Uz rate

Orientation Field

This field defines the rotation from the factory to user axis sets. This rotation is relative to the default factory orientation (connector aft, base plate down). The default factory axis set is (Ux, Uy, Uz) defined by the connector pointing in the –Ux direction and the base plate pointing in the +Uz direction. The user axis set is (X, Y, Z) as defined by this field. An example of the factory axis set is shown below:

Figure 21 Orientation Fields

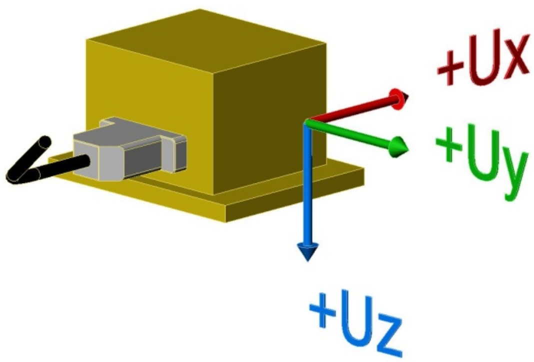


Table 60 Orientation Fields

Axis	Bits	Values
X Axis Sign	0	0 = positive, 1 = negative
X Axis	1:2	0 = Ux, 1 = Uy, 2 = Uz, 3 = N/A
Y Axis Sign	3	0 = positive, 1 = negative
Y Axis	4:5	0 = Uy, 1 = Uz, 2 = Ux, 3 = N/A
Z Axis Sign	6	0 = positive, 1 = negative
Z Axis	7:8	0 = Uz, 1 = Ux, 2 = Uy, 3 = N/A
Reserved	9:15	N/A

There are 24 possible orientation configurations. Setting/Writing the field to anything else generates a NAK and has no effect.

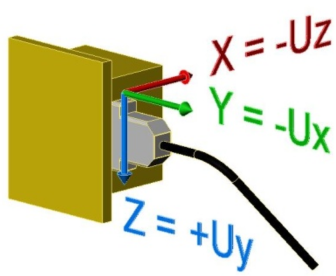
Table 61 Orientation Field Values

Orientation Field Value	X Axis	Y Axis	Z Axis
0x0000	+Ux	+Uy	+Uz
0x0009	-Ux	-Uy	+Uz
0x0023	-Uy	+Ux	+Uz
0x002A	+Uy	-Ux	+Uz
0x0041	-Ux	+Uy	-Uz
0x0048	+Ux	-Uy	-Uz
0x0062	+Uy	+Ux	-Uz

Orientation Field Value	X Axis	Y Axis	Z Axis
0x006B	-Uy	-Ux	-Uz
0x0085	-Uz	+Uy	+Ux
0x008C	+Uz	-Uy	+Ux
0x0092	+Uy	+Uz	+Ux
0x009B	-Uy	-Uz	+Ux
0x00C4	+Uz	+Uy	-Ux
0x00CD	-Uz	-Uy	-Ux
0x00D3	-Uy	+Uz	-Ux
0x00DA	+Uy	-Uz	-Ux
0x0111	-Ux	+Uz	+Uy
0x0118	+Ux	-Uz	+Uy
0x0124	+Uz	+Ux	+Uy
0x012D	-Uz	-Ux	+Uy
0x0150	+Ux	+Uz	-Uy
0x0159	-Ux	-Uz	-Uy
0x0165	-Uz	+Ux	-Uy
0x016C	+Uz	-Ux	-Uy

An example of orientation field value 0x12D is shown in the figure below.

Figure 22 Orientation Fields



User Behavior Switches

This field allows on the fly user interaction with aspects of the algorithm.

Table 62 Behavior Aspects

Algorithm Aspect	Bits	Values
Free Integrate	0	0: use feedback to stabilize the algorithm 1: 6DOF inertial integration without stabilized feedback
Use Mags	1	0: Do not use mags to stabilize heading (heading will run open loop or be stabilized by GPS track) 1: Use mags to stabilize heading
Use GPS	2	0: Do not use GPS to stabilize the system, 1: Use GPS when available
Stationary Yaw Lock	3	0: Do not lock yaw when GPS speed is near zero (<0.75 m/s) 1: Lock yaw when GPS speed is near zero
Restart on Over-range	4	0: Do not restart the system after a sensor over-range, 1: restart the system after a sensor over-range
Dynamic Motion	5	0: vehicle is static, force high gain corrections 1: vehicle is dynamic, use nominal corrections
Reserved	6:15	N/A

Hard and Soft Iron Values

These fields allow access to hard iron bias and soft iron scale ratio values for magnetometer alignment. The calibration values for the internal magnetometer:

Table 63 Internal Magnetometer Calibration Values

Field Name	Field ID	Format	Scaling	Units
X Hard Iron Bias	0x0009	I2	2/2^16	Gauss
Y Hard Iron Bias	0x000A	I2	2/2^16	Gauss
Soft Iron Scale Ratio	0x000B	U2	2/2^16	-
Soft Iron Angle	0x000E	I2	2*pi/2^16	Radians

The hard iron bias values are scaled from (-1, 1) Gauss. These values are subtracted from the tangent plane magnetometer vector before heading is calculated. The soft iron scale ratio is scaled from (0, 2) and is multiplied by the tangent plane x magnetometer value before heading is calculated.

Heading Track Offset

This field is used to set the offset between vehicle heading and vehicle track to be used by the navigation mode filter when no magnetometer heading measurements are available.

Table 64 Heading Track Offset

Field Name	Field ID	Format	Scaling	Units
Heading Track Offset	0x000C	I2	2*pi/2^16 (360°/2^16)	Radians (heading-track)(°)

Commands to Program Configuration

Write Fields Command

Table 65 Write Fields

Write Fields ('WF' = 0x5746)				
Preamble	Packet Type	Length	Payload	Termination
0x5555	0x5746	1+numFields*4	<WF payload>	<CRC (U2)>

This command allows the user to write default power-up configuration fields to the EEPROM. Writing the default configuration will not take effect until the unit is power cycled. *NumFields* is the number of words to be written. The *field0, field1, etc.* are the field IDs that will be written with the *field0Data, field1Data, etc.*, respectively. The unit will not write to calibration or algorithm fields.

- If at least one field is successfully written, the unit will respond with a write field response containing the field IDs of the successfully written fields.
- If any field is unable to be written, the unit will respond with an error response.

Both write fields and an error response may be received as a result of a write fields command. Attempts to write a field with an invalid value is one way to generate an error response. To view a table of field IDs and valid field values, refer to *Configuration Fields* on page 81.

Table 66 Write Fields Contents

WF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields to write
1	field0	U2	—	—	The first field ID to write
3	field0Data	U2	—	—	The first field ID's data to write
5	field1	U2	—	—	The second field ID to write
7	field1Data	U2	—	—	The second field ID's data
…	…	U2	—	—	…
numFields*4 -3	field…	U2	—	—	The last field ID to write
numFields*4 -1	field…Data	U2	—	—	The last field ID's data to write

Write Fields Response

Table 67 Write Fields Response

Write Fields ('WF' = 0x5746)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5746	1+numFields*2	<WF payload>	<CRC (U2)>

The unit will send this packet in response to a write fields command if the command has completed without errors.

Table 68 Write Payload Contents

WF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields written
1	field0	U2	—	—	The first field ID written
3	field1	U2	—	—	The second field ID written
...	...	U2	—	—	More field IDs written
numFields*2 – 1	Field...	U2	—	—	The last field ID written

Set Fields Command

Table 69 Set Fields

Set Fields ('SF' = 0x5346)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5346	1+numFields*4	<SF payload>	<CRC (U2)>

This command allows the user to set the unit's current configuration (SF) fields immediately which will then be lost on power down. *NumFields* is the number of words to be set. The *field0, field1, etc.* are the field IDs that will be written with the *field0Data, field1Data, etc.*, respectively. This command can be used to set configuration fields. The unit will not set calibration or algorithm fields. If at least one field is successfully set, the unit will respond with a set fields response containing the field IDs of the successfully set fields. If any field is unable to be set, the unit will respond with an error response.

Both a set fields and an error response may be received as a result of one set fields command. Setting a field with an invalid value will generate an error response. To view a table of field IDs and valid field values, refer to *Configuration Fields* on page 81.

Table 70 Set Fields Payload Contents

SF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields to set

SF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
1	field0	U2	—	—	The first field ID to set
3	field0Data	U2	—	—	The first field ID's data to set
5	field1	U2	—	—	The second field ID to set
7	field1Data	U2	—	—	The second field ID's data to set
…	…	U2	—	—	…
numFields*4 -3	field…	U2	—	—	The last field ID to set
numFields*4 -1	field…Data	U2	—	—	The last field ID's data to set

Write Fields Response

Table 71 Write Fields

Write Fields ('WF' = 0x5746)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5746	1+numFields*2	<WF payload>	<CRC (U2)>

The unit will send this packet in response to a write fields command if the command has completed without errors.

Table 72 Write Fields Payload Contents

WF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields written
1	field0	U2	—	—	The first field ID written
3	field1	U2	—	—	The second field ID written
…	…	U2	—	—	More field IDs written
numFields*2 – 1	Field…	U2	—	—	The last field ID written

Read Fields Command

Table 73 Read Fields

Read Fields ('RF' = 0x5246)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5246	1+numFields*2	<RF payload>	<CRC (U2)>

This command allows the user to read the default power-up configuration fields from the EEPROM. *NumFields* is the number of fields to read. The *field0, field1, etc.* are the field IDs to read. RF may be used to read configuration and calibration fields from the EEPROM. If at least one field is successfully read, the unit will respond with a read fields response containing the field IDs and data from the successfully read fields.

If any field is unable to be read, the unit will respond with an error response. Note that both a read fields and an error response may be received as a result of a read fields command.

Table 74 Read Fields Contents

RF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields to read
1	field0	U2	—	—	The first field ID to read
3	field1	U2	—	—	The second field ID to read
...	...	U2	—	—	More field IDs to read
numFields*2 - 1	Field...	U2	—	—	The last field ID to read

Read Fields Response

Table 75 Read Fields Response

Read Fields ('RF' = 0x5246)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x5246	1+numFields*4	<RF payload>	<CRC (U2)>

The unit will send this packet in response to a read fields request if the command has completed without errors.

Table 76 Read Fields Payload Contents

RF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields read
1	field0	U2	—	—	The first field ID read
3	field0Data	U2	—	—	The first field ID's data read
5	field1	U2	—	—	The second field ID read
7	field1Data	U2	—	—	The second field ID's data read
...	...	U2	—	—	...
numFields*4 -3	field...	U2	—	—	The last field ID read
numFields*4 -1	field...Data	U2	—	—	The last field ID's data read

Get Fields Command

Table 77 Get Fields

Get Fields ('GF' = 0x4746)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4746	1+numFields*2	<GF Data>	<CRC (U2)>

This command allows the user to get the unit's current configuration fields. *NumFields* is the number of fields to get. The *field0, field1, etc.* are the field IDs to get. GF may be used to get configuration, calibration, and algorithm fields from RAM. Multiple algorithm fields will not necessarily be from the same algorithm iteration. If at least one field is successfully collected, the unit will respond with a get fields response with data containing the field IDs of the successfully received fields.

If any field is unable to be received, the unit will respond with an error response. Note that both a get fields and an error response may be received as the result of a get fields command.

Table 78 Get Fields Payload Contents

GF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields to get
1	field0	U2	—	—	The first field ID to get
3	field1	U2	—	—	The second field ID to get
…	…	U2	—	—	More field IDs to get
numFields*2 – 1	Field…	U2	—	—	The last field ID to get

Get Fields Response

Table 79 Get Fields Response

Get Fields ('GF' = 0x4746)				
Preamble	***Packet Type***	***Length***	***Payload***	***Termination***
0x5555	0x4746	1+numFields*4	<GF Data>	<CRC (U2)>

The unit will send this packet in response to a get fields request if the command has completed without errors.

Table 80 Get Fields Payload Contents

GF Payload Contents					
Byte Offset	***Name***	***Format***	***Scaling***	***Units***	***Description***
0	numFields	U1	—	—	The number of fields retrieved
1	field0	U2	—	—	The first field ID retrieved
3	field0Data	U2	—	—	The first field ID's data retrieved
5	field1	U2	—	—	The second field ID retrieved
7	field1Data	U2	—	—	The second field ID's data
…	…	U2	—	—	…
numFields*4 -3	field…	U2	—	—	The last field ID retrieved
numFields*4 -1	field…Data	U2	—	—	The last field ID's data retrieved

Chapter 11. Built In Test (BIT)

The Built-In Test capability allows users to monitor health, diagnostic, and system status information of the unit in real-time. Built-In Test information is transmitted in each measurement packet.

NOTE: A diagnostic test packet (`T0`) can be requested via `GP`. To contains a complete set of status for each hardware and software subsystem. For more information, refer to *Chapter 10. Programming Guidelines*, *Test 0 (Detailed BIT and Status) Packet* on page 71 and *Get Packet Request* on page 66.

BIT Status Fields

A BIT word consists of two bytes: *Error byte* and *Status byte*.

The first byte (bits 0–7) is the *Errorbyte*: signaled results from internal checks. Four intermediate signals determine when to assert masterFail and the hardware BIT signal. These signals are controlled by three categories of systems checks: hardware (*hardwareError*), communication (*comError*) and software (*softwareError*). Instantaneous soft failures from any category triggers the signals: a flag is raised. masterFail is not triggered unless persistency conditions are met or a hard failure has occurred.

The second byte (bits 8–15) is the *Statusbyte*: signaled status alerts. Four intermediate signals determine when to assert the *masterStatus* flag: *hardwareStatus*, *sensorStatus*, *comStatus*, and *softwareStatus*. masterStatus is the logical OR of these intermediate signals. Each intermediate signal has a separate field with an indication flag. Each indication flag can be enabled or disabled by the user. Any enabled indication flag will trigger the associated intermediate signal and *masterStatus* flag.

The BIT fields are summarized in *Table 81* below. *Table 82* provides additional information about the programmable status field.

Table 81 Default BIT Status Values

BITstatus Field	Bits	Value	Configurable
Error Byte fields (BIT)			N
masterFail	0	0: normal 1: fatal error The *masterFail* flag is thrown when either a hard failure (fatal condition) or a soft failure (persistent problem) occurs.	N
hardwareError	1	0: normal 1: internal hardware error	N
comError	2	0: normal 1: communication error	N
softwareError	3	0: normal 1: internal software error	N
Reserved	4:7	N/A	N
Status Byte Fields			
masterStatus	8	0: nominal 1: one or more status alerts occurred: hardware; com; software; sensor	Y

BITstatus Field	Bits	Value	Configurable
hardwareStatus	9	0: nominal 1: programmable alert(refer to *Programmable Status* below)	Y
comStatus	10	0: nominal 1: programmable alert (refer to *Programmable* Status *Fields* below)	Y
softwareStatus	11	0: nominal 1: programmable alert (refer to *Programmable* Status *Fields* below)	Y
sensorStatus	12	0: nominal 1: programmable alert (refer to *ProgrammableStatus Fields* below)	Y
Reserved	13:15	N/A	N

Programmable Status Fields

The BIT status fields can be configured. The 440 Series functions, AHRS, IU, VG and NAV, affect the default value of the hardware, com, software and sensor status bits. The default settings are appropriate for most installations.

NOTE: The settings should not be configured unless determined necessary; incorrect configurations can adversely affect operations.

NOTE: Error fields cannot be configured.

The default values are listed in *Table 82*below.

Table 82 Programmable BIT Status–Default Values per Function

Status Byte Field	Default Values
masterStatus (bit 8)	The *masterStatus* flag is asserted when an enabled alert signal is asserted. For information about configuring this status field, refer to *BIT Configuration* on 54 and *Configuring masterStatus* on page 97.
hardwareStatus (bit 9)	0: normal 1: programmable alert For information about configuring this status field, refer to *Bit Configuration Tab* on page 45, *comStatus Field* on page 96 and *Configuring masterStatus* on page 97.
comStatus (bit 10)	0: normal 1: programmable alert For information about configuring this status field, refer to *Bit Configuration Tab* on page 45, *comStatus Field* on page 96 and *Configuring masterStatus* on page 97.
softwareStatus (bit 11)	0: normal 1: programmable alert For information about configuring this status field, refer to *BIT Configuration*on on page 54 and *softwareStatus Field* on page 97 and *Configuring masterStatus* on page 97.

Status Byte Field	Default Values
sensorStatus (bit 12)	0: normal 1: programmable alert For information about configuring this status field, refer to *BIT Configuration*on page 54 and *sensorStatus Field* on page 97 and *Configuring masterStatus* on page 97.

hardwareBIT Field

The hardwareBIT field contains flags that indicate various internal hardware errors. Each hardware error has an associated message with low level error signals. The hardwareError flag in the BITstatus field is the bit-wise OR of the hardwareBIT field.

Table 83 hardwareBIT Field

hardwareBIT Field	Bits	Values	Category
powerError	0	0 = normal, 1 = error	Soft
environmentalError	1	0 = normal, 1 = error	Soft
reserved	2:15	N/A	

hardwarePowerBIT Field

The hardwarePowerBIT field contains flags that indicate low level power system errors. The powerError flag in the hardwareBIT field is the bit-wise OR of the hardwarePowerBIT field.

Table 84 hardwarePowerBIT Field

hardwarePowerBIT Field	Bit	Values	Category
inpPower	0	0 = normal, 1 = out of bounds	Soft
inpCurrent	1	0 = normal, 1 = out of bounds	Soft
inpVoltage	2	0 = normal, 1 = out of bounds	Soft
fiveVolt	3	0 = normal, 1 = out of bounds	Soft
threeVolt	4	0 = normal, 1 = out of bounds	Soft
twoVolt	5	0 = normal, 1 = out of bounds	Soft
twoFiveRef	6	0 = normal, 1 = out of bounds	Soft
sixVolt	7	0 = normal, 1 = out of bounds	Soft
grdRef	8	0 = normal, 1 = out of bounds	Soft
Reserved	9:15	N/A	N/A

hardwareEnvironmentalBIT Field

The hardwareEnvironmentalBIT field contains flags that indicate low level hardware environmental errors. The environmentalError flag in the hardwareBIT field is the bit-wise OR of the hardwareEnvironmentalBIT field.

Table 85 hardwareEnvironmentalBIT Field

hardwareEnvironmentalBIT Field	Bits	Values	Category
pcbTemp	0	0 = normal, 1 = out of bounds	Soft
Reserved	9:15	N/A	

comBIT Field

The comBIT field contains flags that indicate communication errors with external devices. Each external device has an associated message with low level error signals. The comError flag in the BITstatus field is the bit-wise OR of the comBIT field.

Table 86 comBIT Field

comBIT Field	Bits	Values	Category
serialAError	0	0 = normal, 1 = error	Soft
serialBError	1	0 = normal, 1 = error	Soft
Reserved	2:15	N/A	

comSerialABIT Field

The comSerialABIT field contains flags that indicate low level errors with external serial port A (the user serial port). The serialAError flag in the comBIT field is the bit-wise OR of the comSerialABIT field.

Table 87 comSerialABIT Field

comSerialABIT Field	Bits	Values	Category
transmitBufferOverflow	0	0 = normal, 1 = overflow	Soft
receiveBufferOverflow	1	0 = normal, 1 = overflow	Soft
framingError	2	0 = normal, 1 = error	Soft
breakDetect	3	0 = normal, 1 = error	Soft
parityError	4	0 = normal, 1 = error	Soft
Reserved	5:15	N/A	

comSerialBBIT Field

The comSerialBBIT field contains flags that indicate low level errors with external serial port B (the aiding serial port). The serialBError flag in the comBIT field is the bit-wise OR of the comSerialBBIT field.

Table 88 comSerialBBIT Field

comSerialBBIT Field	Bits	Values	Category
transmitBufferOverflow	0	0 = normal, 1 = overflow	Soft
receiveBufferOverflow	1	0 = normal, 1 = overflow	Soft
framingError	2	0 = normal, 1 = error	Soft
breakDetect	3	0 = normal, 1 = error	Soft
parityError	4	0 = normal, 1 = error	Soft
Reserved	5:15	N/A	

softwareBIT Field

The softwareBIT field contains flags that indicate various types of software errors. Each type has an associated message with low level error signals. The softwareError flag in the BITstatus field is the bit-wise OR of the softwareBIT field.

Table 89 softwareBIT Field

softwareBIT Field	Bits	Values	Category
algorithmError	0	0 = normal, 1 = error	Soft
dataError	1	0 = normal, 1 = error	Soft
Reserved	2:15	N/A	

softwareAlgorithmBIT Field

The softwareAlgorithmBIT field contains flags that indicate low level software algorithm errors. The algorithmError flag in the softwareBIT field is the bit-wise OR of the softwareAlgorithmBIT field.

Table 90 softwareAlgorithmBIT Field

SoftwareAlgorithmBIT Field	Bits	Values	Category
initialization	0	0 = normal, 1 = error during algorithm initialization	Hard
overRange	1	0 = normal, 1 = fatal sensor over-range	Hard
missedNavigationStep	2	0 = normal, 1 = fatal hard deadline missed for navigation	Hard
Reserved	3:15	N/A	

softwareDataBIT Field

The softwareDataBIT field contains flags that indicate low level software data errors. The dataError flag in the softwareBIT field is the bit-wise OR of the softwareDataBIT field.

Table 91 softwareDataBIT Field

SoftwareDataBIT Field	Bits	Values	Category
calibrationCRCError	0	0 = normal, 1 = incorrect CRC on calibration EEPROM data or data has been compromised by a WE command.	Hard
magAlignOutOfBounds	1	0 = normal, 1 = hard and soft iron parameters are out of bounds	Hard
Reserved	2:15	N/A	

hardwareStatus Field

The hardwareStatus field contains flags that indicate various internal hardware conditions and alerts that are not errors or problems. The hardwareStatus flag in the BITstatus field is the bit-wise OR of the logical AND of the hardwareStatus field and the hardwareStatusEnable field. The hardwareStatusEnable field is a bit mask that allows the user to select items of interest that will logically flow up to the masterStatus flag.

Table 92 hardwareStatus Field

hardwareStatus Field	Bits	Values
unlocked1PPS	0	0 = not asserted, 1 = asserted
unlockedInternalGPS	1	0 = not asserted, 1 = asserted
noDGPS	2	0 = DGPS lock, 1 = no DGPS
unlockedEEPROM	3	0=locked, WE disabled, 1=unlocked, WE enabled
Reserved	4:15	N/A

comStatus Field

The comStatus field contains flags that indicate various external communication conditions and alerts that are not errors or problems. The comStatus flag in the BITstatus field is the bit-wise OR of the logical AND of the comStatus field and the comStatusEnable field. The comStatusEnable field is a bit mask that allows the user to select items of interest that will logically flow up to the masterStatus flag.

Table 93 comStatus Field

comStatus Field	Bits	Values
noExternalGPS	0	0 = external GPS data is being received 1 = no external GPS data is available
Reserved	1:15	N/A

softwareStatus Field

The softwareStatus field contains flags that indicate various software conditions and alerts that are not errors or problems. The softwareStatus flag in the BITstatus field is the bit-wise OR of the logical AND of the softwareStatus field and the softwareStatusEnable field. The softwareStatusEnable field is a bit mask that allows the user to select items of interest that will logically flow up to the masterStatus flag.

Table 94 softwareStatus Field

softwareStatus Field	Bits	Values
algorithmInit	0	0 = normal, 1 = the algorithm is in initialization mode
highGain	1	0 = low gain mode, 1 high gain mode
attitudeOnlyAlgorithm	2	0 = navigation state tracking, 1 = attitude only state tracking
turnSwitch	3	0 = off, 1 = yaw rate greater than turnSwitch threshold
Reserved	4:15	N/A

sensorStatus Field

The sensorStatus field contains flags that indicate various internal sensor conditions and alerts that are not errors or problems. The sensorStatus flag in the BITstatus field is the bit-wise OR of the logical AND of the sensorStatus field and the sensorStatusEnable field. The sensorStatusEnable field is a bit mask that allows the user to select items of interest that will logically flow up to the masterStatus flag.

Table 95 sensorStatus Fields

sensorStatus Field	Bits	Values
overRange	0	0 = not asserted, 1 = asserted
Reserved	1:15	N/A

Configuring masterStatus

The masterStatus byte and its associated programmable alerts are configured using the Read Field and Write Field command as described in *Chapter 10. Programming Guidelines.* The Table below shows the definition of the bit mask for configuring the status signals.

Table 96 masterStatus Fields

Configuration Fields	Field ID	Valid Values	Description
hardwareStatusEnable	0x0010	Any	Bit mask of enabled hardware status signals
comStatusEnable	0x0011	Any	Bit mask of enabled communication status signals
softwareStatusEnable	0x0012	Any	Bit mask of enabled software status signals
sensorStatusEnable	0x0013	Any	Bit mask of enabled sensor status signals

hardwareStatusEnable Field

This field is a bit mask of the hardwareStatus field (refer to *BIT Status Fields* on page 91). This field allows the user to determine which low level hardwareStatus field signals will flag the hardwareStatus and masterStatus flags in the BITstatus field. Any asserted bits in this field imply that the corresponding hardwareStatus field signal, if asserted, will cause the hardwareStatus and masterStatus flags to be asserted in the BITstatus field.

comStatusEnable Field

This field is a bit mask of the comStatus field(refer to *BIT Status Fields* on page 91). This field allows the user to determine which low level comStatus field signals will flag the comStatus and masterStatus flags in the BITstatus field. Any asserted bits in this field imply that the corresponding comStatus field signal, if asserted, will cause the comStatus and masterStatus flags to be asserted in the BITstatus field.

softwareStatusEnable Field

This field is a bit mask of the softwareStatus field (refer to *BIT Status Fields* on page 91). This field allows the user to determine which low level softwareStatus field signals will flag the softwareStatus and masterStatus flags in the BITstatus field. Any asserted bits in this field imply that the corresponding softwareStatus field signal, if asserted, will cause the softwareStatus and masterStatus flags to be asserted in the BITstatus field.

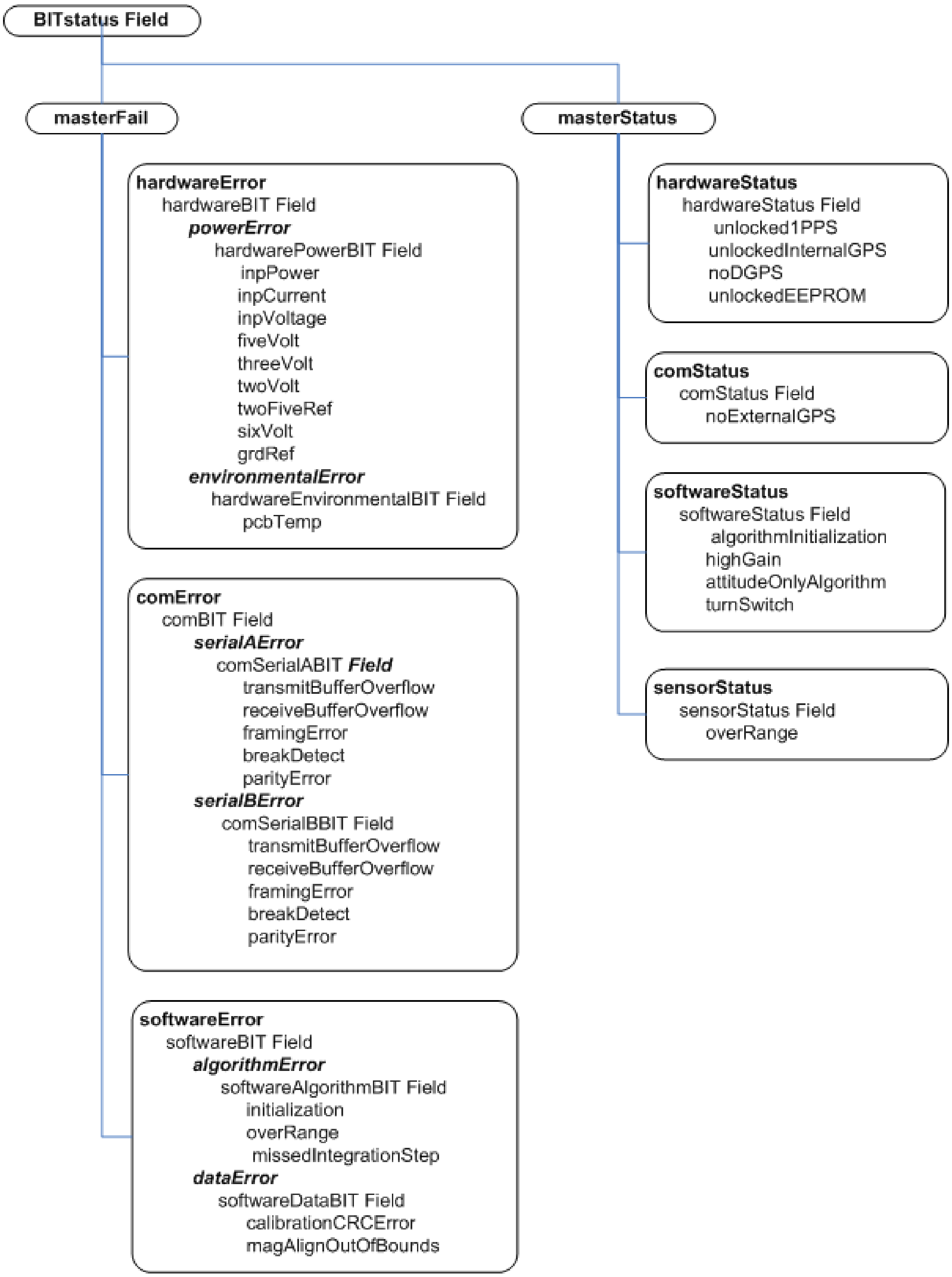
sensorStatusEnable Field

This field is a bit mask of the sensorStatus field (refer to *BIT Status Fields* on page 91). This field allows the user to determine which low level sensorStatus field signals will flag the sensorStatus and masterStatus flags in the BITstatus field. Any asserted bits in this field imply that the corresponding sensorStatus field signal, if asserted, will cause the sensorStatus and masterStatus flags to be asserted in the BITstatus field.

BIT Field Hierarchy

Figure 23 below illustrates the hierarchy of the BIT fields.

Figure 23 BIT Error and Status Hierarchy



Appendix A. NMEA Message Format

The GPS receiver outputs data (from a 440 unit) in NMEA-0183 format at 9600 Baud, 8 bits, no parity bit, and 1 stop bit. Packet formats are described in this section:

- GGA—GPS Fix Data, page 101
- Output Packet Format—Internal GPS, page 102

NOTE: NMEA protocol is not recommended for airborne applications; NMEA protocol does not provide vertical velocity, the vertical velocity that the 440 Series estimates (based upon GPS altitude changes) may not be sufficient for airborne applications.

GGA—GPS Fix Data

Time and position, together with GPS fixing related data (number of satellites in use, and the resulting HDOP, age of differential data if in use, etc.).

```
$GPGGA,hhmmss.ss,Latitude,N,Longitude,E,FS,NoSV,HDOP,msl,m,Altref,m,DiffAge,DiffStation*cs<
CR><LF>
```

Table 97 NMEA Message Format

Name	ASCII String		Description
	Format	Example	
$GPGGA	string	$GPGGA	Message ID: GGA protocol header
hhmmss.ss	hhmmss.sss	092725.00	UTC Time: Current time
Latitude	dddmm.mmmm	4717.11399	Latitude: Degrees + minutes
N	character	N	N/S Indicator: N=north or S=south
Longitude	dddmm.mmmm	00833.91590	Longitude: Degrees + minutes
E	character	E	E/W indicator: E=east or W=west
FS	1 digit	1	Position Fix Indicator (Refer to Table 98below)
NoSV	numeric	8	Satellites Used: Range 0 to 12
HDOP	numeric	1.01	HDOP: Horizontal Dilution of Precision
msl	numeric	499.6	MSL Altitude (m)
m	character	M	Units: Meters (fixed field)
Altref	blank	48.0	Geoid Separation (m)

Name	ASCII String		Description
	Format	Example	
m	blank	M	Units: Meters (fixed field)
DiffAge	numeric		Age of Differential Corrections (sec): Blank (Null) fields when DGPS is not used
DiffStation	numeric	0	Diff. Reference Station ID
cs	hexadecimal	*5B	Checksum
<CR><LF>			End of message

Table 98 Fix Status

Fix Status	Description
0	No fix / Invalid
1	Standard GPS (2D/3D)
2	Differential GPS
6	Estimated (DR) Fix

Output Packet Format—Internal GPS

Table 99 GPS Output Packet Format

NMEA Record	Description
GGA	Global positioning system fixed data
RMC	Recommended minimum specific GNSS data
VTG	Course over ground and ground speed data

Appendix B. Application Examples

This section provides recommended advanced settings for tailoring the 440 Series unit of inertial systems to different types of application and platform requirements.

Fixed Wing Aircraft

A fixed-wing aircraft is a heavier-than-air craft where movement of the wings in relation to the aircraft is not used to generate lift. The term is used to distinguish from rotary-wing aircraft, where the movement of the wing surfaces relative to the aircraft generates lift. The fixed wing aircraft can range in size from the smallest experimental plane to the largest commercial jet.

The dynamic characteristics of the fixed wing aircraft depend on the type of aircraft (such as glider, propeller aircraft, and jet aircraft) and mission phases (such as launch, landing, and maneuver). For best results per dynamic condition, the appropriate settings must be applied. *Table 99* below shows four examples of dynamic conditions with recommended configurations.

Table 100 Recommended Settings for Fixed Wing Aircraft

Recommended Settings	**Dynamic Condition**			
	Pre-launch or known straight and level un-accelerated flight	***Launch***	***Normal Dynamics (Default)***	***High Dynamics***
UseMags	ON	ON	ON	ON
UseGPS	ON	ON (< 4g)	ON	ON (< 4g)
FreelyIntegrate	OFF	OFF [1]	OFF	OFF (< 2g)
Stationary Yaw Lock	OFF	OFF	OFF	OFF
Restart Over Range	ON	OFF	OFF	OFF
Dynamic Motion	OFF	ON	ON	ON
Turn Switch Threshold	0.5 deg/s	0.5 deg/s	0.5 deg/s	0.5 deg/s
Z Filter Accel	5 Hz	5 Hz	5 Hz[4]	15 Hz
Filter Rate Sensor	20 Hz	20 Hz	20 Hz[4]	20 Hz

Rotorcraft

Rotorcraft is a category of heavier-than-air flying machines that use lift generated by rotors. They may also include the use of static lifting surfaces, but the primary distinguishing feature being lift provided by rotating lift structures. Rotorcraft includes helicopters, autogyros, gyrodynes and tiltrotors.

The rotor blade dynamics are faster than the fixed wing aircraft and contain high frequency components; however, it may cause severe vibrations on the airframe. The overall dynamics (translational and rotational motion) of the rotor craft are much slower than the fixed wing aircraft. Also ,the rotors generate significant aerodynamic forces and moments. *Table 100*shows two examples of dynamic conditions and the recommended configurations.

---

[1]FreelyIntegrate should only be set to **ON** for severe launch conditions. Normal takeoff dynamics that a standard aircraft would experience will see the best performance with this setting in the **OFF** position.

Table 101 Recommended Advanced Settings for Rotorcraft

Recommended Settings	Dynamic Condition	
	Normal Dynamics	High Dynamics (with uncoordinated tail motion)
Use Mags	ON	ON
Use GPS	ON	ON (< 4g)
Freely Integrate	OFF	OFF (< 2g)
Stationary Yaw Lock	OFF	OFF
Restart Over Range	OFF	ON
Dynamic Motion	ON	ON
Turn Switch Threshold	1.0 deg/s §	30.0 deg/s §
Z Filter Accel	5 Hz*	5 Hz
Filter Rate Sensor	20 Hz*	20 Hz

§The helicopter can change its heading angle rapidly unlike the aircraft which requires banking. A turnSwitch threshold that is too low may cause turnSwitch activation with high duty cycle causing random walk in roll and pitch angles due to low feedback gains.

*A cutoff frequency must be far away from major frequency components caused by the rotor vibration.

Land Vehicle

Some examples of land vehicles are: automobiles, trucks, heavy equipment, trains, snowmobiles, and other tracked vehicles. *Table 101*shows two examples of land vehicles and the recommended configurations.

Table 102 Recommended Advanced Settings for Land Vehicle

Recommended Settings	Dynamic Condition	
	Heavy Equipment Application	Automotive Testing
Use Mags	ON§	ON§
Use GPS	ON	ON (< 4g)
Freely Integrate	OFF	OFF
Stationary Yaw Lock	OFF	OFF
Restart Over Range	ON	OFF
Dynamic Motion	ON	ON
Turn Switch Threshold	5.0 deg/s	10.0 deg/s
XY Filter Accel	5 Hz	5 Hz
Z Filter Accel	5 Hz	5 Hz
Filter Rate Sensor	20 Hz	20 Hz

§When not in distorted magnetic environment.

Water Vehicle

Water vehicle is a craft or vessel designed to float on or submerge and provide transport over and under water. Table 102provides the recommended advanced settings for two applications.

Table 103 Recommended Advanced Settings for Water Vehicle

Recommended Setting	***440 Series Unit***	
Recommended Settings	***Application***	
	Surfaced	***Submerged***
Use Mags	ON [2]	ON[3]
Use GPS	ON	OFF
Free Integrate	OFF	OFF
Stationary Yaw Lock	OFF	OFF
Restart Over Range	OFF	OFF
Dynamic Motion	ON	ON
Turn Switch Threshold	10 deg/s	5 deg/s
XY Filter Accel	5 Hz	2 Hz
Z Filter Accel	5 Hz	2 Hz
Filter Rate Sensor	15 Hz	10 Hz

Example

Table 103 below shows a typical flight profile of the fixed wing aircraft and the corresponding advanced settings that can be configured per flight phase.

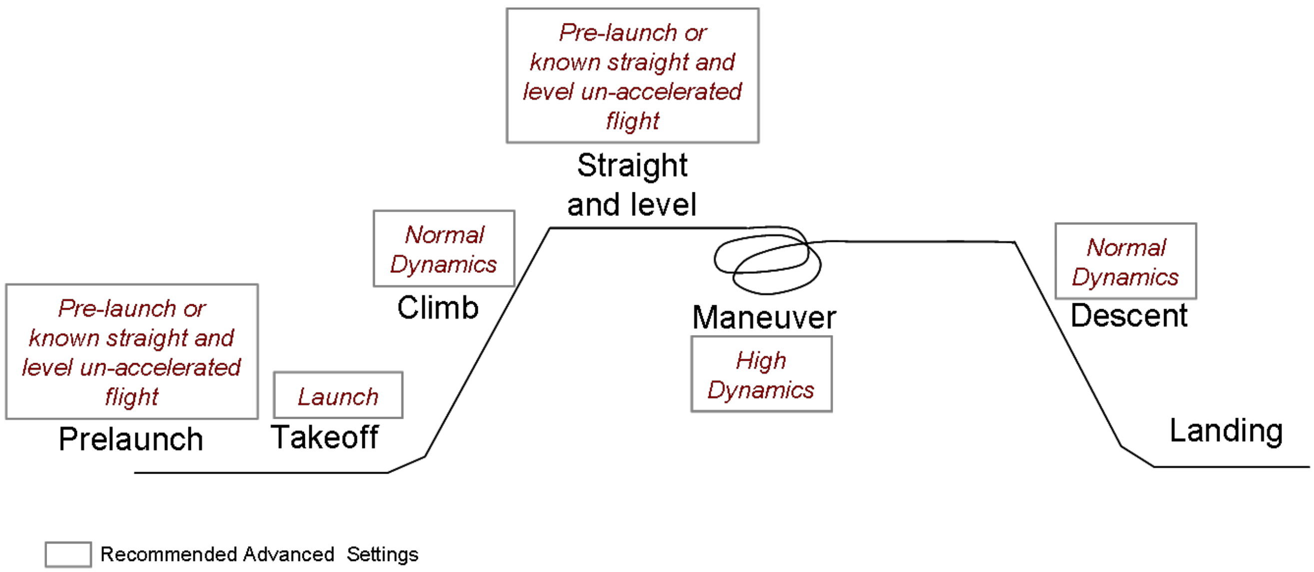
Table 104 Flight Profile Phases

Phase	**Description**
Prelaunch	The phase of flight in which an aircraft goes through a series of checkups (hardware and software) on the ground before takeoff. The aircraft is a static condition,
Takeoff	The phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air, usually along a runway. The aircraft is under horizontal acceleration and may suffer from vibrations coming from an engine and ground contact forces transmitted from its landing gear..
Climb	The phase of a flight, after takeoff, consisting of getting the aircraft to the desired flight level altitude. More generally, the term 'climb' means increasing the altitude. The aircraft is under vertical acceleration until it reaches the steady-state climb rate.
Straight and level flight	The phase of flight in which an aircraft reaches its nominal flight altitude and maintains its speed and altitude. The aircraft is under equilibrium.

[2]When not in distorted magnetic environment.

Phase	Description
Maneuver	The phase of flight in which an aircraft accelerates, decelerates, and turns. The aircraft is under non-gravitational acceleration and/or deceleration.
Descent	The phase of flight in which an aircraft decreases altitude for an approach to landing. The aircraft is under vertical deceleration until it captures a glide slope.
Landing	The last part of a flight, where the aircraft returns to the ground.

Figure 24 Typical flight profiles of fixed wing aircraft and the corresponding advanced settings



Appendix C. Sample Packet—Parser Code

Overview

This section includes an example of code written in ANSI C for parsing packets from data sent by the 440 Series Inertial Systems. This example is for reading data directly from the 440 Series unit or from a log file.

Sample Code

The sample code contains the actual parser as well as several support functions for CRC calculation and circular queue access.

Table 105 Code Functions

Function	Description
process_xbow_packet	Parse out packets from a queue. Returns these fields in structure XBOW_PACKET (see below). Checks for CRC errors
calcCRC	Calculate CRC on packets.
Initialize	Initialize the queue
AddQueue	Add item in front of queue
DeleteQueue	Return an item from the queue
peekWord	Retrieve 2-bytes from the queue, without popping
peekByte	Retrieve a byte from the queue without popping
Pop	Discard item(s) from queue
Size	Return number of items in queue
Empty	Return 1 if queue is empty, 0 if not
Full	Return 1 if full, 0 if not full

The parser will parse the queue looking for packets. Once a packet is found and the CRC checks out, the packet's fields are placed in the XBOW_PACKET structure. The parser will then return to the caller. When no packets are found the parser will simply return to the caller with return value 0.

The XBOW_PACKET structure is defined as follows:

```
typedef struct xbow_packet
{
   unsigned short   packet_type;
   char          length;
   unsigned short   crc;
   char          data(256);
} XBOW_PACKET;
```

Typically, the parser would be called within a loop in a separate process, or in some time triggered environment, reading the queue looking for packets. A separate process might add data to this queue when it arrives. It is up to the user to ensure circular-queue integrity by using some sort of mutual exclusion mechanism within the queue access functions.

```
Code Listing#include <stdio.h>

/* buffer size */
#define MAXQUEUE 500

/*
 * circular queue
 */
typedef struct queue_tag
{
   int count;
   int front;
   int rear;
   char entry(MAXQUEUE);
} QUEUE_TYPE;

/*
 * Moog Crossbow packet
 */
typedef struct xbow_packet
{
   unsigned short   packet_type;
   char                     length;
   unsigned short   crc;
   char                     data(256);
} XBOW_PACKET;

QUEUE_TYPE circ_buf;

/*******************************************************************************
 * FUNCTION:  process_xbow_packet looks for packets in a queue
 * ARGUMENTS: queue_ptr: is pointer to queue to process
 *                  result: will contain the parsed info when return value is 1
 * RETURNS:      0 when failed.
 *                  1 when successful
 *******************************************************************************/
int process_xbow_packet(QUEUE_TYPE *queue_ptr, XBOW_PACKET *result)
{
   unsigned short myCRC = 0, packetCRC = 0, packet_type = 0, numToPop=0, counter=0;
   char packet(100), tempchar, dataLength;

   if(Empty(queue_ptr))
   {
      return 0; /* empty buffer */
   }

   /* find header */
   for(numToPop=0; numToPop+1<Size(queue_ptr) ;numToPop+=1)
   {
      if(0x5555==peekWord(queue_ptr, numToPop)) break;
```

```
    }

    Pop(queue_ptr, numToPop);

    if(Size(queue_ptr) <= 0)
    {
       /* header was not found */
       return 0;
    }

   /* make sure we can read through minimum length packet */
   if(Size(queue_ptr)<7)
   {
    return 0;
   }

   /* get data length (5th byte of packet) */
   dataLength = peekByte(queue_ptr, 4);

   /* make sure we can read through entire packet */
   if(Size(queue_ptr) < 7+dataLength)
   {
    return 0;
    }


    /* check CRC */
    myCRC = calcCRC(queue_ptr, 2,dataLength+3);
    packetCRC = peekWord(queue_ptr, dataLength+5);

    if(myCRC != packetCRC)
    {
       /* bad CRC on packet – remove the bad packet from the queue and return */
       Pop(queue_ptr, dataLength+7);
       return 0;
    }

    /* fill out result of parsing in structure */
    result->packet_type = peekWord(queue_ptr, 2);
    result->length       = peekByte(queue_ptr, 4);
    result->crc          = packetCRC;
    for(counter=0; counter < result->length; counter++)
    {
       result->data(counter) = peekByte(queue_ptr, 5+counter);
    }

    Pop(queue_ptr, dataLength+7);

    return 1;
}

/*******************************************************************************
 * FUNCTION:  calcCRC calculates a 2-byte CRC on serial data using
```

```
 *            CRC-CCITT 16-bit standard maintained by the ITU
 *                  (International Telecommunications Union).
 * ARGUMENTS: queue_ptr is pointer to queue holding area to be CRCed
 *                  startIndex is offset into buffer where to begin CRC calculation
 *                  num is offset into buffer where to stop CRC calculation
 * RETURNS:      2-byte CRC
 ******************************************************************************/
unsigned short calcCRC(QUEUE_TYPE *queue_ptr, unsigned int startIndex, unsigned int num) {
   unsigned int i=0, j=0;
   unsigned short crc=0x1D0F; //non-augmented inital value equivalent to augmented initial
value 0xFFFF

   for (i=0; i<num; i+=1) {
      crc ^= peekByte(queue_ptr, startIndex+i) << 8;

      for(j=0;j<8;j+=1) {
         if(crc & 0x8000) crc = (crc << 1) ^ 0x1021;
         else crc = crc << 1;
      }
   }
   return crc;
}


/*******************************************************************************
 * FUNCTION:  Initialize - initialize the queue
 * ARGUMENTS: queue_ptr is pointer to the queue
 ******************************************************************************/
void Initialize(QUEUE_TYPE *queue_ptr)
{
   queue_ptr->count =  0;
   queue_ptr->front =  0;
   queue_ptr->rear  = -1;
}

/*******************************************************************************
 * FUNCTION:  AddQueue - add item in front of queue
 * ARGUMENTS: item holds item to be added to queue
 *                  queue_ptr is pointer to the queue
 * RETURNS:      returns 0 if queue is full. 1 if successful
 ******************************************************************************/
int AddQueue(char item, QUEUE_TYPE *queue_ptr)
{
   int retval = 0;
   if(queue_ptr->count >= MAXQUEUE)
   {
      retval = 0;  /* queue is full */
   }
   else
   {
      queue_ptr->count++;
      queue_ptr->rear = (queue_ptr->rear + 1) % MAXQUEUE;
      queue_ptr->entry(queue_ptr->rear) = item;
```

```
      retval = 1;
   }
   return retval;
}

/*******************************************************************************
 * FUNCTION:  DeleteQeue - return an item from the queue
 * ARGUMENTS: item will hold item popped from queue
 *                 queue_ptr is pointer to the queue
 * RETURNS:     returns 0 if queue is empty. 1 if successful
 *******************************************************************************/
int DeleteQueue(char *item, QUEUE_TYPE *queue_ptr)
{
   int retval = 0;
   if(queue_ptr->count <= 0)
   {
      retval = 0; /* queue is empty */
   }
   else
   {
      queue_ptr -> count--;
      *item = queue_ptr->entry(queue_ptr->front);
      queue_ptr->front = (queue_ptr->front+1) % MAXQUEUE;
      retval=1;
   }
   return retval;
}

/*******************************************************************************
 * FUNCTION:  peekByte returns 1 byte from buffer without popping
 * ARGUMENTS: queue_ptr is pointer to the queue to return byte from
 *                 index is offset into buffer to which byte to return
 * RETURNS:     1 byte
 * REMARKS:     does not do boundary checking. please do this first
 *******************************************************************************/
char peekByte(QUEUE_TYPE *queue_ptr, unsigned int index) {
   char byte;
   int firstIndex;

   firstIndex = (queue_ptr->front + index) % MAXQUEUE;

   byte = queue_ptr->entry(firstIndex);
   return byte;
}


/*******************************************************************************
 * FUNCTION:  peekWord returns 2-byte word from buffer without popping
 * ARGUMENTS: queue_ptr is pointer to the queue to return word from
 *                 index is offset into buffer to which word to return
 * RETURNS:     2-byte word
 * REMARKS:     does not do boundary checking. please do this first
 *******************************************************************************/
```

```
unsigned short peekWord(QUEUE_TYPE *queue_ptr, unsigned int index) {
   unsigned short word, firstIndex, secondIndex;

   firstIndex = (queue_ptr->front + index) % MAXQUEUE;
   secondIndex = (queue_ptr->front + index + 1) % MAXQUEUE;

   word = (queue_ptr->entry(firstIndex)<< 8) & 0xFF00;
   word |= (0x00FF & queue_ptr->entry(secondIndex));
   return word;
}

/*******************************************************************************
 * FUNCTION:  Pop - discard item(s) from queue
 * ARGUMENTS: queue_ptr is pointer to the queue
 *                  numToPop is number of items to discard
 * RETURNS:     return the number of items discarded
 *******************************************************************************/
int Pop(QUEUE_TYPE *queue_ptr, int numToPop)
{
   int i=0;
   char tempchar;
   for(i=0; i<numToPop; i++)
   {
      if(!DeleteQueue(&tempchar, queue_ptr))
      {
         break;
      }
   }
   return i;
}
/*******************************************************************************
 * FUNCTION:  Size
 * ARGUMENTS: queue_ptr is pointer to the queue
 * RETURNS:     return the number of items in the queue
 *******************************************************************************/
int Size(QUEUE_TYPE *queue_ptr)
{
   return queue_ptr->count;
}

/*******************************************************************************
 * FUNCTION:  Empty
 * ARGUMENTS: queue_ptr is pointer to the queue
 * RETURNS:     return 1 if empty, 0 if not
 *******************************************************************************/
int Empty(QUEUE_TYPE *queue_ptr)
{
   return queue_ptr->count <= 0;
}

/*******************************************************************************
 * FUNCTION:  Full
```

```
 * ARGUMENTS: queue_ptr is pointer to the queue
 * RETURNS:      return 1 if full, 0 if not full
 *******************************************************************************/
int Full(QUEUE_TYPE *queue_ptr)
{
   return queue_ptr->count >= MAXQUEUE;
}
```

Appendix D. Sample Packet Decoding

Example payload from Angle Data Packet 2 (A2)

5555 4132 1e 0006ffe4ed91 fff9fffdffed fff7fff9f331 2c642ce12d85 00010b1c 0300 6945

preamble type length

CRC (invalid)

0006ffe4ed91fff9fffdffed fff7fff9f3312c642ce12d8500010b1c 0300

Angles	
Hex Data	Value (deg)
0006 (roll)	0.033
FFE4 (pitch)	-0.154
ED91 (yaw)	-25.922

Accelerometers	
Hex Data	Value (g)
FFF7 (x)	-0.0027
FFF9 (y)	-0.0021
F331 (z)	-1.0007

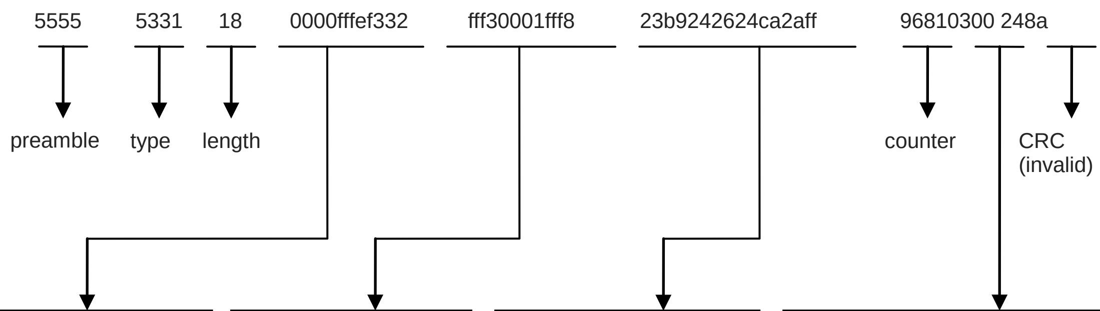
timeITOW	
Hex Data	Value (s)
00010b1c	68380

Angular Rates	
Hex Data	Value (deg/s)
FFF9 (roll)	-0.13
FFFD (pitch)	-0.06
FFED (yaw)	-0.37

Temperature	
Hex Data	Value (deg. C)
2C64	34.680
2CE1	35.062
2D85	35.562

BIT status Field	
Field	Value
masterFail	0
hardwareError	0
comError	0
softwareError	0
reserved	0000
masterStatus	1
hardwareStatus	1
comStatus	0
softwareStatus	0
sensorStatus	0
reserved	000

Example payload from Scaled Sensor 1 data packet (S1)



Accelerometers	
Hex Data	Value (g)
0000	0
FFFE	-0.001
F332	-1

Angular Rates	
Hex Data	Value (deg/s)
FFF3	-0.25
0001	0.02
FFF8	-0.15

Temperature	
Hex Data	Value (deg. C)
23B9	28.241
2426	28.741
24CA	33.591
2AFF	38.968

BIT status Field	
Field	Value
masterFail	0
hardwareError	0
comError	0
softwareError	0
reserved	0000
masterStatus	1
hardwareStatus	1
comStatus	0
softwareStatus	0
sensorStatus	0
reserved	000

Example payload from Nav Data Packet 1 (N1)

5555 4e31 2a   001bffdf3a5bfffe0000ffe . . . fff8fff70000002d1900288a3e0300 a3ad

preamble   type   length   CRC (invalid)

001bffdf3a5bfffe0000ffeafff8fff7f3370015fda9fd4f00000000000000000000002d1900288a3e   0300

Angles	
Hex Data	Value (deg)
001b	0.148
FFFD	-0.181
3A5B	82.062

Accelerometers	
Hex Data	Value (g)
FFF8	-0.0024
FFF7	-0.0027
F337	-0.9988

Temperature	
Hex Data	Value (deg. C)
2D19	35.233

timeITOW	
Hex Data	Value (s)
00288a3e	2656830

Velocity	
Hex Data	Value (m/s)
0015	0.164
FDA9	-4.680
FD4F	-5.383

Angular Rates	
Hex Data	Value (deg/s)
FFFE	-0.04
0000	0.00
FFEA	-0.42

BIT status Field	
Field	Value
masterFail	0
hardwareError	0
comError	0
softwareError	0
reserved	0000
masterStatus	1
hardwareStatus	1
comStatus	0
softwareStatus	0
sensorStatus	0
reserved	000

GPS	
Hex Data	Value
00000000	0.000000000 Rad
00000000	0.000000000 Rad
0000	0.0 m

Appendix E. Mechanical Specifications

Footprint

3.00" x 3.75"

Specifications

Environment

Operating Temperature -40° to +71°C

Enclosure IP66 compliant

Electrical

Input Voltage 9 to 42 VDC

Power Consumption < 4 W

Digital Interface RS232

Physical

Size 5.3”w x 4.8”l x 2.7”h

Weight 2.7 lbs (1.2 kg)

Interface Connector DB-15

Mechanical Drawings

Figure 25 440 Outline: IMU, VG

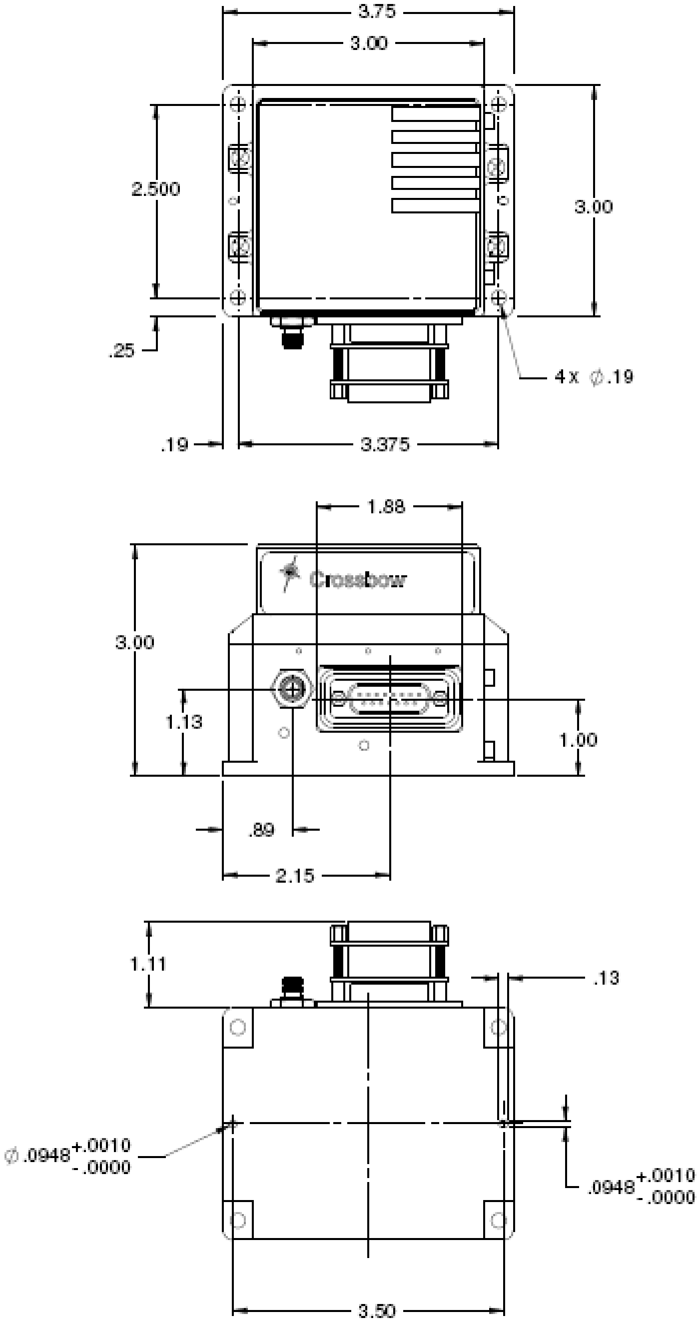


Figure 26 440 Outline: AHRS, NAV

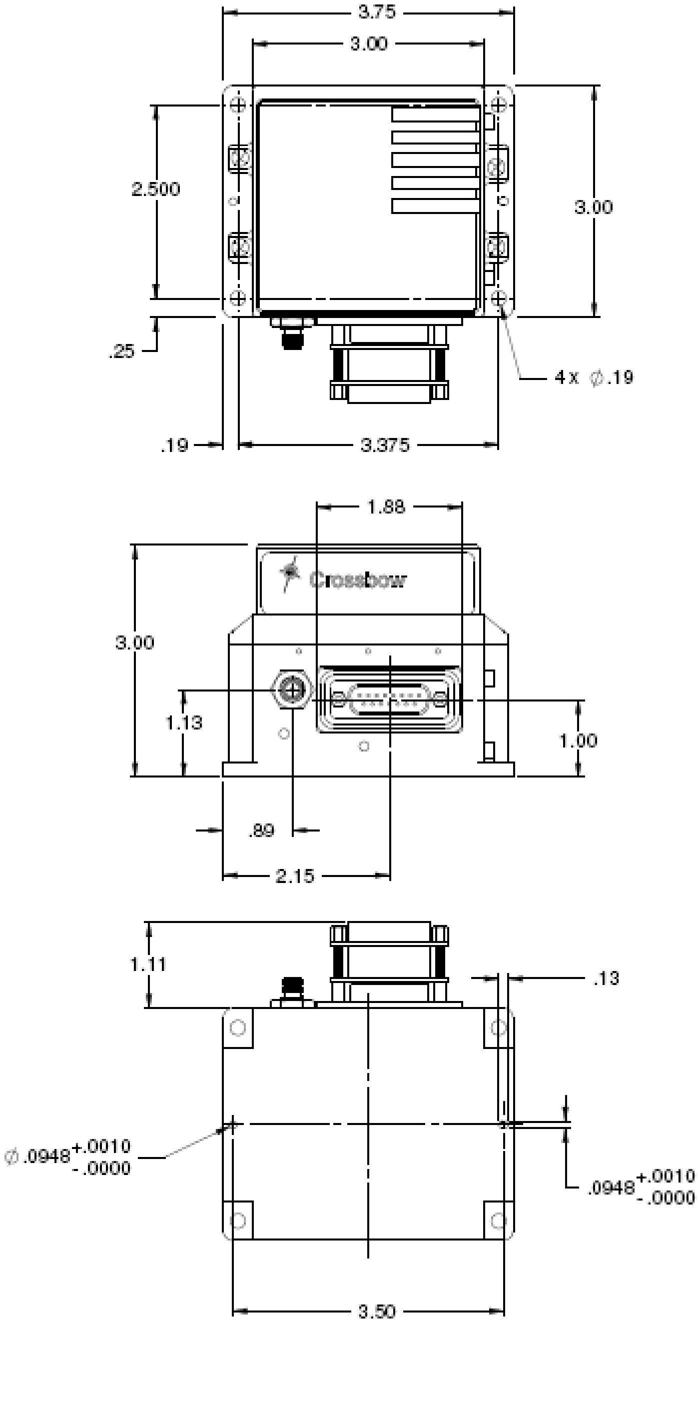
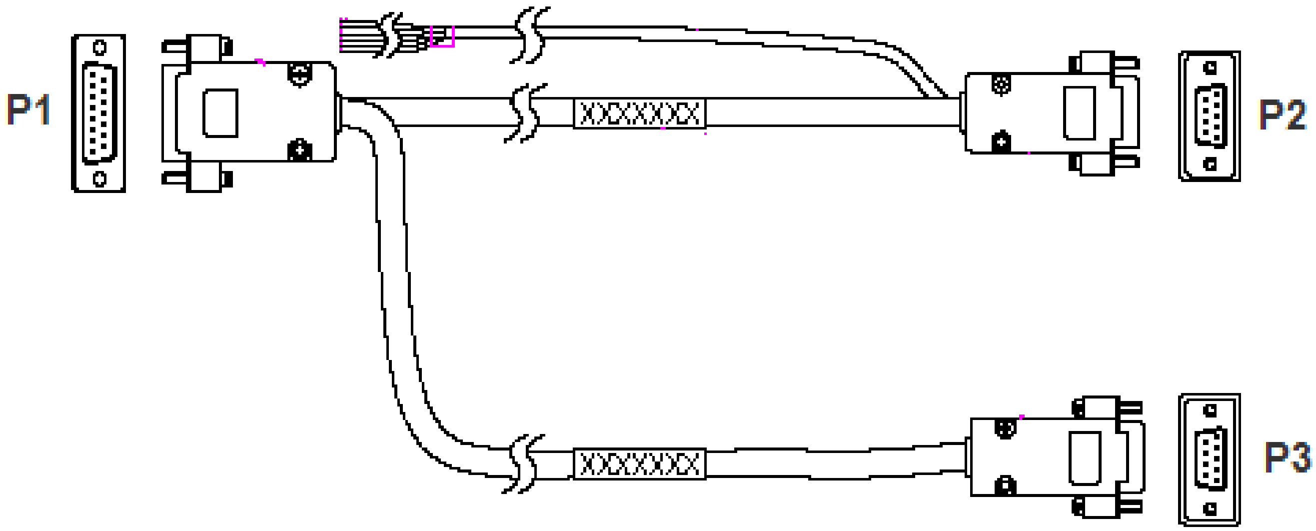


Figure 27 Evaluation Kit 440 Series Cable



Appendix F. Moog Crossbow Service Policies

Customer Service

Moog Crossbow customers have access to product support services:

- Single-point return service
- Web-based support service
- Same day troubleshooting assistance
- Worldwide Moog Crossbow representation
- Onsite and factory training available
- Preventative maintenance and repair programs
- Installation assistance available

Warranty

The Moog Crossbow product warranty is one year from the date of shipment.

Returning Equipment

Before returning any equipment, please contact Moog Crossbow to obtain a Returned Material Authorization number (RMA).

Provide the following information when requesting a RMA:

Contact Point

- Company
- Address
- Contact name
- Telephone, Fax, Email

Product Details

- Equipment Model Number
- Equipment Serial Number
- Installation Date
- Failure Date
- Description of Failure
- Does the device connect to NAV-VIEW 2.2

Packing Item for Return

If the equipment is to be shipped to Moog Crossbow for service or repair:

- In all correspondence, refer to the equipment by the model number, the serial number, and the RMA number.

- Attach a tag to the equipment, as well as the shipping container(s): on the tab, include the RAM and the owner.
- Include a description of the service or repair required, a description of the problems with the unit, and the conditions that the problems occurred, such what function was being used.
- Place the equipment in the original shipping container(s), making sure there is adequate packing around all sides of the equipment. If the original shipping containers were discarded, use heavy boxes with adequate padding and protection.
- On each side of the container, clearly label the container with “FRAGILE – HANDLE WITH CARE”.
- Seal the shipping container(s) with heavy tape or metal bands strong enough to handle the weight of the equipment and the container.

Return Address

Use the following address for all returned products:

Moog Crossbow
1421 McCarthy Blvd.
Milpitas, CA 95035
Attn: RMA Number (XXXXXX)

Source Code License

For qualified commercial OEM users, a source code license of NAV-VIEW 2.2 can be made available under certain conditions. Please contact your Moog Crossbow representative for more information.

Contact Information

United States	Phone: 1-408-965-3300 (8 AM to 5 PM PST) Fax:1-408-324-4840 (24 hours) Email: techsupport@moog-crossbow.com	
Outside of the United States	Visit website	www.moog-crossbow.com

Appendix G. Revision History

Table 106 Document Revision History

Revision	Date	Contributor(s)	Comments
F	2011	R. C. Ayeras S. McGuigan	Update the format and organization of the contents.
G	May 2012	R.C. Ayeras J. Zhiang	Corrections: heading title "Configuring NAV440 Functions" and footer; Table 8 (incomplete sentence)

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