SYSTRON DONNER INERTIAL

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SDN500
User's Guide

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SDN500 Integrated INS/GPS

Overview

Systron Donner Inertial (SDI) has developed a family of Guidance, Navigation, and Control (GN&C) products that use the latest solid-state inertial sensor technology integrated with advanced Standard Positioning Service (SPS) and Precise Positioning Service (PPS) Global Positioning System (GPS) engines.

SDN500 is a tightly coupled SPS INS/GPS containing a twelve channel, Coarse/Acquisition (C/A) code, L1 frequency GPS engine (Jupiter Pico), and the Systron Donner SDI500 IMU. The two subsystems are integrated together through a modular Kalman filter mechanization to produce a small, lightweight, synergistic GN&C system. It requires only an antenna, a +12 to 42 Vdc power supply (+28 V nominal) and any device capable of accepting RS-232 or RS-422 (user selectable) asynchronous serial data. The electronics are housed in an aluminum chassis, forming a compact, robust package.

The IMU portion provides delta-velocity and delta-theta information about three axes at various output rates over synchronous SDLC. The IMU uses micro-machined quartz rate sensors and accelerometers to achieve low weight and volume while maintaining high performance.

Proven off-the-shelf products integrated into one package translate into affordability and low risk. SDN500 provides all essential GN&C data, including three-dimensional position and velocity, precise time, attitude, heading, angular rate, and acceleration.

SDN500 configurations can be tailored to meet operational performance requirements, while meeting budgetary constraints to provide affordable, operationally effective system solutions. These integrated solutions offer an affordable suite of compact and lightweight systems that are ideally suited for GN&C applications, such as tactical missiles, guided munitions, unmanned aerial vehicles (targets, decoys, etc.), land vehicles, geo-location, and a host of other uses.

Additional technical data, physical characteristics, operation, and system integration information for the SDN500 product are presented in subsequent chapters of this guide.

Why INS/GPS?

Many guidance and control problems in the past have been addressed with stand-alone Inertial Navigation System (INS) or GPS solutions; however, the inherent characteristics of each system do not provide an ideal GN&C solution. By properly integrating the INS and GPS systems, the strengths of one can offset the deficiencies of the other.

An INS is generally characterized as a self-contained, autonomous navigator, whose position and velocity outputs will degrade over time. Alternatively, the GPS is generally described as a navigator relying on external satellite signals, whose high accuracy solution is time independent.

When the two systems are combined, the INS/GPS system will bound the INS error growth, and provide a continuous navigation solution when GPS signals are not available. In addition, high-speed attitude, velocity, angular rate, and acceleration are available at accuracies not achievable by GPS alone.

About This Book

This guide provides basic navigation concepts, INS/GPS concepts, configuration, operation, and characteristics of the system, and defines the mechanical, electrical, and data interfaces of SDN500 to the Host Vehicle (HV). The inertial portion (SDI500) and the Navman Jupiter Pico GPS engine will be typically referred to in this guide as the *Inertial Measurement Unit* (IMU) and the *GPS receiver*, respectively.

This guide will discuss and illustrate some possible system applications for commercial and military markets, and will help the end-user determine how to use the SDN500 features.

The glossary contains abbreviations of terms commonly used by SDI and in the navigational and inertial fields, as well as some terms common to commercial electronics and software fields.

Note pages have been included to allow the designer to jot down notes for quick easy reference that might otherwise be misplaced.

Chapter 2- INS/GPS Concepts

What is Navigation?

Navigation is the art and science of directing a vehicle from one place to another. When navigating for long periods of time, a slight error in direction will create a sizable distance off course. This shows that the efficiency of a vehicle depends ultimately on the navigation accuracy.

The science of navigation can be reduced to five basic questions, and the navigator must be capable of obtaining quick and accurate answers to them.

- What is the present *position* (latitude, longitude, and altitude)?
- What is the vehicle's *heading*?
- What is the vehicle's *attitude* (roll and pitch)?
- What is the vehicle's *velocity* (north/south, east/west, total, and vertical)?
- What is the vehicle's *acceleration*?

Answer these questions and you have the solution to navigation. With proper navigation equipment, these questions can be answered with reasonable accuracy.

The primary task of navigation is the determination of present position. *Inertial navigation* is the method of accurately and continuously extrapolating a vehicle's position, velocity, and attitude, by processing changes in its motion as sensed by inertial instruments.

An *Inertial Navigation System* (INS) measures changes in velocity through the use of accelerometers and gyroscopes. This information is fed to a computer that is used to keep track of velocity and to continuously maintain an indication of position. Today these same instruments typically provide rate and state data to other avionics subsystems such as weapon computers, flight controls, or radar sensors.

An INS makes its measurements with respect to *inertial space*. Inertial space is a reference frame, consisting of a set of axes that do not rotate, and has no acceleration from its origin relative to the average position of the fixed stars. Any set of rigid axes moving with constant velocity, and without rotation relative to inertial space, also constitutes an inertial reference frame.

The INS needs to be properly initialized and periodically reinitialized.

As with any dead reckoning system, it is important that an INS be properly initialized and periodically reinitialized. Other methods of navigation, such as Navigation Satellite Timing and Ranging (NAVSTAR) GPS, can be used in conjunction with the INS. Both of these methods are discussed later in this chapter.

Inertial Navigation Advantages

Some of the advantages of inertial navigation are as follows:

- All types of navigation data are determined simultaneously, i.e., position, velocity, heading, and attitude. Most other methods of navigation provide only position data.
- Navigation data is continuously available.
- Even though some errors can be additive, inertial navigators can be made to be very accurate.
- Navigation data is provided at a high rate so vehicle, weapon, or sensor stabilization is possible.

Since the earth is itself moving in inertial space, the relationships between a vehicle, the earth, and inertial space are fundamental to the solution of the inertial navigation problem.

These relationships are defined by the laws of mechanics, which describe the motions and interactions of material bodies in inertial space. The inertial navigation systems that we typically deal with compute and output velocity and attitude parameters, as well as latitude, longitude, and altitude position.

Position

Position is defined as the *location of a body in space*, and can be described completely by referencing the body to an appropriate coordinate system. Usually, rectangular coordinates are used.

Heading

Heading is commonly known as *compass direction*, or, the direction that the vehicle points. True heading is defined as the angle in the local horizontal plane measured clockwise (about a downward vertical) between North and a vertical plane, containing the ship's, aircraft's, or other vehicle's longitudinal axis (with an aircraft, this axis is known as the *thrust* axis).

Attitude

Attitude is defined as the angular position of a ship, aircraft, or other vehicle, determined by the relationship between its axes and a reference datum, such as the horizon or a particular star. Attitude parameters are defined in terms of three "Euler" angles: true heading, pitch, and roll. See the previous paragraph for true heading.

Pitch is the angle measured in the vertical plane between a vehicle's longitudinal axis and the horizontal axis (nose up in an aircraft would be positive).

Roll is the angle measured about the vehicle's longitudinal axis that will rotate the vehicle from a horizontal orientation (such as an aircraft's wings being normally horizontal, to the actual flight orientation).

An example of roll is a climbing right hand turn from a level northerly flight path direction, generating a positive heading, pitch, and roll angle. A *drift angle* can be generated by crosswinds, causing the aircraft to point in the direction of the wind, rather than along the ground-referenced velocity direction.

Velocity

Displacement indicates *extent of motion*, that is, the magnitude and direction of change in position. Velocity is a measure of *how fast displacement takes place*, or, how much displacement occurs in a given unit of time.

Velocity parameters are typically expressed in terms of the vertical and horizontal components of translational movement relative to the earth. In an example of an aircraft, the vertical component of velocity is called the *altitude rate.* The horizontal component of velocity can be expressed in terms of North and East components, or in terms of the net horizontal velocity component magnitude (commonly called *ground speed*), and horizontal velocity vector direction relative to North (known as the *track angle*).

Acceleration

Since the velocity of a body has both magnitude and direction, a change in velocity occurs whenever:

- The body's *rate* of motion changes while its direction remains the same.
- The body's *direction* of motion changes while its rate of motion remains the same.
- The body's *rate* and *direction* of motion change simultaneously.

Whenever the velocity of a body changes in any manner, the body is said to be *accelerating*.

Gravity

In addition to the forces caused by the motions of the INS and the Earth, the system is subject to the mass attraction, or *gravitational force* of the Earth, which is the most significant force acting on inertial instruments.

Gravity's interaction with the Earth's rotational forces is responsible for the very shape of the Earth itself. The shape of the Earth is fundamental to terrestrial navigation, since the designation of a system's position is only as precise as the relationship between the describing coordinates and the Earth's shape. Gravitational attraction is a property of matter (inertial mass) that is possessed by all material bodies.

NAVSTAR GPS General Theory

NAVSTAR GPS is a space-based satellite radio navigation system developed by the United States Department of Defense (DoD).

GPS receivers provide land, marine, and airborne users with continuous three-dimensional position, velocity, and time data. This information is available free of charge to an unlimited number of users. The system operates under all weather conditions, 24 hours a day, anywhere on Earth.

GPS System Design

The GPS system consists of three major segments: Space, Control, and User, as shown in Figure 2-1.

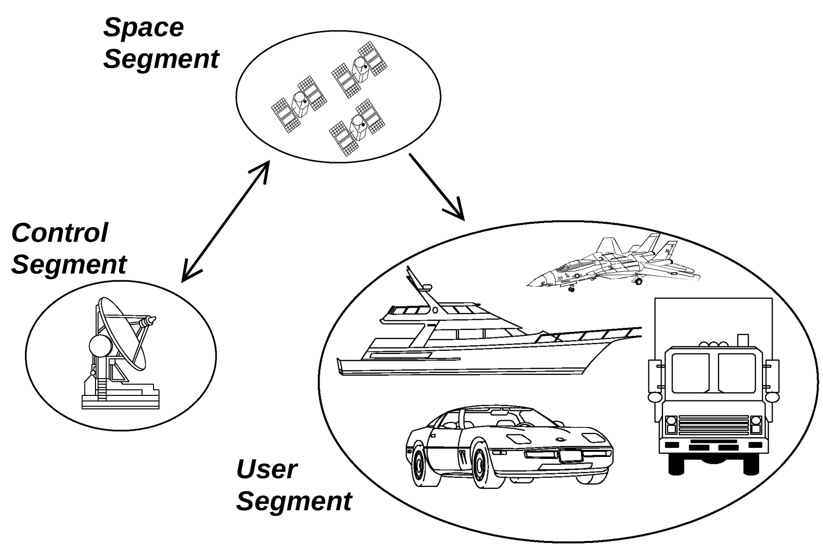

Figure 2-1. Major Segments of the NAVSTAR GPS System

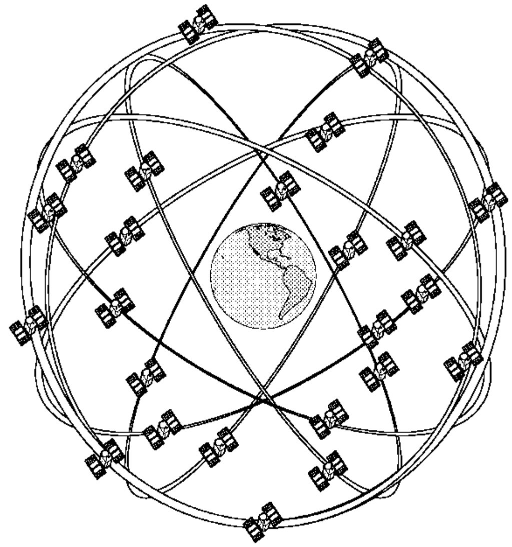

Figure 2-2. NAVSTAR GPS Operational Satellite Constellation

The satellites are in circular orbits with a 12-hour orbital period and inclination angle of 55 degrees as depicted in Figure 2-2. This orientation normally provides a GPS user with a minimum of five satellites in view from any point on Earth at any one time.

Each satellite continuously broadcasts Radio Frequency (RF) signals at two L-band frequencies. The L1 frequency is 1575.42 MHz and is modulated by a 10.23 MHz clock rate Precise ranging signal (P), or *Precision Code* (P-code), and by a 1.023 MHz clock rate C/A code ranging signal, or *Coarse/ Acquisition Code* (C/A-code). The L2 frequency is 1227.6 MHz and carries P-code only. Non-military navigation sets, such as the SDN500, typically have access to the L1 C/A-code only.

Before the P-code and C/A-code are modulated for transmission, they are combined with navigation data, 50 bits per second (bps), by Modulo-2 addition. The navigation data, which is computed and controlled by the GPS Control Segment, includes each satellite's time, clock correction, ephemeris parameters, almanac data, and health status for all GPS satellites. From this information, the user computes the satellite's precise position and clock offset.

Currently, the DoD encrypts P-code ranging signals and thus denies access to the Precise Positioning Service (PPS) by unauthorized users. The Standard Positioning Service (SPS) uses the C/A-code ranging signal, which is intended for general public use.

Control Segment

This segment consists of a Master Control Station, located in Colorado Springs, Colorado, and a number of monitor stations at various locations around the world.

Each monitor station tracks all GPS satellites in view and passes signal measurement data back to the Master Control Station. There, computations are performed to determine precise satellite ephemeris and satellite clock errors.

The Master Control Station generates the upload of user navigation data for each satellite. This data is subsequently re-broadcast by the satellite as part of its navigation data message.

User Segment

This segment is the collection of all GPS receivers and their application support equipment, such as antennas and processors. This equipment allows users to receive, decode, and process information necessary to obtain accurate position, velocity, and timing measurements. This data is used by the GPS receiver's support equipment for specific application requirements.

GPS supports a wide variety of applications including navigation, surveying, and time transfer. Receivers may be used in a stand-alone mode, or integrated with other systems to enhance overall system performance.

How The GPS Receiver Determines Position

The GPS receiver determines its geographic position by measuring the ranges of several satellites and computing the geometric intersection of these ranges.

Range is the distance between a satellite with known coordinates in space and the receiver's antenna.

To determine a range, the receiver measures the time required for a GPS signal to travel from a satellite to a receiver antenna. A timing code generated by each satellite is compared to an identical code generated by the receiver.

The receiver's code is shifted until it matches the satellite's code. The resulting time shift is multiplied by the speed of light to arrive at the apparent range measurement.

Since the resulting range measurement contains propagation delays due to atmospheric effects, and satellite and receiver clock errors, it is referred to as a *pseudorange*. Changes in each of these pseudoranges over a short period of time are also measured and processed by the receiver. These measurements, referred to as *delta-pseudoranges*, are used to compute velocity.

A minimum of four pseudorange measurements are required by the GPS receiver to mathematically determine time and the three components of *position* (latitude, longitude, and altitude). The equations used for these calculations are shown in Figure 2-3.

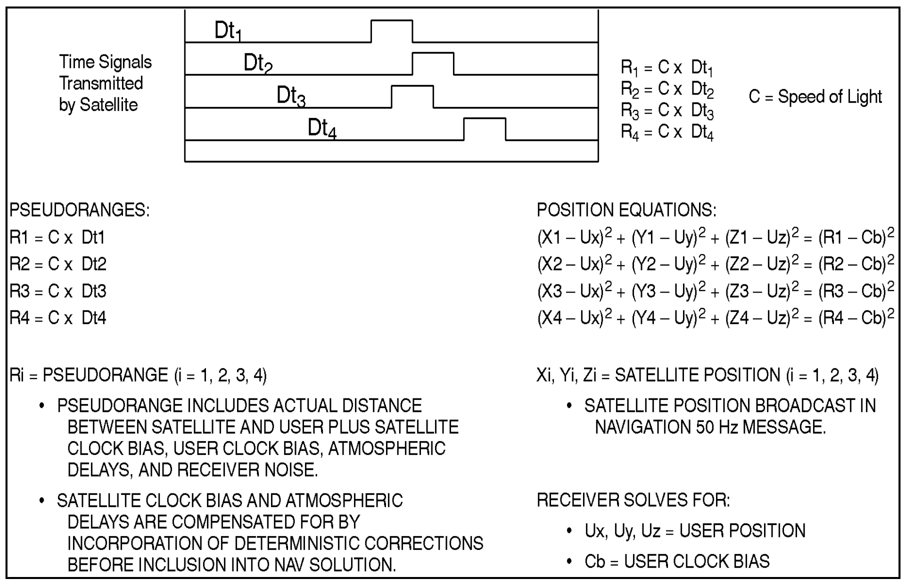

Figure 2-3. Range Processing Equations

The solution of these equations may be visualized as the *geometric intersection* of four ranges from four known satellite locations.

Figure 2-4 illustrates triangulation, which is a way to envision the navigation process. For ease of understanding, time information, which would be derived from a fourth satellite, is not shown.

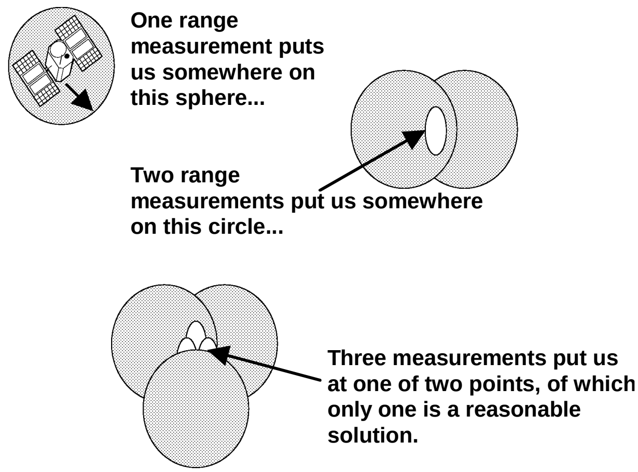

Figure 2-4. Satellite Ranging Intersections

After the four range equations are solved, the GPS receiver has estimates of its position and time. Similar equations are then used to calculate velocity using relative velocities instead of pseudoranges. The position, velocity, and time data are generally computed once per second.

GPS Accuracy

GPS accuracy has a statistical distribution that is dependent on two important factors. The expected accuracy will vary with the *error* in the range measurements, as well as the *geometry* or *relative positions* of the satellites and the user.

Dilution of Precision (DOP)

The Geometric Dilution of Precision (GDOP) indicates how much the geometric relationship of the tracked satellites affects uncertainty of the GPS receiver's position, velocity, and time estimates.

There are four DOP components that are commonly used to indicate how the geometry specifically affects errors in horizontal position (HDOP), vertical position (VDOP), three-dimensional position (PDOP), and time (TDOP). DOPs are computed based on spatial relationships of the lines of sight between the satellites and the user. The motion of the satellites relative to each other and the user causes the DOPs to vary constantly. For the same range measurement errors, lower DOPs relate to more accurate estimates.
The errors in range measurements (the measurements that are used for solving position) can be magnified by poor geometry. The least amount of error results when the lines of sight have the greatest *angular separation* between them (see Figure 2-5).

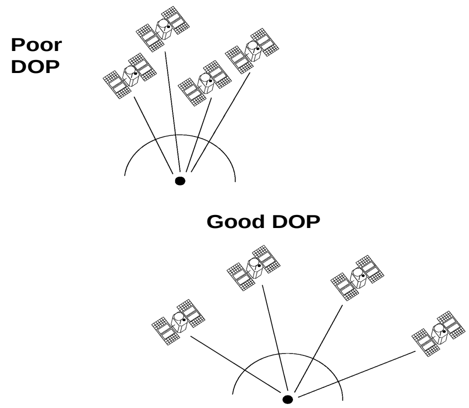

Figure 2-5. Geometric Dilution of Precision

For example, if two lines of sight are necessary to establish a user position, the least amount of error is present when the lines cross at right angles.

Range Measurement Error

The error in the range measurement is dependent upon one of two levels of GPS accuracy. PPS is the most accurate, but is reserved for use by the DoD and certain authorized users. SPS is less accurate and intended for general public use. This is the level of accuracy used by the SDN500 GPS receiver.

Quartz IMU General Theory

The IMU (Figure 2-6) is designed around an *Inertial Sensor Assembly* (ISA). The ISA consists of six single-axis sensors, three *Quartz Rate Sensors* (QRS), three *Vibrating Quartz Accelerometers* (VQA), the drive electronics, preamplifier circuitry for the sensor outputs, and digital conversion electronics.

The output of the VQA is digital, and will be explained later in this section. The QRS output is an analog sinusoid, which is converted to a digital signal in the IMU. The IMU also supplies monitors for health checks and sensor compensation.

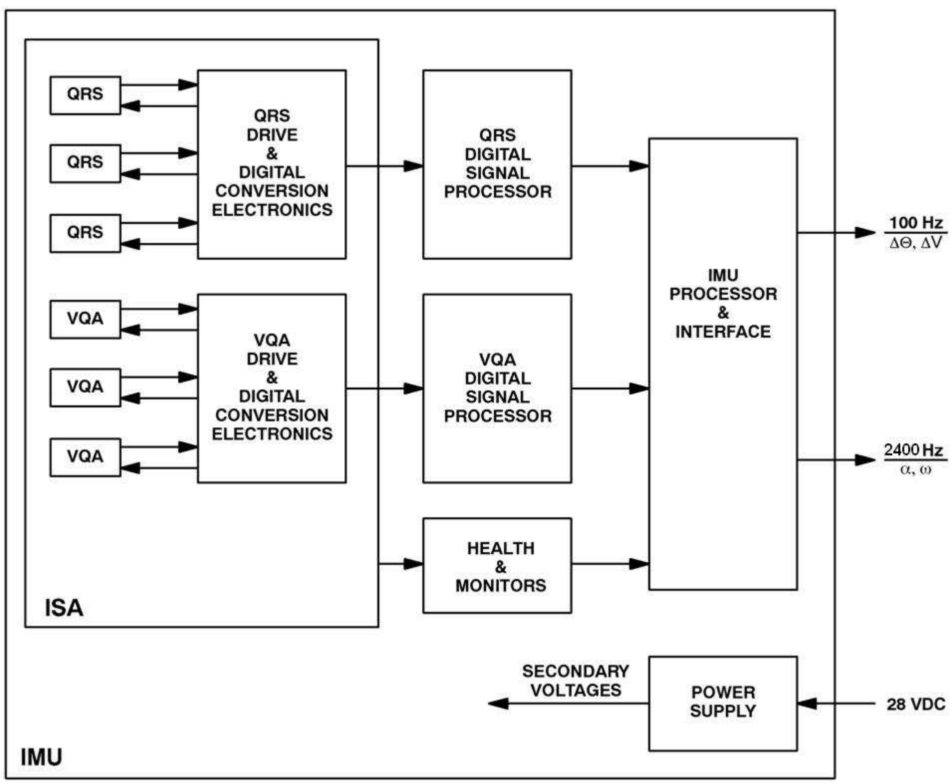

Figure 2-6. SDN500 IMU Functional Block Diagram

The IMU contains the electronics that process the raw sensor signals for compensation. It provides $\Delta\theta$ data and Δv data for navigation at 100 Hz, and acceleration and angular rate for flight control or sensor stabilization at up to 2400 Hz.

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VQA Principles

The basic principle of the VQA is to use a long narrow vibration beam as a *force sensor*. When a force is applied to the beam, the fundamental natural frequency of vibration of the beam will change.

An *acceleration sensor* can be designed using a proof mass, so that the force transmitted from the case of the accelerometer through the vibration beam to the proof mass is proportional to acceleration, per Newton's law.

Several *piezoelectric accelerometers* of this type have been developed, and have at least one vibrating beam as a *free sensor* attached to a pendulous or translational mass. Figure 2-7 shows a typical configuration.

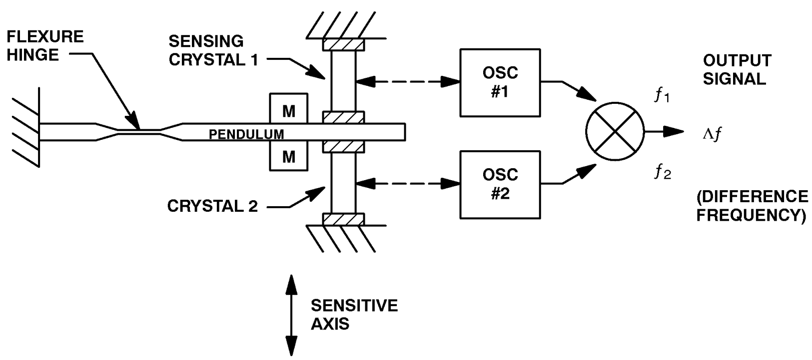

Figure 2-7. VQA Configuration

The vibration of the tines are in the plane of the figure and horizontal. In drive mode of oscillation, the tine of each fork vibrates 180 degrees out of phase with respect to each other.

Double-Ended Tuning Fork Technology

Most *vibrating beam accelerometers* have been designed with two vibrating beam sensors, each consisting of a Double-Ended Tuning Fork (DETF). The DETF design has been chosen because of the inherently higher quality (Q) factor over the single-beam resonator.

The DETF is constructed of crystalline quartz, and made to oscillate electrically by its piezoelectric nature. An input acceleration will cause the beam to be placed into tension or compression, depending on the direction of motion of the proof mass.

The DETF resonance frequency will change, as a piano string resonance frequency changes, with applied tension.

Common mode errors for the two DETFs associated with mounting strain and thermal mismatch will cancel with the configuration.

One frequency will increase and the other decrease with motion of the proof mass. Many error sources cause the frequencies to move in the same direction. In signal processing, the difference frequency is used to determine acceleration.

This differencing increases the sensitivity by a factor of two, and the nonlinear frequency versus acceleration characteristic contains only odd terms in the acceleration power series expansion approximation. In practice, the linear term dominates and modeling accounts for the third order term.

VQA Framed Crystal Advantages

The crystal is mounted using the framed crystal approach shown in Figure 2-8. This has eliminated several problems plaguing recent DETF designs. Using linkage to frame the crystal avoids rotation of the end mounts, which causes tines to decouple and oscillate at different frequencies.

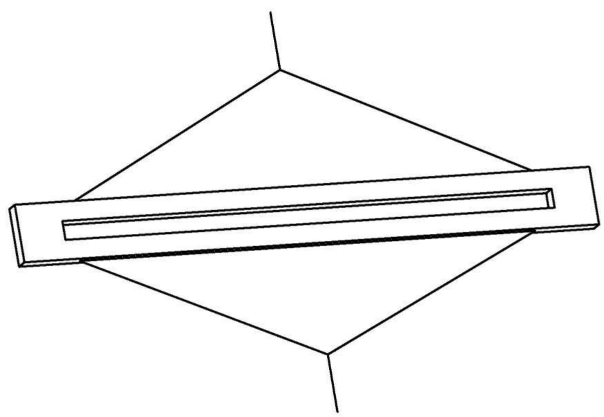

Figure 2-8. Framed Crystal

The typical DETF can withstand very little (~0.002 in.) deformation before fracturing. The framed crystal approach decreases the sensitivity to deflection by a factor of five, and realistic shock caging is easily obtained.

Another advantage to the framed crystal approach is that the tines are better isolated acoustically from surrounding structures. This is important for the sensor assembly, which contains six vibrating sensors operating in a non-vibration free environment. There is also a decrease in sensor length, which aids in manufacturing a smaller IMU.

The VQA's seismic mass is suspended using a Quartz Flexure Suspension (QFS), and is also made of crystalline quartz for stability and elasticity. Resonant frequencies of each sensor assembly exceeds 2000 Hz, and are spaced apart from the crystal drive resonant frequencies to avoid any interaction.

QRS Principles

The SDI500 uses a *dual tuning fork design* shown in Figure 2-9. The drive fork is set into oscillation at its natural frequency. When the device is rotated about the vertical axis, the Coriolis force causes the tines to oscillate at the drive frequency, which is orthogonal to the plane of the fork.

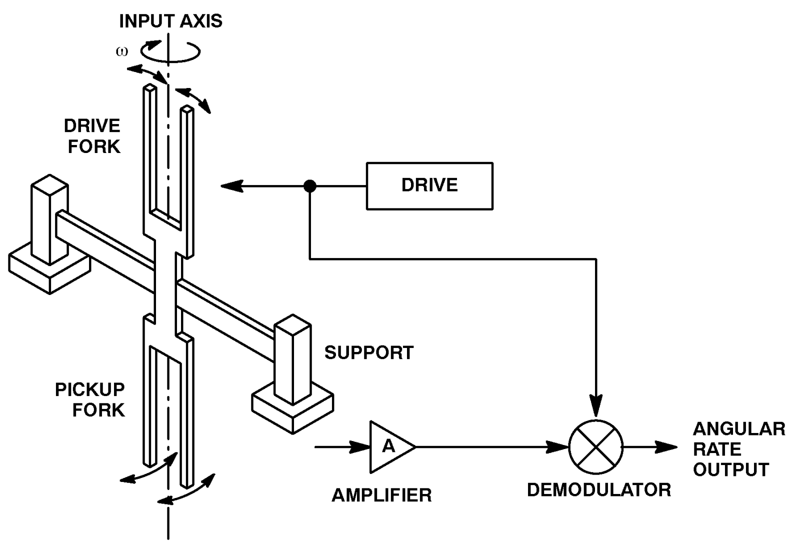

Figure 2-9. Simplified Block Diagram Quartz Rate Sensor

The Coriolis motion is transmitted to the pickoff tines, causing them to oscillate orthogonal to the plane of the fork. The amplitude of the pickoff motion is proportional to the velocity of the drive tines and the angular rate.

The pickoff motion is detected by electrodes attached to the pickoff tines. This pickoff signal is demodulated with respect to the reference drive signal, to give a DC output proportional to the input rate.

To maintain scale factor stability, an automatic gain control loop around the drive tines ensures a constant oscillation amplitude over temperature.

QRS Technological Advances

Micromachining has opened up the potential of using crystalline structures as the complete sensor element.

Recently, the technological approach of *micromachining* has opened up the potential for using crystalline structures as the complete sensor element. This approach is used in manufacturing the IMU by using quartz for the fork material, and by using deposited electrodes on both the drive and pickoff sides.

The mount that supports the quartz element provides isolation to maximize Coriolis coupling torque into the pickoff tines. Drive and pickup voltages are also routed via the mount.

INS/GPS General Theory

Accuracy vs. Time

Inertial navigation systems sense acceleration and angular rate information, which can be integrated to determine position, velocity, and attitude solutions. However, due to inertial instrument imperfections, inertial navigation solution accuracies will deteriorate, or *drift* over time.

INS position error will drift with time; GPS high accuracy solution is time independent.

A GPS high accuracy solution is based on 1-Hertz measurements from GPS satellites. As long as GPS satellite signals are available, the accuracy of the GPS solution is time independent. This characteristic allows the GPS solution to be used to bound the error growth in the inertial navigation solution in an integrated INS/GPS system.

Data Frequency

INS output is high frequency and relatively quiet; GPS output is low frequency.

The INS measurement data is high frequency (greater than or equal to 100 Hz), which allows for computation of *position*, *velocity*, and *attitude* solutions based on integration of high-rate data.

GPS measurement data is low frequency (typically computed at 1 Hz), which allows for computation of *position*, *velocity*, and *time* solutions.

Guidance and control algorithms require accurate, high frequency data. Although some GPS solutions can provide solutions up to 10 Hz, this method is not accurate in dynamic environments when velocities are not uniform over extrapolation intervals.

Therefore, when GPS bounds long-term, IMU-based solution error drift, the IMU provides measurements for computation of accurate, high-frequency solution data for dynamic environments.

GPS Satellite Signal Dependency

GPS solutions depend on availability of GPS satellite signals. When GPS satellite measurements become

INS is a totally self-contained autonomous operation; GPS is dependent on availability of satellite signals.

unavailable, GPS stand-alone system navigation accuracies quickly degrade due to dead reckoning-based solutions. Although GPS satellite signals are always transmitted, a GPS receiver may not be able to track the GPS signals due to the operational environment. Typical conditions that may preclude the ability to track GPS satellites include *jamming* and *antenna masking*.

Jamming can be the result of intentional GPS signal interference or random signal interference. Antenna masking is an obstruction between the antenna and the GPS satellite, such as the wing of an aircraft or a tall building. Regardless of the cause of GPS signal denial, the IMU system is autonomous, which allows an INS/GPS system to continue navigating during periods of GPS signal loss.

The IMU can also be used to aid the GPS in reacquisition after periods of shading or jamming. *Shading* can occur when the line-of-sight GPS signal is obscured by blockage or maneuvers.

Attitude Data Capabilities

As previously mentioned, inertial navigation systems sense acceleration and angular rate. Angular rate data can be integrated to determine *attitude*. GPS systems inherently do not provide attitude information; however, GPS can be used with multiple antenna inputs to estimate attitude, but is limited by jamming, antenna masking, and shading.

INS provides accurate, high rate attitude data; GPS attitude capability is limited.

GPS attitude determination systems are not robust in dynamic environments, and encounter the same deterioration as GPS position solutions when GPS signal obscuration occurs. In an INS/GPS system, inertial angular rate data can be integrated to determine attitude.

In addition, the GPS velocity vector can be used to estimate INS attitude errors. This results in an attitude solution with greatly reduced inertial-based errors. It also enables integrated INS/GPS solutions with low-cost, less accurate IMUs to achieve the attitude accuracy of high-accuracy IMU systems. Error growth over time (an INS-only problem) is also eliminated.

Initialization Capabilities

Stand-alone IMU systems make assumptions about gravity and earth rate to self-initialize. This self-alignment process usually takes time, and often requires a stationary platform.

INS requires dynamic-limited initial conditions; GPS can self-initialize on the fly, and "align" the IMU.

When a GPS system is initialized with crude position, velocity, and time data, it can acquire and track satellites in less than a minute. Even without initialization data, a GPS receiver can acquire satellites in a dynamic environment.

This is achieved by using data stored in GPS memory from a prior successful period of navigation, or by executing *cold start* algorithms that search the sky for any GPS satellite signals.

Once the GPS receiver acquires satellites for navigation, the GPS information can be used to align the IMU. This IMU alignment does not require a stationary platform. In fact, this type of alignment requires vehicle dynamics, which provides increased visibility into IMU navigation solution error sources.

To summarize, an integrated INS/GPS system can power up and self-align in a dynamic or stationary environment without cumbersome stationary alignment requirements.

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Chapter 3- System Overview

System Configuration

The SDN500 is designed to provide a low-cost solution for applications that require an Integrated INS/GPS system. As introduced earlier in this guide, SDN500 is composed of two basic elements: the SDI500 IMU and the Navman Jupiter Pico GPS receiver.

The SDI500 provides angular rate and linear acceleration information at up to 2400-Hz rate, and delta-velocity and delta-theta information about three axes at a 100-Hz rate. The angular rate and linear acceleration data is output over an SDLC serial interface. The SDI500 uses micro-machined quartz rate sensors and vibrating quartz accelerometers to achieve low cost, weight, and volume.

The Jupiter Pico Receiver is a single board, twelve-parallel channel L1 only Coarse/Acquisition (C/A) code GPS engine. This GPS receiver tracks up to twelve satellites, providing accurate satellite-based positioning data while using minimal power. The GPS receiver is a highly integrated digital receiver incorporating custom devices, including a fully integrated radio frequency (RF) front end. This minimizes the receiver's size to about 8 square centimeters and satisfies harsh environmental requirements.

System Technical Description

The SDN500 system, shown in Figure 3-1, combines the SDI500’s high-rate, inertial delta-velocity and delta-theta outputs, and the Jupiter Pico 1-Hz GPS range and range rate measurements to compute a complete navigation solution.

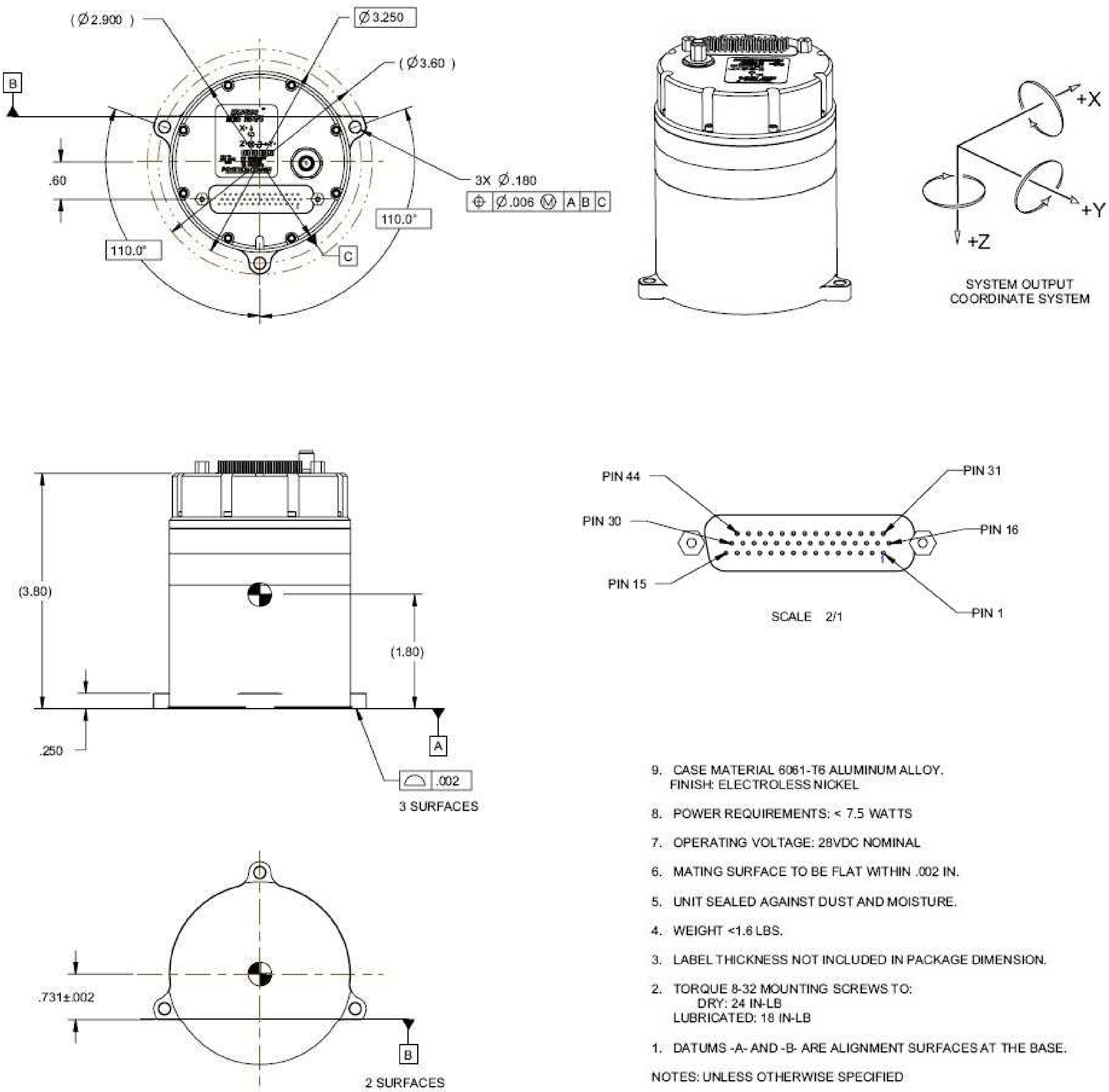

Figure 3-1. SDN500 Form Factor

In normal operation, a three-dimensional navigation solution (including attitude and heading) is computed based on integrated inertial data. This inertial solution is corrected using a Kalman filter, which processes GPS range and range rate measurements at a 1-Hz rate. This results in a robust navigation solution that reduces inertial sensor errors. This solution remains accurate during periods of GPS signal loss due to satellite obscuration or high dynamics.

The SDN500 must complete both inertial system alignment and GPS signal acquisition to achieve an integrated navigation solution. In this system, inertial alignment can occur in both stationary and dynamic environments.

Stationary alignment assumes a motionless platform, and requires heading initialization data. This alignment process requires that the platform remain motionless for a period of three minutes. *Dynamic alignment* assumes a moving platform. This alignment process requires GPS measurement information to compute IMU alignment.

The SDN500 also offers a hybrid mode designated Large Azimuth Alignment. In this mode the IMU is initialized without *a priori* knowledge of the vehicle's heading. The initial heading is then determined after the alignment process is completed using the vehicles dynamics.

SDN500 satellite acquisition time is dependent on the initialization data quality and age of GPS almanac. An external battery may be utilized to maintain acquisition critical information such as ephemeris and time.

Table 3-0. GPS Signal Acquisition TTFF

Initial Error Uncertainties (3 sigma)			**Maximum Almanac Age**	**Maximum Ephemeris Age**	**Time-To-First-Fix ***	
Position (km)	Velocity (m/sec)	Time (min)	(weeks)	(hours)	Typical (minutes)	90% Probable (minutes)
100	75	5	1	4	0.3	0.4
100	75	5	1	U/A	0.8	1.0
100	75	U/A	1	U/A	2	2.5
U/A	U/A	U/A	52	U/A	8	15

* = Assumes no GPS signal blockage
U/A = Unavailable in real-time to the receiver

The length of time required to receive four satellite measurements such that a fully determined three-dimensional solution can be computed is referred to as the Time-To-First-Fix (TTFF). Table 3-0 provides the TTFF information for the SDN500. The values shown are based on unobscured satellite signals.

System Operation

Operation of the SDN500 system requires conditioned power, L1 GPS RF Standard Positioning Service (SPS) signals (1575.42 MHz) from a passive or active antenna, and an RS-232 or RS-422 bi-directional serial port to interface with SDN500 data.

The bi-directional serial port is used to output position, velocity, time, and attitude (PVTA), and status information. Input initialization data and commands are received on this port.

An additional *SDLC synchronous serial output* (two RS-422 pairs) provides high output rate control acceleration and angular rate, as well as inertial delta-velocity and delta-angle data. Use of this interface is optional; it is typically used for flight control applications that require data rates of 100 Hz or greater. The output rates can be configured to be 2400 Hz control data with 100 Hz inertial data, 1200 Hz control data with 100 Hz inertial data or 600 Hz control data with 100 Hz inertial data.

In a stationary environment, the SDN500 powers up in *Initialization* mode. When it receives serial port initialization data including position, heading, and time, SDN500 will begin IMU alignment. GPS acquisition will start immediately upon power application, and will utilize serial port initialization data only if it has not already acquired GPS satellite signals. This flow logic can be controlled by the user. For instance the SDN500 can be configured to only begin alignment using only GPS data, in which case the system would wait until a proper GPS fix is acquired.

After a set static alignment period of 2 minutes, the system will transition to *Navigation* mode, using GPS signals when available.

In a dynamic environment, SDN500 powers up in *Initialization* mode. Once again, GPS satellite acquisition will start immediately upon power application, and will utilize serial port initialization data only if it has not already acquired GPS satellite signals. After satellite acquisition is complete, the GPS position and velocity vector is used to initiate INS dynamic alignment.

IMU dynamic alignment quality then becomes a function of system dynamics. Vehicle maneuvers including heading changes are required for the system to complete dynamic alignment and proceed to *Navigation* mode.

Product Performance

Integrated INS/GPS PVTA Accuracy

The SDN500 GPS operates in Standard Position Service (SPS) mode. The integrated INS/GPS Position, Velocity, Time and Attitude accuracies (PVTA) are defined the Table 3-1. The position velocity and time accuracies are determined by the performance of the GPS. The attitude accuracy is determined by the combined performance of the SDI500 IMU inertial sensors and the GPS receiver.

Table 3-1. Position, Velocity, Time, and Attitude Accuracies

	Position (meters)			**Velocity (meters/sec)**		**Time**	**Roll/Pitch**	**Heading**
State	3D Position SEP	Horizontal Position CEP	Vertical Position VEP	Horizontal (East or North) 1 sigma	Vertical 1 sigma	μsec 1 sigma	mrad 1 sigma	mrad 1 sigma
SPS	3.9	2.5	3	0.1	0.1	1	1.0	1.5 + d

Notes:

1. Time performance is for GPS time as referenced to Time Mark 1 PPS output pulse.
2. Attitude accuracies are referenced to the IMU case mounting interface.
3. Heading accuracy assumes dynamic motion, which allows for IMU instrument calibration. If there is no dynamic motion, then heading will drift (d) per the gyro bias in-run stability parameter.

SPS performance shall apply when conditions in Table 3-2 are satisfied.

Table 3-2. INS/GPS System Accuracy Assumptions, SPS Operation (Corrected Data Only)

User range error due to Control/Space Segment errors.	$\leq$ 6 m, 1σ
PDOP (RMS)	$\leq$ 2.6
HDOP (RMS)	$\leq$ 1.45
VDOP (RMS)	$\leq$2.21
TDOP (RMS)	$\leq$ 1.21
Ionospheric model error, per satellite.	$\leq$ 5 m, 1σ
Tropospheric model error, per satellite.	$\leq$ 2 m, 1σ
Multipath signal error, per satellite.	$\leq$ 1.2 m, 1σ
State 5 J/S (20 MHz BW AWGN)	$\leq$ 41 dB
State 3 J/S (20 MHz BW AWGN)	$\leq$ 57 dB

INS Only Performance

Accuracy during *INS-Only operation* (e.g. during periods of heavy jamming or satellite obscuration) is determined by the level of calibration obtained during *INS/GPS operation* and the level and type of dynamics sustained after GPS is lost.

SDN500 INS-only outputs meet the accuracies described below, which depicts SDN500 performance under a typical UAV flight condition. The performance depicted in the figures assume that the SDN500 is under nominal flight conditions shown after a period of normal Air Navigation Mode INS/GPS operation, and includes a minimum of two, 30-degree turns just prior to the start of *INS-Only operation*. Failure to provide sufficient dynamics for IMU calibration will result in degraded performance.

The UAV flight profile utilized for this *INS-Only operation* example is a fixed wing UAV flying several racetrack and coordinated turn maneuvers after the loss of the GPS signal. The profile lasted for 1.3 hours.

Figure 3-2 shows the expected position error after the loss of GPS while flying this typical UAV flight envelope. Figure 3-3 shows the expected attitude error after the loss of GPS.

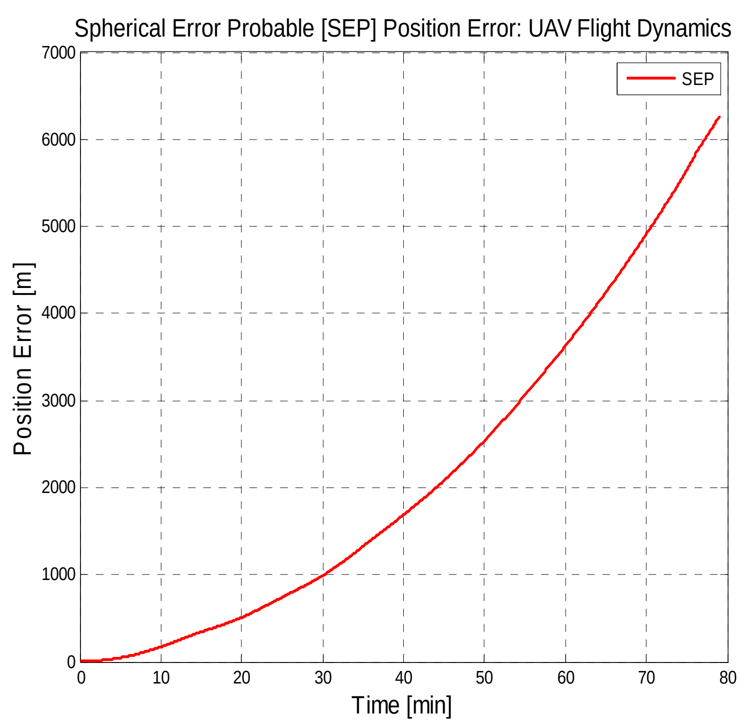

Figure 3-2. Expected Position Error Growth

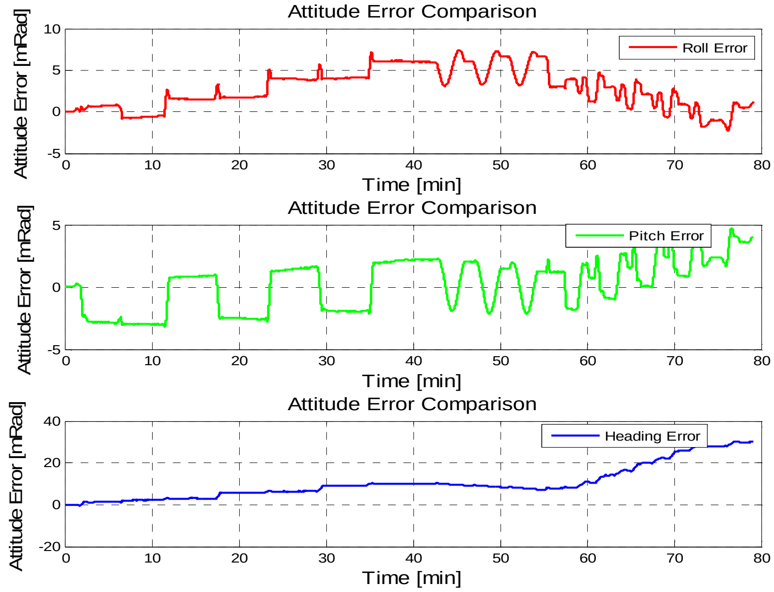

Figure 3-3. Expected INS Only Attitude Error Growth

System Power Requirements

The following is a brief overview of SDN500 power requirements, including input voltage, current, overvoltage protection, and battery voltage.

Input Voltage

The prime power input voltage to SDN500 is 12-42 volts DC, as measured at the input, referenced to power return/ground ("GND"). The input power supply is reverse voltage protected.

Current

The typical steady-state current drawn by SDN500 is 250 mA at 24 volts DC. The typical input current surge is less than 3 amps at 15 volts DC.

Battery Voltage

SDN500 provides for an *optional battery input*. This optional input power is used when prime power is off, to maintain a low-power time source and an accurate set of satellite parameters in the GPS receiver SRAM.

Signal Interface Environment

SDN500 provides one full-duplex asynchronous RS-232 or RS-422 (user selectable) serial data port for navigation data output and navigation software command and control, and a single-directional (output) synchronous SDLC data port for SDI500 IMU data output at high output rates.

Radio Frequency Signal Environment

The GPS RF input is 1575.42 MHz (L1 band) at a level between -130 dBW and -163 dBW. Burnout protection is provided for a -10 dBW signal within a bandwidth of 10 MHz centered about the L1 carrier frequency.

Physical Dimensions

This section describes the SDN500 envelope dimensions, installation requirements, mass properties, coordinate systems, and polarities.

Envelope Dimensions

The SDN500 envelope dimensions are shown in Figure 3-4 and are: Width = 2.9”, Height = 3.80”, Volume = 25.0 cu in.

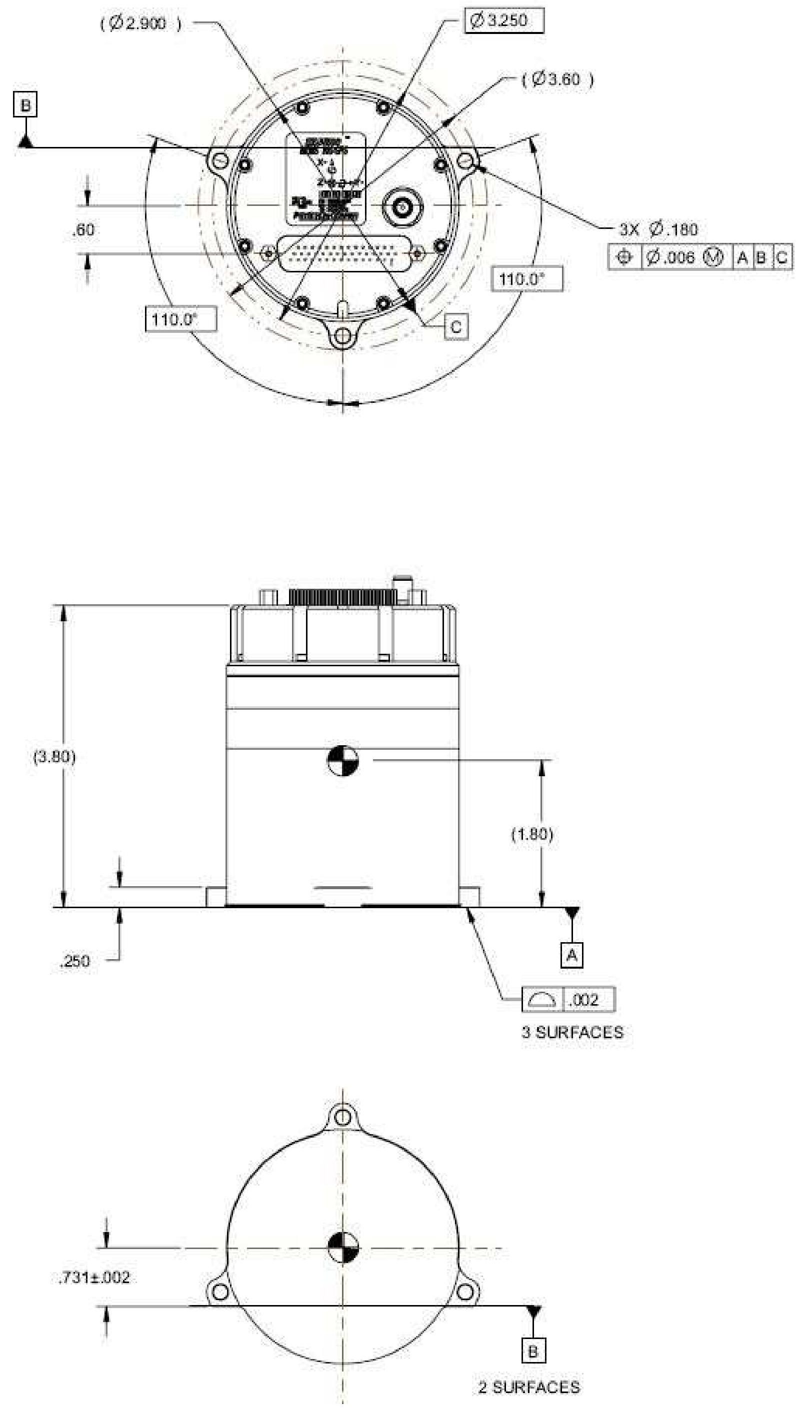

Figure 3-4. SDN500 Mechanical Dimensions

Installation Requirements

As specified in Figure 3-4, system alignment is achieved via the alignment surfaces shown as reference A and B in the figure and the mounting holes. The mounting screw torque requirements are as follows:

Dry: 24 In-Lb
Lubricated: 18 In-Lb

Mass Properties

The weight of the SDN500 is < 1.60 pounds.

Boresight / Axis Alignment

Mechanical system axes are a right-hand orthogonal set labeled x, y, and z, as shown in Figure 3-5. The Z-Axis is positive down through the unit perpendicular to the base plate, the X-Axis is positive perpendicular to the connector and the alignment surface shown in reference B in Figure 3-5, and the Y-Axis is positive parallel to the connector and the alignment surface shown in reference B in Figure 3-5.

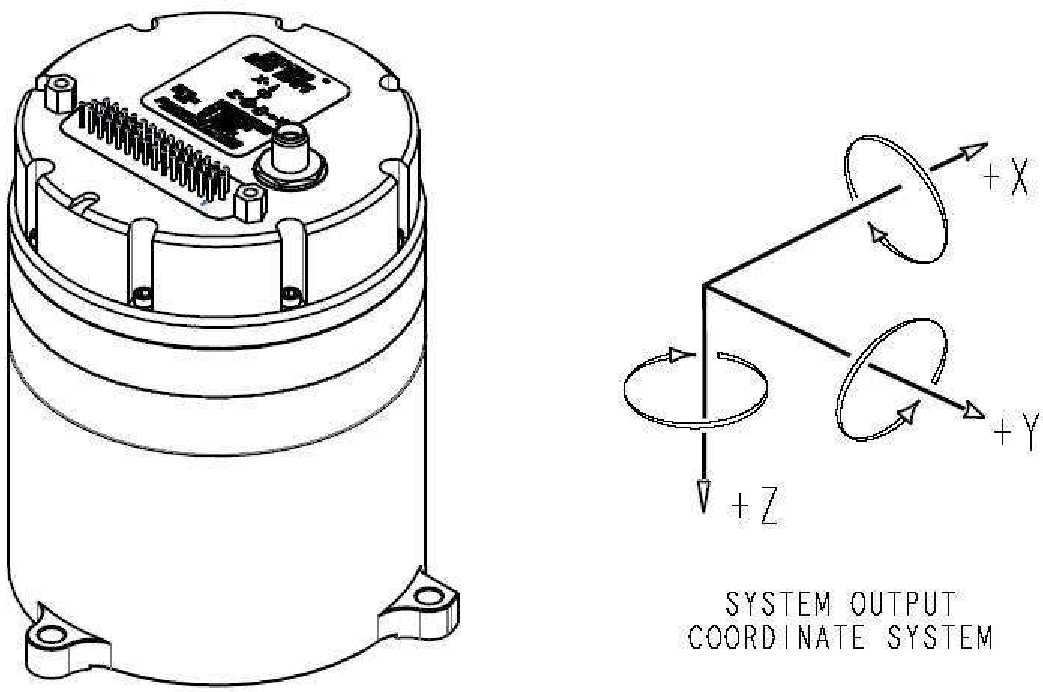

Figure 3-5. SDN500 Axes Definition

Environmental Specifications

The SDN500 environmental specifications are provided in Table 3-3. These conditions are without safety and/or intensification factors. Under these conditions the SDN500 will perform within the limitations defined herein.

Table 3-3. SDN500 Environmental Specifications

Characteristic	Specification
Temperature *Mounting Base Temperature*	-40 C to + 71 C Operating -54 C to + 85 C Storage
Humidity	95%RH, 60°C 10 Cycles @ 24 hrs
Thermal Shock (Non-op)	-40 C to + 71 C, 0.42 C/sec

Thermal Slew (operating)	5°C/min
Thermal Cycling	>400 cycles over range -40 C to + 71 C
Random Vibration *Captive Carry*	12g RMS performance flat spectrum, 20 Hz–2 kHz
Sine sweep vibration	DO160E helicopter 2g beyond delta-f. Curve L(3g modified to go through delta-f)
Shock	Survival – 150 g 11 msec half sine Operating – 40g 30 msec Operating – 250g 1.5 msec
ESD	Mil-Std-1686C, Class 1
EMI Emissions/Susceptibility Mil-Std-461F	**CE03:** Conducted Emissions. Power leads, 15kHz to 50 MHz **CE07:** Conducted Emissions. Power leads, Switching spikes (42V to 9V) **CS01:** Conducted Susceptibility. Power leads, 30Hz to 50KHz, 2.8Vrms. **CS02:** Conducted Susceptibility. Power leads, 50Khz to 400MHz, 1Vrms. **CS06:** Conducted Susceptibility. Spikes, Power leads, 0.15usec @150V peak to peak, 10 usec @200V peak to peak **RE02:** Radiated Emissions. E-Field, 10kHz to 18GHz < or = 10V/m **RS03:** Radiated Susceptibility. E-Field, 2MHz to 40GHz < or = 200V/m
Altitude	< 50,000 ft: full accuracy < 60,000 ft: maximum altitude for GPS aiding
Compression	Collapse: 2280 Pa/sec (0.33 psia/sec) Burst: 480 Pa/sec (0.07 psia/sec)
Rain	Mil-Std 810G Method 506.4 (Use Procedures I, II, III)
Salt fog	Mil-Std 810G Method 509.4 (48 hour exposure)
Fungus	Mil-Std 810G Method 508.5 (28 day period)
Operating Life	20 Years
MTBF (Ground Benign) *MIL-HDBK-217F*	> 50000 Hours
MTBF (Air Inhabited Cargo) *MIL-HDBK-217F*	> 6000 Hours
Acceleration Full Navigation Solution	4 G
Acceleration Inertial Only Solution	50 G
Acceleration Endurance	100 G
Jerk	9 G/sec

Velocity	500 m/sec maximum velocity for GPS aiding
Angular Rate	1000 deg/sec

Chapter 4 - Operation

Operating Modes

The processing state of the SDN500 at any particular time is defined by a mode. SDN500 utilizes the following operating modes:

- *Test*
- *Initialization*
- *Fine Alignment, Air Alignment*
- *Air Navigation*
- *GPS-Only Navigation*

Mode sequencing after a normal startup of the SDN500 is shown in Figure 4-1. After startup, the SDN500 sequences automatically through Test mode to Initialization mode.

After navigation initialization data is entered by the user and accepted, sequencing continues to one of two alignment modes: *Fine Alignment* or *Air Alignment.* The choice of sequencing is made by user input. (At this time Transfer Alignment is not implemented.) During these modes a Kalman filter is used to estimate IMU parameter errors and vehicle attitude.

After completion of an *Alignment* mode, sequencing continues to the navigation mode: *Air Navigation*. Choice of sequencing, again, is by user input.

In this mode, navigation is performed based on INS data, with updates from GPS data. If GPS data temporarily becomes unavailable, navigation will continue with only INS data.

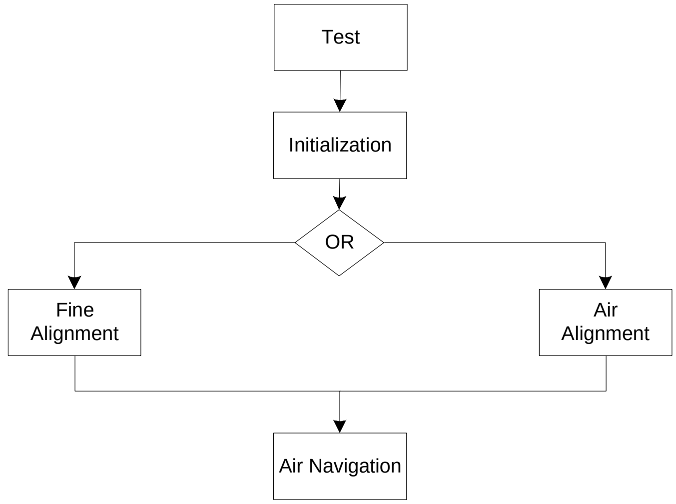

Figure 4-1. SDN500 Operational Mode Sequence

The processing performed by SDN500 during the various modes is described below.

Test Mode

Test mode is in effect while *Built-In Test (BIT)* is being performed as a part of normal startup sequence.

The BIT function is entered immediately after power-on or after software reset. BIT tests the functional areas of SDN500.

Initialization Mode

Initialization mode is in effect after completion of BIT, but before navigation initialization data is provided. During this mode, the GPS processor attempts to acquire satellite signals and enter navigation mode. It can succeed in doing this even before navigation initialization data is provided.

Navigation initialization data may either be provided by the user, or obtained from the GPS processor after it enters navigation mode. Choice of these options is made by user input.

Once navigation initialization data is obtained, then position, velocity, and heading are initialized. Accelerometer data is used to obtain initial coarse estimates of pitch and roll. After this is performed, Initialization mode is exited automatically, and continues to one of the *Alignment* modes.

Fine Alignment Mode

Fine Alignment mode performs alignment when SDN500 is stationary. Fine Alignment consists of estimation via a Kalman filter of the vehicle orientation, as well as estimation of IMU parameter errors (accelerometer scale factor and bias, and gyro scale factor and bias). Fine Alignment mode is exited automatically after 120 seconds to Air Navigation mode, or must be commanded to exit if the automatic sequence feature is not selected. For a thorough explanation of the automatic sequencing, please see the section labeled Message 3510 - SDN500 Control and Initialization on page 127. Information can also be found in Appendix A-Frequently Asked Questions.

Air Alignment Mode

This mode performs alignment using GPS data as a velocity reference. GPS data must be available for the processing of this mode to be complete. The alignment process estimates the vehicle orientation and IMU parameter errors, and also the GPS clock error and antenna lever arm. *Air Alignment* mode is exited to air navigation mode when the Kalman Filter covariances of the heading and the lever arms fall below specified thresholds.

If *Air Alignment* is entered while the vehicle is traveling at speeds greater than 50 m/sec, a submode called *Coarse Air Alignment* will be initiated. This submode is indicated by bit 8 (mask 0x0100) of the System Status Validity word (word 11) of the System Status message, 3500. During this submode, the vehicle should maintain a straight and level course until the submode bit indication is reset. Straight and level flight is defined as the ability to maintain the airplane on a constant altitude and heading. The following parameters should be maintained:

- Airspeed within +/- 10 knots
- Heading constant within +/- 15 degrees
- Altitude within +/- 200 feet

Exceeding these parameters can result in poor performance from the *Coarse Air Alignment* mode, which could result in reduced performance once the system enters Air Navigation mode. Once *Coarse Air Alignment* mode is complete, the SDN500 will continue in normal *Air Alignment* mode and it will no longer be necessary to maintain a straight and level course. In fact, some maneuvers are advisable to speed up the convergence of the error covariance values that control the exit from *Air Alignment* mode. For further information, see Appendix A- Frequently Asked Questions on Air Alignment.

Air Navigation Mode

This mode is the navigation mode of the SDN500. Navigation is performed using IMU data, and the Kalman filter is used to estimate errors in position, velocity, attitude, IMU parameters, and GPS time. The observables for the Kalman filter are the GPS pseudorange and delta pseudorange measurements.

Figure 4-1 shows the normal mode sequencing of the SDN500 after startup. Other mode transitions are also possible by user command. Allowed mode transitions and the conditions for them are summarized in Table 4-1 below.

Table 4-1. Mode Transition Table

From/To	Test	Init	Fine Align	Air Align	Air Nav
Test	-	A	-	-	-
Initialization	C	-	A	A	-
Fine Alignment	C	C	-	-	A
Air Alignment	C	C	-	-	A
Air Navigation	C	C	-	-	-

A = automatic, C = commanded

Heading Hold Mode

Heading hold feature is another feature implemented inside of the SDN500. The heading hold feature can be used when the system is in air navigation mode, and when the system is required to be stationary for a long period of time (Greater than 5 minutes). It will prevent heading from drifting and help to achieve better performance while stationary and afterwards once navigation resumes. The basic concept of heading hold is to use the SDN500 system heading value at the time the heading hold is commanded, and to maintain that heading value for the entire heading hold period. When in heading hold mode, any external heading reference input, such as magnetometer data, will be ignored and when not in heading hold mode, external heading reference data will be processed if available.

Heading hold control is commanded through Message 3504 - SDN500 Parameter Control when the SDN500 is in air navigation mode and stationary. The vehicle must be kept stationary while in the heading hold period. Once motion is desired to resume, a heading hold off command via Message 3504 - SDN500 Parameter Control has to be sent to the unit to take it out of heading hold mode. Heading hold mode however does have a movement checking function, which checks whether your vehicle is stationary or not. If some movement is detected, then heading hold will be automatically released. However, because of the nature of pure heading change without forward velocity and the velocity resolution from the GPS, performance cannot be guaranteed if the automatic release algorithm is executed. It is highly recommended that the user use the command controls to engage and disengage the Heading Hold mode prior to moving the vehicle. Entry into and exit from Heading Hold Mode can be monitored through the System Status Validity Word in Message 3500 - SDN500 System Status.

GPS Receiver Operation

This section summarizes the operation of the GPS receiver during acquisition of GPS data.

Satellite Acquisition

The GPS receiver enters acquisition when system power is applied, and continuously on channels that have not already acquired a satellite. Activities performed by the receiver while in acquisition involve searching for satellite signals with which to navigate, acquiring and tracking those satellite signals, and collecting data from the tracked signals, if necessary, before navigating.

RF Signal Requirements

The signal strength at the RF input into the receiver should support a Carrier-to-Noise density ratio (C/No) of at least 34 dB-Hz. This is required in order for a given satellite to have a 99 percent chance of being successfully acquired in one attempt. The success rates are reduced to less than five percent as the signal-to-noise ratio is reduced to 29 dB-Hz.

Data Requirements

To begin acquisition activities, the GPS receiver must determine the approximate position and movement of satellites in relation to the position and movement of the receiver's antenna. The receiver will attempt to acquire and track those satellites visible to the receiver antenna at the current time. To do this, the GPS receiver, at a minimum, needs the following:

- Current antenna position
- Current antenna velocity
- Current UTC time
- Satellite almanac

In addition to satellite orbit information, almanac data includes the health status of the satellites. No attempt is made by the GPS receiver to acquire satellites indicated as "unhealthy" in the almanac data. An elevation mask angle value is used to screen out lower elevation satellites, whose signals are likely to be obscured. The default angle for the receiver is 10 degrees

Data Initialization

There are two fundamental means by which the data outlined above is initialized. The first, *Initialization*, occurs automatically each time the receiver enters the Operational Mode from either the “Off” or "Keep-Alive" state. The second, *Commanded Initialization*, is an initialization commanded by the Host Vehicle.

Self-Initialization

The receiver first examines internal RAM and the Real-Time Clock (RTC) to determine if the data required to begin acquisition exists. This is the case if the GPS received battery back-up power (after successfully navigating in Air Navigation Land, or GPS Only mode), and none of the data has become invalid (either the ephemeris is older than 4 hours or it has been corrupted).

If the data is not there, data from the receiver’s memory is used as a source of satellite almanac, antenna position, and current week. Also, the antenna velocity components are set to zero, the current time-of-week is set to a default setting of Saturday midnight, and Cold Start is enabled.

Except for Cold Start, a valid current time must be supplied by the Host Vehicle when battery back-up power is not maintained.

Commanded Initialization

A critical step in reducing the acquisition time, or time to first fix (TTFF), is to ensure that the receiver is supplied the correct values for the self-initialization data. If any of the data from self-initialization is incorrect or unavailable, TTFF is increased.

The Host Vehicle can supply data and command the receiver to perform initialization through the use of serial input messages. After powering up the receiver, and receiving the first Time Mark Solution message (message 3623) via serial data output, a serial input Position, Velocity, and Time (PVT) initialization message (message 3510) can be safely transmitted to the receiver for data initialization.

Current user antenna position, velocity, and current time may be initialized to the correct values through the use of the initialization message. Until such a message is input, the self-initialization values of these three data items are shown in the Time Mark Solution message that is output by the receiver.

If an initialization message is input, then the values in the Time Mark Solution message during acquisition will be replaced by these new values.

When initial position and velocity values are within the uncertainty limits described in Table 3-1, the average TTFF will continue to be reduced as the uncertainties in the supplied values become smaller. The initial Universal Time Coordinate (UTC) time should be within five minutes of actual UTC time.

Cold Start

Lacking position, time, current ephemeris, and almanac data, the receiver can still arrive at a navigation solution. This situation is known by the term "Cold Start". Cold Start is an enhanced algorithm by which the GPS receiver searches the sky to locate visible satellites. The TTFF for this process is longer than commanded or self- initialization (see Table 3-0).

Acquiring Satellites (With the Exception of Cold Start)

When acquiring GPS data, the GPS receiver determines the approximate positions of all visible satellites. From this group, a set of four satellites with the best GDOP is chosen. This group is called a *Primary* set.

The GPS receiver then begins acquisition of the first satellite by choosing the highest of the primary satellites (by elevation angle) and commanding all twelve receiver channels to search for that satellite, each in a different Doppler frequency range. These frequency ranges are obtained by applying Doppler shifts, computed from the satellite's position and movement, to the Ll satellite signal frequency.

In each channel, the GPS receiver correlates the incoming signal with a locally generated replica of the C/A code sequence for the particular satellite being acquired.

Once the code is detected (i.e., correlated), a pair of tracking loops is activated to track both the code sequence and the signal carrier. As the code and carrier are tracked, the GPS receiver determines the location of the navigational data bit sequence within the signal. This provides additional time-of-day and time-of-arrival data to be used along with the current value of GPS time to compute more precisely the Doppler frequency ranges in which the remaining satellites may be found.

On occasion, the GPS receiver may "miss" the first satellite, or, unable to acquire the satellite within a certain amount of time. This could be due to an obscuration, incorrect, or old initialization data. If the receiver is unable to find the first satellite, the next highest primary satellite (by elevation angle) is assigned to all twelve channels and the acquisition process restarts. The receiver will continue cycling through the visible satellite list, according to its current almanac, until a satellite is acquired and tracked.

After successful acquisition and tracking of the first satellite has been accomplished, one of the receiver channels continues to track it while each of the remaining channels is released to search for a different visible satellite.

Cold Start Acquisition

In Cold Start operation, the GPS receiver computes a visibility list based on whatever initialization data is available. If no acquisitions occur from the highest four satellites on this list and Cold Start is enabled, Cold Start function will be entered, and at which time the remaining satellites will be added to the search queue. The order of search may be modified as time and position data is obtained from tracked satellites.

Ephemeris

Satellite ephemeris data is considered to be valid if its age is within its curve-fit validity window (usually 4 hours). When available in RAM, valid satellite ephemeris is used instead of the almanac to determine visible satellites, their positions, and movements relative to the GPS receiver.

The GPS receiver must have valid ephemeris for at least four satellites being tracked to begin navigating.

Therefore, for each acquired satellite that is to be used for navigation, but has non-existent or invalid ephemeris in RAM, ephemeris data must be collected for the satellite before the receiver begins navigating.

If the ephemeris data is valid, but has been updated by the GPS Control Segment (i.e., the data in RAM is greater than 1 hour old), then new ephemeris data is collected to update the data onboard the GPS receiver. Usually 18 to 36 seconds of uninterrupted tracking of a given satellite is required to obtain ephemeris for that satellite.

Collected ephemeris data may indicate that the satellite is "unhealthy", in which case the satellite cannot be used for navigation and is replaced with another satellite if one is available. This increases TTFF.

Acquisition from First Power-Up

When powering up the GPS receiver for first time, initial acquisition data will reflect default factory settings. For a rapid TTFF, it is necessary to send an initialization message containing position and time, or rely on a Cold Start.

Reducing Time-to-First-Fix

The GPS receiver contains a section of volatile static RAM (SRAM) where navigation data can be maintained for a limited time on battery power while the receiver is off. During this time, the GPS receiver is said to be in the "Keep-Alive" state. After the navigation data is lost, the GPS receiver is said to be in the "Off" state.

Minimized Acquisition Time From Off State

When power is applied to the system from the "Off" state, the receiver loses the data retained in SRAM. Through self-initialization, the receiver retrieves position, almanac, and current week data stored in EEPROM. An initialization message containing, at a minimum, UTC time is required to overwrite the default time.

Note: The last stored position in EEPROM is not necessarily the last user position just prior to the previous power-down.

A new position is stored during a navigation state when both of the following occur:

- The distance to the previously stored position is greater than 100 km.
- The age of the previously stored position is greater than 6 hours.

If the position uncertainty is greater than 100 km (e.g., due to transport of the receiver while in the "Off" state), then the initialization message should also contain current position. As before, it will be necessary to include current velocity in this message if the uncertainty is greater than 75m/sec.

If the receiver has been off for a period of time greater than six months, the almanac will be updated when satellite tracking is resumed.

Minimized Acquisition Time from "Keep-Alive" State

When powering up using backup battery power (or the “Keep-Alive” state), and, assuming there has been prior operation the normal navigational modes and the receiver has not been removed from its battery power, the receiver has access to the data maintained in volatile memory (SRAM). Therefore, it has the last navigation solution and set of satellite ephemeris that were present at the time of power-down.

The TTFF depends on the age of this data (i.e., the length of time that the receiver was using keep-alive power). The low-power timer will maintain time when utilizing keep-alive power, but position and velocity may require initialization if uncertainties are outside the 100 km and 75 m/sec limits, respectively.

If the receiver was using keep-alive power for a length of time that caused the resident ephemeris to be older than the age allowed by its curve-fit validity window (typically 4 hours), then TTFF will be impacted due to collection of new ephemeris, which takes 18 to 36 seconds (24 seconds average).

Almanac

Almanac data is used by the receiver to determine where best to search for the satellites' signals. This data is uploaded to the satellites by the GPS Control Segment of NAVSTAR. Although frequently updated, the same set of almanac parameters can be effectively used for several months, except in rare cases when satellites are repositioned or new satellites are launched.

Once a satellite is being tracked by the GPS receiver, ephemeris parameters are used to continue tracking the satellite or re-acquire a satellite if its signal is lost. Ephemeris data is more accurate than almanac data, but is typically valid for a 4-hour portion of the satellite's orbit. If the GPS receiver remains without power for several months, acquisition time increases.

Note: Almanac data for all GPS satellites is broadcast by each satellite, but each satellite broadcasts ephemeris data only for itself.

Solution Time of Validity

GPS receivers provide almost instantaneous position and velocity solutions. In general, GPS receivers take a snapshot of the satellite measured ranges, at a precise moment in time, to calculate the user position. Then, a time-exposed snapshot of the change in ranges is taken to reach the velocity solution.

The single snapshot is actually called a pseudorange measurement, while the time-exposed snapshot is called a pseudorange rate or delta-range measurement. A GPS receiver requires processing time between measurements to calculate the user position and velocity.

During the computations, the receiver compensates for position errors by propagating the user position forward one second, based on the velocity of the user. The user velocity is derived from a delta-range measurement. The delta-range measurement is calculated by monitoring and integrating the Doppler shift between the receiver and a satellite over a finite, predetermined period of time.

At the completion of a delta-range measurement, a pseudorange measurement (see Figure 4-2) is performed. This provides the receiver velocity and instantaneous range for each of the receiver channels. The receiver processes this data and calculates a user position and velocity. Since the receiver may be moving during processing time, the data is extrapolated by using the user velocity projected in time by one second (the time required to provide the data at the serial data port).

The GPS receiver provides the user with position and velocity data every second. The system integrator's equipment is provided a Time Mark pulse at the instant the data at the serial port is valid. Figure 4-2 illustrates a timing diagram for these events.

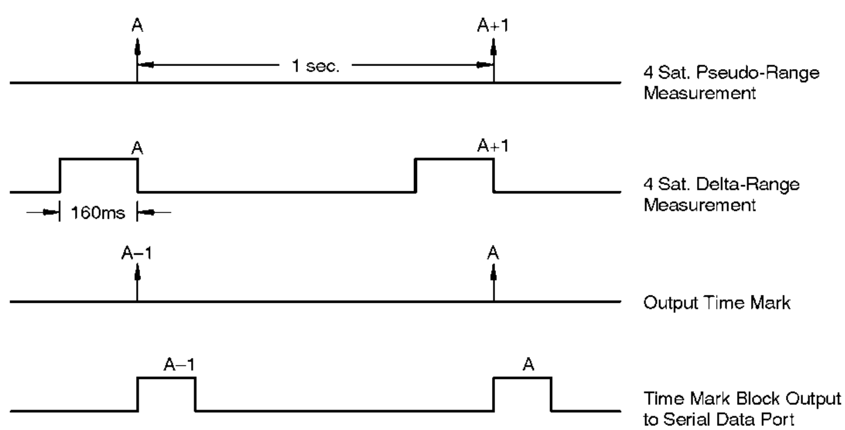

Figure 4-2. Typical Navigation Solution "Time Mark" Output

"A" represents a particular navigation solution, whereas "A-l" and "A+1" represent the prior and future navigation solutions, respectively.

Once the satellite pseudorange and delta-range measurements are made, the data is processed and projected forward 1 second to prepare for an *Output Time Mark* pulse. At the leading edge of this pulse, the valid navigation data is provided to the *serial data port*.

In some instances, the navigation data will be delayed by a short period of time due to "bus" contention by the Host Vehicle, or by messages previously queued or in progress as a valid transmission by the receiver to the Host Vehicle. In any case, the navigation solution presented is valid at the instant the Time Mark pulse occurred. The SDN500 output messages contain a time stamp that specifies the time at which the measurements contained within that message are valid.

Geometric Dilution of Precision

During navigation modes, SDN500 maintains a constellation of four satellites (if four are available) that provide the best geometry for an accurate navigation solution. These satellites are referred to as *primary* satellites. The remaining satellites are considered to be *secondary*.

The measure of the quality of a satellite constellation's geometry is called *Geometric Dilution of Precision* (GDOP). GDOP reflects the influence of satellite geometry on the accuracy of user position estimates and user time. The best geometry is that which produces the lowest GDOP value. GDOP is a multiplier of position error due to other sources.

Components of GDOP

GDOP is a composite measure. It includes *Position Dilution of Precision* (PDOP), which reflects the effects of geometry on three-dimensional position estimates, and *Time Dilution of Precision* (TDOP), which reflects geometric effects on time estimates. The relationship can be expressed as:

$$GDOP = \sqrt{(PDOP)^2 + (TDOP)^2}$$

In turn, PDOP can be expressed in terms of *Horizontal Dilution of Precision* (HDOP) and *Vertical Dilution of Precision* (VDOP), which are geometric effects on two-dimensional horizontal position estimates and on vertical position (altitude) estimates, respectively. This relationship can be expressed as:

$$PDOP = \sqrt{(HDOP)^2 + (VDOP)^2}$$

IMU Operation

The IMU is designed to provide internally compensated, sensor axis referenced, orthogonal, simultaneous measurements of angular rate and linear acceleration at a 600 Hz, 1200 Hz or 2400 Hz rate. The rate is user selectable. In addition, the IMU provides delta velocity information in three axes and delta attitude information about three axes at a 100-Hz rate. The data is output on an SDLC formatted serial bus with the higher rate data defined as *autopilot data* and 100-Hz data defined as *inertial data*.

The IMU consists of an *Inertial Sensor Assembly* (ISA) and *Inertial Sensor Electronics* (ISE). The ISA contains a cluster assembly and an electronics module. The cluster assembly consists of three block mounted, mutually orthogonalized *Quartz Rate Sensors* (QRS), and three mutually orthogonalized *Vibrating Quartz Accelerometers* (VQA), in a shock-mount configuration.

The electronics module contains the direct interface electronics to the inertial instruments that provide a digital interface to the ISE. The ISE provides the signal processing and computational capability required to convert the inertial instrument outputs to formatted autopilot and inertial data.
A summary of error sources used to characterize the SDN500 IMU outputs for the *autopilot data* is shown in Table 4-2. There are three flavors of the SDN500 available and their IMU performance levels are defined in the columns labeled (A), (B) and (C). Where they are common, a general IMU performance level is defined.

Table 4-2 SDN500 IMU Performance Levels (1)

Gyro Channel	Units	Type	Value (A)	Value (B)	Value (C)
Bias In-Run Stability from turn-on	deg/hr	1σ	1.0	1.5	2.0
Angle Random Walk	deg/root-hr	Nominal	0.02	0.02	0.03
Angular Rate – Calibrated Range	deg/sec	Minimum	±1000	±1000	±1000
Accelerometer Channel	**Units**	**Type**	**Value (A)**	**Value (B)**	**Value (C)**
Bias In-Run Stability from turn-on	ug	1σ	100	200	200
Velocity Random Walk	ug/root-Hz	Nominal	100	100	120
Acceleration - Calibrated Range	g	Minimum	±50	±50	±50

Table 4-2 SDN500 IMU Performance Levels (2)			
Gyro and Accelerometer Channels	Units	Type	Value
Axes Non-Orthogonality	milli-rad	1σ	0.2
Axes to Case Misalignment	milli-rad	Maximum	<5
Alignment Stability	milli-rad	1σ	<0.5
2400 Hz Bandwidth, Phase (-90º)	Hz	Nominal	88
2400 Hz -3 db down point	Hz	Nominal	>150
1200 Hz Bandwidth, Phase (-90º)	Hz	Nominal	50
1200 Hz -3 db down point	Hz	Nominal	>150
600 Hz Bandwidth, Phase (-90º)	Hz	Nominal	30
600 Hz -3 db down point	Hz	Nominal	132
Start Up Time to Valid Data	seconds	Maximum	1.5
2400 Hz Data Latency	milli-second	Maximum	1

INS/GPS Interaction

The SDN500 system contains Integrated INS/GPS software algorithms that reside in a Central Processing Unit (CPU). The CPU is a Texas Instruments TMS320F28335 floating point processor. An overview of the software architecture is shown in Figure 4-3.

INS/GPS interaction is accomplished using a 28-error state Kalman filter. This filter uses GPS range and range rate data inputs to compute corrections for an IMU driven strapdown navigation solution. The corrections are updated by the Kalman filter at a 1-Hz rate, then provided as controls for the strapdown and navigation algorithms.

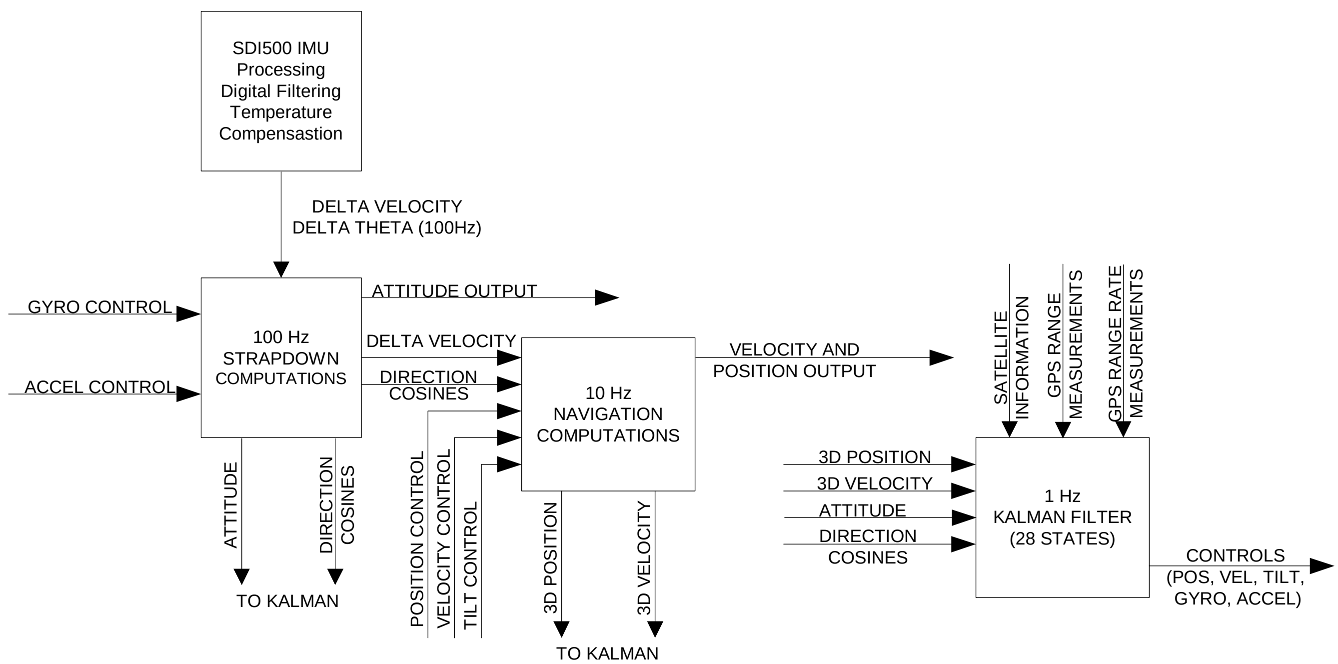

Figure 4-3. SDN500 INS/GPS Software Algorithm

Chapter 5- Hardware Integration

Overview

The SDN500 system is designed to be integrated into a navigation or flight control system by a systems integrator. The system can be implemented in many end-product solutions, including missiles, aircraft, guided munitions, and other military and commercial applications; however, it is not limited to these markets.

This chapter describes the various hardware-related features of the SDN500 that should be considered for efficient and effective system integration.

Electrical Interface

Main Connector

The SDN500 has two main connector inputs, the Data Interface connector and the RF connector for the GPS antenna. The main system connector contains all the digital interface signals utilized by the user to obtain navigation data and IMU data from the SDN500, as well as the power supply and ground signals and the available system discretes. The connector face is depicted in Figure 5-1, and the main system connector pinout is defined in Table 5-1.

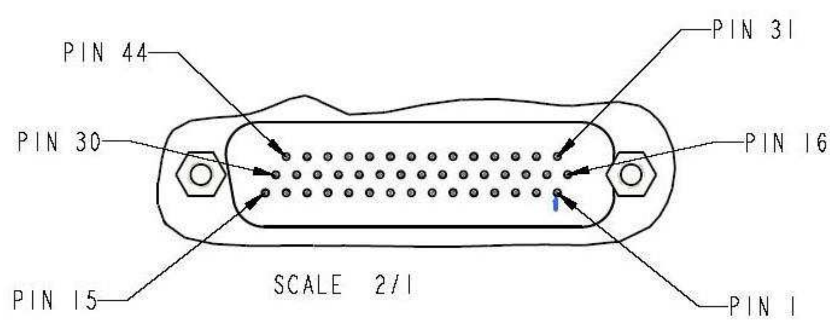

Figure 5-1. SDN500 Main System Connector

Table 5-1 SDN500 Main 44 pin Connector (Pin Order View)		
Pin #	**SDN500 Name**	**SDN500 Description**
16	CASE_GND	Unfiltered pin is connected to case
1	VINRTN	Input power return voltage
31	VIN	Positive Power supply voltage (Nom 28V Range 10V to 42V)
17	NC	
2	NC	
32	IO_RS232/422RX+	**RS232 IMU** RX Data (or RS422+ when pins 5 and 35 tied)
18	IO_RS422RX-	**RS422- IMU** RX Data when pins 5 and 35 tied
3	IO_BTLD	Boot Load Control (when low) for SDI500 IMU Software Load
33	IO_RESET	IO Reset Control (when low) for SDI500 IMU Software Load
19	IO_SDLC_TX_DTA+	RS422**+ SDLC IMU** Transmit Data output
4	IO_SDLC_TX_DTA-	RS422**- SDLC IMU** Transmit Data output
34	IO_SDLC_TX_CLK+	RS422**+ SDLC IMU** Transmit Data Clock (Input or output)
20	IO_SDLC_TX_CLK-	RS422**- SDLC IMU** Transmit Data Clock (Input or output)
5	RS422SEL_L	RS422 Select (when tied to pin 35, selects RS422 output)
35	IO_SIG_COM	Circuit or Signal common (or Gnd)
21	NC	
6	NC	
36	IO_BIT_HARD	Open Drain output. Latches (low) when Hard BIT asserted
22	IO_BIT_SOFT	Open Drain output. Sets (low) during Soft BIT condition
7	NC	
37	NC	
23	IO_HRD_RST_L	IMU Processor Reset
8	IO_SIG_COM	Circuit or Signal common (or Gnd)
38	IO_SIG_COM	Circuit or Signal common (or Gnd)
24	NC	
9	NC	
39	IONAV_RS232/422TX-	**RS232 Navigation** TX Data (or RS422- when pins 5 and 35 tied)
25	IONAV_RS422TX+	**RS422+ Navigation** TX Data when pins 5 and 35 tied
10	IONAV_RS232/422RX+	**RS232 Navigation** RX Data (or RS422+ when pins 5 and 35 tied)
40	IONAV_RS422RX-	**RS422- Navigation** RX Data when pins 5 and 35 tied
26	IONAV_BTLD	Boot Load Control (when < 0.5V) for Navigation Software Load
11	NAV_RESET_L	Navigation Processor Reset (also resets GPS receiver)
41	F_1PPS_RS232/422TX-	**RS232 1PPS** pulse from GPS (or RS422- when pins 5 and 35 tied)
27	F_1PPS_RS422TX+	**RS422+ 1PPS** pulse from GPS when pins 5 and 35 tied
12	F_NAVGPS_BATT_BU	Battery backup to GPS (+2.5 to +3.5Vdc , 3V nominal)
42	NC	
28	IONAV_BIT_CMD	Built in Test Command (when < 0.5V)
13	NC	
43	NC	
29	NC	

14	NC	
44	VIN	Positive Power supply voltage (Nom 28V Range 10V to 42V)
30	VINRTN	Input power return voltage
15	CASE_GND	Unfiltered pin is connected to case

"NC" denotes "no connection". No connection is to be made to these pins, even to an unterminated wire in a cable bundle. They are for factory test and programming use only.

RF Interface

This interface signal provides the path for GPS RF signals from an antenna to SDN500. SDN500 is capable of operating with GPS signals generated by a mixture of all GPS satellite types specified in SS-GPS-300.

Impedance

The input impedance at the RF connector is 50 Ohms, with a VSWR of 2:1 or better.

Center Frequency Input

The input center frequency is 1575.42 MHz.

Signal Level Input

The operational input range is -163 to -130 dBW (with operational satellite signals).

Noise Figure Input

The composite noise figure of a preamplifier, cable, and GPS receiver must be less than 5.0 dB for operation with minimum guaranteed GPS satellite signal levels.

To determine this composite noise figure, a typical noise figure of 4.0 dB is used for the GPS receiver, measured at the RF input port at L1 with a 10-MHz bandwidth.

Input Burnout Protection

The maximum input power level is -10 dBW at the RF port (at L1 with a 10-MHz bandwidth).

Delay

The delay (for example, due to line length) between the antenna and J2 RF connector is not important. The GPS receiver will compute a navigation solution at the phase-center of the antenna.

Antenna

The antenna is required to be right-hand circular polarized, exhibiting a gain of not less than -3 dBiC above a 10-degree elevation.

Power Interface

Input Voltage

The prime power input voltage to SDN500 is 10-42 volts DC, as measured at the input, referenced to power return/ground (IO_SIG_COM). The input power supply is reverse voltage protected.

Current

The typical steady-state current drawn by SDN500 is 250 mA at 24 volts DC. The typical input current surge is less than 3 amps at 15 volts DC.

Power Supply Considerations

The primary function of any regulated power supply is to hold the voltage in its output circuit while maintaining the current delivery over temperature. It is quite evident that power, current, and ripple under full load are important.

The system integrator needs to account for noise contributors when placing a power supply in a system. Even though the power supply required for a SDN500 system is dependent on the application, care should be taken to specify the electrical and mechanical characteristics of the power supply.

In a system design using a switching power supply, EMI is a natural by-product of the on-off switching. The interference can be conducted to the load, resulting in higher output ripple and noise. It also can be conducted back into the AC line in the case of AC-to-DC switchers, and can be radiated into the atmosphere and surrounding equipment. Shielding and filter networks may be needed to reduce the ripple and noise.

Keep Alive Battery

The F_NAVGPS_BATT_BU input to SDN500 provides "keep-alive" power to the SRAM and real-time clock in the GPS receiver. This is intended to provide the GPS receiver with a "hot start" capability by maintaining position, time, and ephemeris data in SRAM when primary power is removed from SDN500.

The battery input voltage to SDN500 should be in the range of +2.5 to +3.5Vdc (3V nominal), as measured at the input, referenced to power return/ground (IO_SIG_COM). Current draw is less than 1 microampere.

Ground

The power ground (IO_SIG_COM) on pins 8, 35 and 38 are tied together inside SDN500. It is generally recommended that they be also be tied together close to the SDN500. The case ground CASE_GND pin is an unfiltered pint tied to the case. Note that these signals are electrically isolated from the power return signal (VINRTN).

SDN500 Navigation Asynchronous Serial Interface

The SDN500 Navigation data interface is a full-duplex asynchronous RS-232 serial data communication port on IONAV_RS232. This port is the interface for receiving navigation messages from the SDN500 and to perform command and control of the SDN500 by the host vehicle. Message format, communications, and control protocol are defined in Chapter 7- Software Integration. When pins 5 and 35 (RS422SEL_L and IO_SIG_COM) are tied together then the interface become an RS-422 interface on IONAV_RS422. These signals are all referenced to IO_SIG_COM.

This port uses a Maxim MAX3160E driver. Data is transmitted and received within a UART-compatible frame. The default format (which can be adjusted) is:

- One start bit
- 8 data bits (least significant bit first)
- One parity bit (odd parity)
- One stop bit
- Default data rate of 115200 baud (can be selected by user – see Chapter 7- Software Integration)
- Port idle is nominally a logical low (-5 Vdc

SDN500 IMU Asynchronous Serial Interface

The SDN500 IMU data interface is a full-duplex asynchronous RS-232 serial data communication port on IO_RS232. This port is the interface for sending commands to the IMU portion (SDI500) of the SDN500 by the host vehicle. Command format and protocol is defined in

Chapter 7- Software Integration. When pins 5 and 35 (RS422SEL_L and IO_SIG_COM) are tied together then the interface become an RS-422 interface on IO_RS422. These signals are all referenced to IO_SIG_COM.

This port uses a Maxim MAX3160E driver. Data is received within a UART-compatible frame. The format is

- One start bit
- 8 data bits (least significant bit first)
- One parity bit (odd parity)
- One stop bit
- Data rate of 57600 baud
- Port idle is nominally a logical low (-5 Vdc)

Timemark Signal (1PPS)

SDN500 provides a Timemark (1 PPS) signal described below. The Timemark signal's type is compatible with RS-232 and is found on F_1PPS_RS232. When pins 5 and 35 (RS422SEL_L and IO_SIG_COM) are tied together then the interface become an RS-422 interface on F_1PPS_RS422. These signals are all referenced to IO_SIG_COM.

The Timemark is a one pulse-per second (1PPS) output signal to the external equipment. This pulse represents the instant in time when the navigation solution is valid. The precision of the Timemark output is ±1 μsec.

This pulse is provided for synchronization with the Timemark output message (binary message 3; refer to Chapter 7- Software Integration). This output message contains the local estimate of GPS time and position. The Timemark pulse width is 25.6 msec, and the polarity is positive.

The navigation solution that is provided subsequent to the pulse contains solution data that is valid at the leading edge of the Timemark pulse.

SDI500 IMU Synchronous Serial Interface (SDLC)

The SDN500 also provides a single-directional (output), synchronous SDLC data port for outputting data messages at very high frame rates over IO_SDLC_TX_DTA+ and IO_SDLC_TX_DTA-. The signal levels for this port are standard RS-422, and it uses a Maxim MAX3077E Driver/Receiver. The data is clocked in using

IO_SDLC_TX_CLK+ and IO_SDLC_TX_CLK-. By default, the SDN500 generates the data clock signal on the data clock lines. For message output rates of 600/100 Hz and 1200/100 Hz, the clock output is 1 MHz. For message output rates of 2400/100 Hz, the clock output is 2 MHz. The SDN500 also allows the user to input the SDLC data clock (see SDI500 Input Command Messages). The SDN500 can accept up to a 2 MHz data clock. The data format and message are defined in Chapter 7- Software Integration.

SDLC data polarity

The IMU considers the state where the differential voltage (IO_SDLC_TX_DTA+ - IO_SDLC_TX_DTA-) is positive to be a binary 1 and where it is negative to be a binary 0. This polarity can be reversed if necessary by reversing the connections of the two data lines.

SDLC Clock Polarity

The IMU transmits data on the rising edge of the clock, so the receiver should sample the data on the falling edge of the clock. This polarity can be reversed if necessary by reversing the connections of the differential clock lines.

Software Loading Interface

The SDN500 is designed to support an in the field update of its internal software. This is achievable in part by using the Software Load Signals, IO_BTLD and IO_RESET for the IMU portion, and IONAV_BTLD and NAV_RESET_L for the INS/GPS portion.

System Discretes

There are two BIT status discrete output signals available from the SDN500, a Soft BIT (IO_BIT_SOFT), and a Hard BIT (IO_BIT_HARD). This information is also present in the Normal Mode Message status word and in the BIT data message from the IMU portion and from the 3500 and 3503 messages from the INS/GPS portion. The Soft BIT signal will register when momentary non-fatal system errors occur. These errors are by default considered to be non-sticky in that if the system error is removed, then the Soft BIT will no longer continue to register a fault. The Hard BIT signal registers fatal system errors from which the SDN500 cannot recover. These errors are by default considered to be sticky in that even if the system error is removed, the Hard BIT will continue to register a fault. These discrete signals are open drain output, capable of working up to 50 volts DC. The maximum sink current for these discretes is 50 mA, although less than 20 mA is recommended.

IMU Processor Reset Line

There is a system reset line available from the SDN500 for the IMU portion. This line (IO_HRD_RST_L), when pulled low, will reset the IMU portion of the SDN500 and achieve a complete re-start and transition through initialization mode and power-on BIT. The line can be left floating and pulled to less than 0.5 volts to achieve the reset. It can also be treated as a logic line and be driven at 5 volts and then pulled to less than 0.5 volts to achieve the reset. The line is internally protected to 25 volts.

Navigation Processor Reset Line

There is a system reset line available from the SDN500 for the Navigation (INS/GPS) portion. This line (NAV_RESET_L), when pulled low, will reset the Navigation processor and the GPS receiver in the SDN500 and achieve a complete re-start and transition through initialization mode and power-on BIT. The line can be left floating and pulled to less than 0.5 volts to achieve the reset. It can also be treated as a logic line and be driven at 5 volts and then pulled to less than 0.5 volts to achieve the reset. The line is internally protected to 25 volts.

Built In Test (BIT)

The SDN500 contains internal circuitry that runs the internal BIT test when the IONAV_BIT_CMD signal is pulled below 0.5 volts. The duration of the external command is 0.2 seconds minimum and the SDN500 remains in the BIT mode for the duration of the signal application.

The SDN500 resumes nominal performance within 0.1 second after application of a logic one or open. The BIT command can be applied at any time, including simultaneously with the application of power to the SDN500. It achieves the same results as that of selecting a BIT Test request using message 3504 (please see Chapter 7- Software Integration). The input circuit for the BIT request is shown in Figure 5-2.

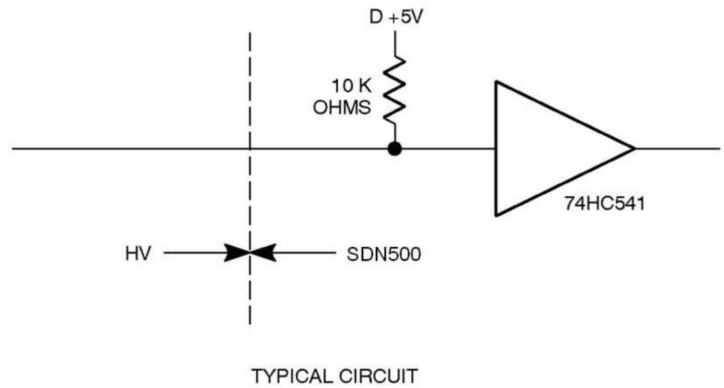

Figure 5-2. BIT Input Circuit Diagram

Connector Types

Connectors that are used to interface SDN500 to the Host Vehicle are defined in Table 5-2. Examples of mating connectors are included in the table.

Table 5-2. SDN500 Connector Types		
Connector Designation	**Type**	**Example Mating Type**
Data Interface	44 Pin High Density D	Amphenol 44 P Comm 17EHD-044-S-AA-0-00
RF Interface	SMA Jack (socket) Receptacle	Any SMA plug (pin) MIL-C-39012 series, Typically RG-400, 50-ohm, coaxial cable used.

Data Interface Connector

The Data Interface is through a 44-pin High Density receptacle type connector.

RF Interface Connector

The straight RF input connector is standard SMA jack (female) receptacle of the MIL-C-39012 series. Below is a list of possible mating connector manufacturers for procurement. Final choice of connector is affected by cable selection, which is discussed in Cable Considerations.

Tyco Electronics Corporation
1050 Westlakes Drive
Berwyn, PA 19312
Telephone (610) 893-9800
http://www.tycoelectronics.com

AMPHENOL RF
4 Old Newtown Road
Danbury, CT 06810
Telephone (203) 743-9272
http://www.amphenolrf.com/

Avnet
http://www.avnet.com/

Richardson Electronics (RFPD)
http://www.rell.com

Email: rfpd@rell.com
Telephone (800) 737 6937

Antenna Considerations

Antenna Types

Although there is some flexibility in the choice of GPS antennas, there are some essential requirements. The Jupiter Pico receiver inside the SDN500 will accept passive or active antennas. When choosing an active antenna, the following table summarizes some recommended specifications.

Antenna Specification	
Minimum Gain	15-20 dB (To compensate signal loss in RF cable)
Maximum Noise Figure	1.5 dB
Maximum Gain	50 dB

Two types of commonly available GPS antennas are *Patch* antennas and *Helix* antennas. Each has distinct electrical and physical properties, lending each to different applications. The system integrator must evaluate the performance requirements together with the mechanical size, form, and mounting capability, along with the physical aesthetics of the overall product, to determine the type of antenna to use.

Patch Antennas

Patch antennas are simple in design and predictable in performance, using microstrip technology for their receiving elements. Microstrip *Patch* antennas are typically mass-produced and are inexpensive to manufacture.

The most appealing aspect of the *Patch* antenna, and a major reason for its acceptance, is its low profile. Microstrip designs require only a patch of thin metallic film bonded to a dielectric substrate with a ground plane, allowing the *Patch* antenna to be shaped to meet specific mechanical requirements. The most common shapes produced are rectangles and circles.

Patch antenna patterns typically contain one main lobe in the direction normal to their surface. Therefore, the gain of the signal is reduced as a satellite moves from the perpendicular axis of the antenna.

This reduction in gain at the horizon can help reduce multipath interference. Most *Patch* antennas are integrated with a radome. The radome provides essential protection from the environment.

Helix Antennas

The design of a *Helix* antenna uses a conductor wound in the shape of a screw thread (*Helix*) together with a flat metal plate called a ground plane. This type of antenna is not extremely complicated in design and offers a predictable performance.

The *Helix* antenna demonstrates slightly higher gain and smoother phase than the *Patch* antenna. The patterns of a *Helix* antenna are a main lobe normal to the ground plane and minor lobes at oblique angles to the main lobe. As a result of these patterns, when a satellite moves from the antenna's perpendicular axis, the gain is reduced. However, the minor lobes provide more gain than the *Patch* antenna when the satellite is off axis due to the symmetry of the *Helix* design. Lobing can degrade tracking under certain kinds of motion.

The height and broad bandwidth are disadvantages to the *Helix* antenna. Since the *Helix* antenna is made of a helical coil, the shape is not flat as with *Patch* antennas. In general the higher the required gain, the longer the coil. *Helix* antennas typically have broader bandwidths than *Patch* antennas, permitting the reception of more interfering signals.

Helix antennas require mounting in a filled radome to mechanically stabilize the coil from shock and vibration. These radomes usually are molded in cylindrical or aerodynamic shapes.

If the system's design requires an active antenna and alternative cable types or lengths, SDI application engineers are available to help the system integrator with link budget calculations. Please contact your local sales office for assistance. Also, see the discussion of preamplifiers later in this chapter. The following is a list of antenna manufacturers to contact for procurement.

Sensor Systems Inc.
8929 Fullbright Avenue
Chatsworth, CA 91311
Telephone (818) 341-5366
http://www.sensorantennas.com/

Tecom Industries, Inc.
375 Conejo Ridge Ave
Thousand Oaks, CA 91361
Telephone (805) 267-0100
http://www.tecom-ind.com/

Antcom Corporation
367 Van Ness Way, Suite 602
Torrance, California 90501
Telephone (310) 782-1076
http://www.antcom.com/

Cable Considerations

As with antennas, the choice of cable is application-dependent. There are many cables manufactured that will meet the performance requirements for specific applications that mate with a variety of connectors.
The primary consideration in choosing a cable is the net attenuation at the desired frequency. The secondary consideration is the shielding of the cable. Other considerations such as flexibility, jacketing, size, and cost need to be factored into the selection process.

Cable Attenuation

The attenuation a cable exhibits at the desired frequency is important to the system design. The materials of a cable directly relate to the attenuation characteristics it exhibits. The center conductor of a good quality cable is typically copper or aluminum with a copper coating. Copper is a good electrical conductor with relatively low DC resistance per meter. This is important in the event a preamplifier needs to be powered via the center conductor for extra system gain.

Cable Dielectric

The dielectric material is the key to the characteristic impedance of a cable. RF applications generally use a cable with a polyethylene dielectric material. Polyethylene has a low dielectric constant that provides low capacitance and low electrical loss. This material is also lightweight and water-resistant. The outer conductor plays a role in the characteristic impedance of the cable, as well as its shielding effectiveness.

Cable Shielding

There are numerous outer conductor (shield) designs. The outer conductor can be made of braided mesh, a solid foil, or a solid shell. Braided shields of copper or aluminum are ideal for minimizing low frequency interference and exhibiting a low DC resistance. This type of shield provides good structural integrity and flexibility. As a rule, higher braid coverage yields a more effective shield.

Foil shields are made of aluminum and are laminated to a polypropylene film to provide mechanical strength to the foil. The DC resistance of a foil shield is not as low as a braided shield, but the foil shield provides 100 percent coverage of the center conductor. This shield is more cost effective, but has less structural integrity than a braided shield. Solid shields afford the best performance, but are inflexible and expensive.

Shields can be arranged in many different combinations. Combination shields consist of more than one layer of shielding. Typical combinations can include a braid or a braid with foil. A braid-type shield significantly lowers the DC resistance of the overall shield, while a braid-foil type shield provides the low DC resistance and structural strength of the braid plus 100 percent shielding of the foil.

The outside jacketing of a cable does not provide any EMI/RFI shielding to a cable. The jacket provides resistance to weather deterioration, mechanical abuse, and heat.
For most SDN500 applications where the cable runs are relatively short, a cable can be selected with any of the characteristics previously described. If an application requires extensive lengths of cable (> 30 ft) from the antenna to SDN500, other types of cable commonly larger in diameter with solid copper outer conductors should be considered. These types of cables exhibit very low attenuation and excellent shielding, but tend to be larger, costing more per linear meter.

Installation Considerations

When installing SDN500, the following areas are of primary concern: *GPS Signal Obscuration*, *GPS Selective Availability*, *Multipath Interference*, and *EMI*.   Additional areas of concern are *Feedlines and Preamplifiers*, *RF Signal Levels*, and the *Noise Floor*. Each is discussed below.

GPS Signal Obscuration

Normal operation of SDN500 requires undisturbed reception of signals from four satellites as discussed earlier in Chapter 2- INS/GPS Concepts. The signals propagating from the satellites cannot penetrate water, soil, walls, dense foliage, or other similar obstacles.

Antennas and satellites are required to be in a "line of sight" with each other.

SDN500 cannot be used in INS/GPS mode for underground navigation in tunnels, mines, or subsurface marine navigation. In surface navigation, the signal will be obscured by buildings, bridges, trees, and other matter that locks an antenna's line of sight to the GPS satellites. In airborne applications, the aircraft's body may block the signal during high banking or pitching maneuvers.

For moving vehicles, signal shading or temporary outages will likely be transitory and will minimally degrade the overall positioning solution. However, a common case of signal blockage occurs in urban areas lined with skyscrapers. In these cases, the signals can be obstructed for long periods of time resulting in accuracy degradation. In aircraft applications, transitory outages may occur due to the location of the antenna on the aircraft. In some instances, the motion of an aircraft can temporarily obstruct the line-of-sight due to its own structure, or can induce dynamics that exceed the capabilities of the SDN500’s tracking loop.

SDN500 uses fifty channels to minimize the effects of obscuration. During normal operation, channels track the primary GPS satellites while the other channels track the remaining visible satellites and recover the ephemeris data on each one. Therefore, if any of the primary satellites are obscured, SDN500 contains the data to support a rapid transition to alternate satellites.

Standard Positioning Service (SPS) Policy:

SPS is a positioning and timing service available to all GPS users on a continuous, worldwide basis with no direct

charge. SPS is provided on the *GPS Ll frequency*, which contains a C/A code and a navigation data message.
GPS Ll frequency also contains a P-Code that is not part of SPS, and is not available with the SDN500 product.

***Precise Positioning Service (PPS) Policy**:*

PPS is a military positioning, velocity, and timing service available on a continuous, worldwide basis to users authorized by the DoD. It is not currently available with SDN500. PPS is the data transmitted on GPS Ll and L2 frequencies. PPS was designed primarily for U.S. and Allied military use. It is denied to unauthorized users by use of cryptography. The encrypted P-code is called *Y-code*. PPS is available to U.S. Federal and Allied Government (civilian and military) users through special agreements with the DoD.

Limited civilian use of PPS, both domestic and foreign, is considered upon request and authorized on a case-by-case basis provided that:

- It is in the U.S. national interest to do so.
- Specific GPS security requirements can be met by the applicant.
- A reasonable alternative to the use of PPS is not available.

Multipath Interference

Multipath errors result when data is combined from more than one propagation path. This distorts the signal characteristics from which the range measurements are made, resulting in pseudorange errors. These errors are dependent on the nature and location of a reflective surface peculiar to each user location. The effects are less detrimental for a moving user, since small antenna movements can completely change the multipath characteristics.

In general, multipath interference is caused by signal reflection from buildings or other large objects interfering with a direct signal from a satellite. The effects of surface-replicated multipath interference can be minimized by using an antenna with a sharp gain roll-off near the horizon. A *patch* antenna exhibits this type of pattern while providing nominal gain for the primary satellite signal and attenuation for the undesired multipath signal. Circular antenna polarization also serves to minimize reflected multipath effects.

Electromagnetic Interference (EMI)

A common source of EMI is the operation of a nearby transmitting RF facility, such as a radio station, television station, or airport. Operation near a facility such as these can result in front-end overload or intrusion into Intermediate Frequency (IF) stages. United States television channels 10, 23, and 66 often have harmonics in the GPS signal band.

The GPS receiver circuitry contains onboard filters to help reject out-of-band signal interference.

EMI can be emitted from black boxes, or electronic systems around the SDN500 system. An example of this type could be a switching power supply or other circuits operating nearby without proper shielding.

SDN500 is susceptible to EMI around 1575 MHz. This arises from the high sensitivity required by the GPS receiver to selectively capture the Ll signal at -160 dBW. Interference degrades the C/No density ratio of the SDN500 system. The C/No density ratio directly relates to the ability of the GPS receiver to acquire and track the GPS signal.

Non-GPS, continuous wave (CW) signals within a ±2-MHz bandwidth of 1575 MHz can cause interference to SDN500. The effect on C/No, with the introduction of continuous wave interference, can be characterized by the following equation:

$$C/No(eff) = \frac{C}{No + \left(\frac{Pi}{Rc}\right)}$$

where:

C/No = the carrier-to-noise density without interference
Pi = the power in Watts of the interfering signal
Rc = the coding rate of 1.023 Mbps
No = the typical system noise in W/Hz

The system noise in dBW/Hz can be estimated by:

10 LOG (antenna noise temperature) + cable loss in dB + cascaded receive system Noise Figure (NF) in dB - Boltzmann's Constant

where Boltzmann's Constant equals -228.6 dBW/Kelvin-Hz and the cascaded receiver system NF is as demonstrated in the *Mechanical Interface* section.

If the system integrator's application requires the SDN500 system to operate in a signal environment where in-band interference may occur, the GPS receiver should be tested for EMI susceptibility in the unique environment targeted by the system.

C/No data from SDN500 should be closely monitored during testing of EMI susceptibility to determine the effects of different interference levels and frequencies.

Feedlines and Preamplifiers

When undertaking the design and layout of a system using SDN500, careful consideration should be given to using a passive antenna and a short length of low loss feedline. This configuration will yield good results at minimum cost. If a preamp is required to overcome feedline losses or noise sources at the receiver, use the lowest gain device that will set the system NF to the required level.

SDN500 is equipped with a very sensitive front-end. Under most circumstances, no preamplifier is required. A passive patch antenna is most frequently used which provides approximately 0 dBiC of gain, and 5 to 15 feet of low loss coaxial cable can be used, representing about 0.5 dB of loss. Figure 5-3 provides a schematic representation of SDN500 in its basic configuration.

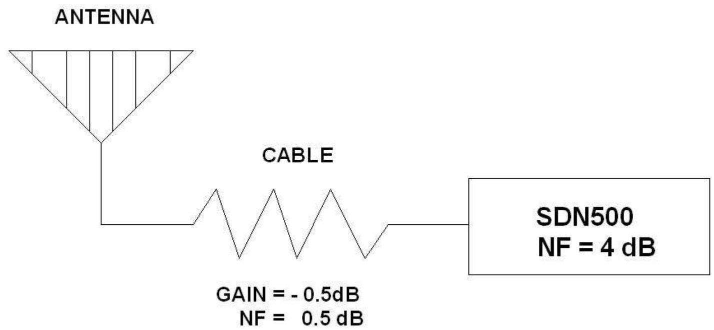

Figure 5-3. Basic Configuration

Carrier-to-Noise Ratio

To predict the Carrier-To-Noise (C/No) density ratio in the SDN500 system, a link budget analysis of the available signal compared to the existing noise must be performed. This is accomplished by determining the available signal from the satellites, and then comparing it to the noise floor of the receiver. This yields the C/No density ratio.

The signals received from GPS satellites are a function of the transmission power of the satellites, the gain of the satellite antennas, the free space path loss of the signal, and the gain of the receiving antennas. According to the specifications, the U.S. military guarantees the signal power from GPS satellites to GPS receivers to be at least -160 dBW. This signal level will then be amplified (or attenuated) by the receiving antenna as a function of antenna gain.

RF Signal Levels

The unobstructed L1 C/A power incident on a user from any Block II satellite is a minimum of -160 dBW. The minimum input signal level of SDN500 is -163 dBW, providing the systems integrator an additional 3 dB for design margin with GPS antennas and other system components.

This is the minimum free space signal power from the satellite. For the past several years, the satellites have been transmitting signals that are 3 to 6 dB higher than the guaranteed figure. However, good engineering practice dictates that the minimum specified signal power be used for all equipment design and link studies. Table 5-3 shows the link margins for 90 percent probability of acquisition for a system with 4 dB of composite NF, 0 dB of antenna spatial loss, and satellites at a 10-degree elevation angle.

Table 5-3. Typical GPS Link Margins		
GPS Signal Level at Antenna	Acquisition	Track
-160 dBW (guaranteed minimum)	3 dB	10 dB
-156 dBW (current typical levels)	9 dB	16 dB

SDN500 is designed to operate with low-cost passive antennas, exhibiting -3 dBiC or greater gain at 5 degrees elevation, and a reasonable length of cable. This feature allows the overall system cost to be minimized. The system integrator should always calculate a link budget for the system.

Most commercial and military users of GPS use a Patch type or Helical antenna, with the Patch antenna being somewhat more popular. In general, the patch antenna exhibits about 2 to 3 dBiC of gain on zenith, and between -4 to 0 dBiC on the horizon. For most "quick" calculations, it is convenient to assume a gain of 0 dBiC.

The Noise Floor

GPS signals are spread spectrum, so noise power spectral density is used in establishing a signal-to-noise power ratio figure of merit. This important figure is *C/No*, or the total carrier power-to-noise power spectral density. The resulting units of this ratio are in dB-Hertz.

Noise power is typically modeled as a thermally generated white noise source. The simple model for thermally generated noise power spectral density is expressed by the following equation:

$$Np = K \times T^{\circ} \times B$$

where:

K = Boltzman's Constant (1.38 x 10^{-23} Watts/Kelvin-Hz)
T°= The equivalent noise temperature in degrees Kelvin (typical assumption is T = 290 degrees K)
B = The bandwidth in Hz

In a 1-Hz system at 290°K, the noise power can be seen to be -204 dB W/Hz (4.002 x 10^{-21} Watts per Hz). This figure represents the absolute noise floor in a 1-Hz bandwidth at room temperature.

The next contributor to the noise floor is the noise generated internally by the SDN500 system. This noise is the sum of the noise generated by SDN500, attenuation of the feedline, noise of the preamp (if used), and external noise received by the antenna.

There is a general assumption that the antenna, the feed system, any preamplifiers, and the receiver are all properly impedance matched. The standard gross assumption is a 50-Ohm characteristic impedance and *Voltage Standing Wave Ratio* (VSWR) of less than 2:1 (1.6:1 or less is preferred) at each interface.

Noise Factor is defined as the signal-to-noise ratio at the input divided by the signal-to-noise ratio at the output. The result is always greater than or equal to one. *Noise Figure* is defined as the noise factor converted to decibels, i.e. 10log (NF). The determination of a noise figure is made assuming an input noise source of 290 degrees Kelvin. A noise figure generally is an approximation, and is usually acceptable when receiver noise is the dominant contributor.

The system noise factor (NF_{SYS}) of several cascaded receiver elements is determined by the following equation:

$$NF_{sys} = NF1 + \frac{NF2-1}{G1} + \frac{NF3-1}{G1 \times G2} + \ldots\ldots \frac{NFn-1}{G1 \times G2 \times \ldots\ldots \times G(n-1)}$$

where:

NFl	=	Noise Factor of Stage 1
G1	=	Gain (or loss) factor of Stage 1
NF2	=	Noise Factor of Stage 2
G2	=	Gain (or loss) factor of Stage 2
NF3	=	Noise Factor of Stage 3
G3	=	Gain (or loss) factor of Stage 3
NF*n*	=	Noise Factor of the *nth* stage
G*n*	=	Gain factor of the *nth* stage

As shown by this formula, the primary contributor of the system noise figure is the noise factor of the first stage (NFl). If the first stage is a low loss feedline, the attenuation of the line will directly add to the system NF. The loss must be entered as a gain term (G or loss) , but will be a gain of less than one.

The formula's calculation usually becomes asymptotic after the first couple of stages in a good system design. Typically, the system integrator only needs to be concerned with antenna gain, preamplifier gain if used, coaxial losses, and the specified noise figure of the receiver.

An analysis of SDN500 in the basic configuration (see Figure 5-3) yields a system NF of 4.5 dB at the junction of the antenna and the coaxial feedline, as shown by the following:

- NF_{db} of the receiver = 4 dB
- NF of the receiver = 2.51
- NF_{db} of the cable = 0.5 dB
- NF of the cable = 1.122
- Gain of the cable = –0.5 dB
- Gain factor of the cable = 0.891

Note: For lossy medium such as cable, Gain is always <1, in other words, less than or equal 0 db. Noise factor = 1/Gain Factor, Noise figure= -Gain db.

$$NF_{SYS} = 1.122 + \frac{2.51 - 1}{0.891}$$

NF = 2.817

NF_{db} = 10log (2.817) = 4.5 dB

The last contributor to the noise floor of SDN500 is *implementation loss*. Implementation losses are the degradation in the C/No density ratio resulting from imperfect A/D converters, filters, and quantization errors.

In SDN500 the implementation losses have been observed to be approximately 2 dB. Therefore, the system noise floor in the basic configuration is as follows:

Noise power in 1 Hz	=	-204.0 dBW/Hz
NF of system	=	+4.5 dB
Implementation losses	=	+2.0 dB
=>Noise floor	=	-197.5 dBW/Hz

When the noise figure must be below 2 dB, it may be wise to do a thorough analysis of actual system noise temperature, because the noise figure becomes an inaccurate measure of merit. This would be the case when a very low-noise preamplifier is used ahead of the receiver. In such cases it is common to use a system level figure called *G/T*, which is the ratio of a system antenna's *Gain* to system noise *Temperature*.

If this type of condition occurs during your system analysis, contact a SDI applications engineer.

Link Calculations

Through analysis and field trials at SDI, it was determined that a 34 dBHz C/No density ratio is required for satellite acquisition. Once SDN500 has acquired the satellite and recovered navigation data, the "track" mode requires as little as a 26 dBHz C/No density ratio.

At this point, the signal power available, the system noise floor, and the required C/No for acquisition is known. A link budget can then be calculated as follows:

Carrier power guaranteed	= -160 dBW
Antenna gain	= 0 dBi
Noise floor ("Basic" configuration)	= -197 dBW/Hz
C/No = -160 - (-197)	= 37 dBHz
C/No required	= 34 dBHz
=> C/No margin = 37 - 34	= 3 dB

With a 3-dB margin, SDN500 is quite useable with a passive antenna and a short run of low loss feedline. Outside factors such as foliage or building blockage may reduce the available signal.

It is advised not to significantly reduce the gain of the antenna or increase the feedline loss. As a rule, the feedline losses should be kept to less than 2.5 dB to 3 dB totals, when used with a standard passive GPS patch antenna.

Preamplifiers

Under some circumstances, a preamplifier antenna system may be desirable. This configuration is illustrated in Figure 5-4. However, it should be emphasized that a preamplifier will not compensate for a poorly located or inferior antenna. The preamp can only amplify what it receives from the antenna.

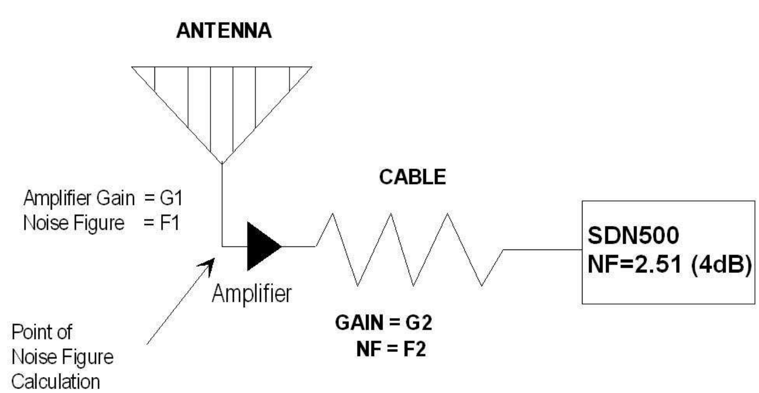

Figure 5-4. SDN500 with Preamplifier

In addition, the preamp will amplify the noise as well as the signal, and will contribute some internally generated noise of its own. Poor preamp selection may actually *decrease* the C/No density ratio of the receiver's system.
The main reason for selecting a preamp is to optimize the signal-to-noise ratio of a receiver system. As demonstrated by the cascaded NF_{SYS} equation (discussed earlier), the system NF is set primarily by the first active or passive stage encountered after the antenna.

However, if the first stage encountered is a low noise preamp, the system NF can be set and optimized at this point. After thorough analysis, it may be more convenient to think of a preamp as a device that lowers the total system noise rather than raises the signal level.

The preamplifier should be selected to give similar or superior system performance to that of the basic configuration. In other words, the preamp should be selected to set the system NF at 4 dB or better. For example, if the feedline from the Patch antenna to the receiver was measured to have 6 dB of loss, a preamplifier with 10 dB of gain would need an NF of 2.07 dB to maintain the system NF at 4 dB as follows:

Desired system NF	= 4 dB
	= 2.51 NF
Amplifier gain	= 10 dB
	= 10 Gain
Factor	
Cable gain (loss)	= -6 dB
	= 0.251 Gain
Factor	
Cable NF	= 6 dB
	= 3.981 NF
Receiver NF	= 4 dB
	= 2.51 NF

$$2.51 = NF1 + \frac{3.981 - 1}{10} + \frac{2.51 - 1}{10 \times 0.251}$$

NF1	= 1.61
NF = 10*log(l.61)	= 2.07

The graphs shown in Figure 5-5 and Figure 5-6 represent the gain and NF of a preamplifier required to maintain a system NF of 3 and 4 dB, respectively. For example, to maintain a system NF of 3 dB with 6 dB of cable loss, a preamp with 15 dB of gain would require an NF of 2.3 dB. This is certainly an achievable combination with available technology.

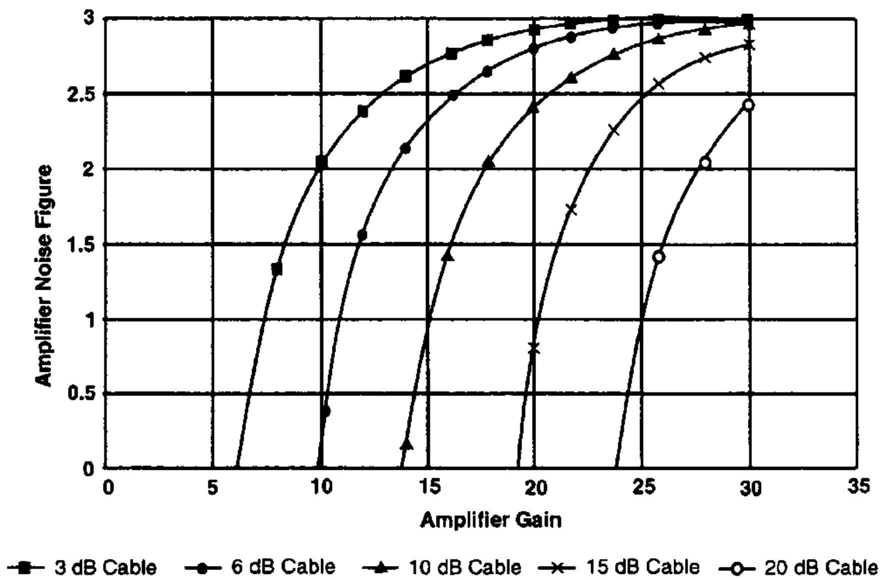

Figure 5-5. Preamplifier Gain and NF for a 3 dB System NF

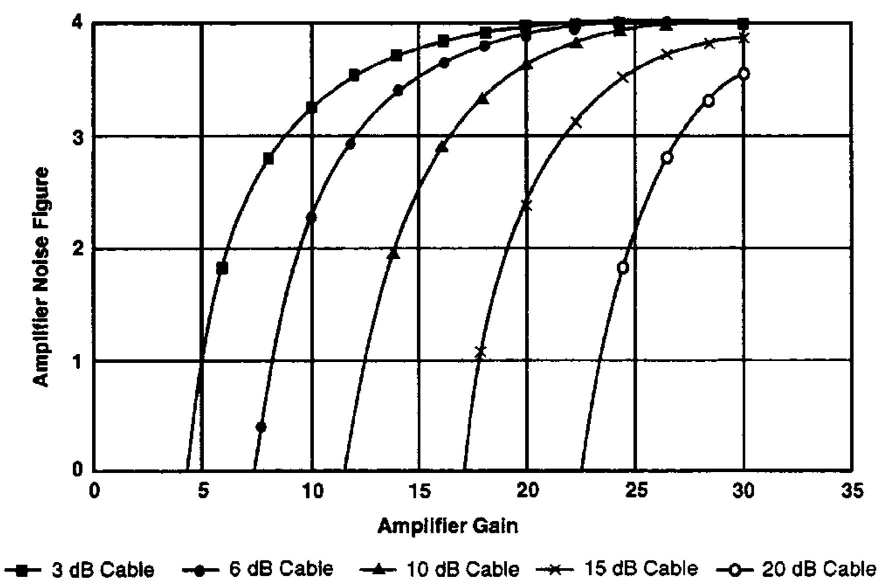

Figure 5-6. Preamplifier Gain and NF for a 4 dB System NF

Maximum Preamp Gain

Improving preamp specifications can be considered; however, there are a few parameters to address. SDN500 has a very sensitive front end. Acceptable C/No density ratios are obtained with -163 dBW into a 4 dB system NF (the basic configuration). If a preamp is used, the GPS signal power delivered to SDN500 must be kept under -130 dBW.

As a rule of thumb, select the minimum preamp gain that will provide the desired performance. Amplifier gains of 10 to 20 dB are easily obtainable and should be adequate to set the desired system NF. This maximizes the performance of SDN500 and minimizes preamp costs. If an amplifier is required, but the overall gain available exceeds the -100 dBm GPS signal limit, an attenuator can be used. The attenuator then must be placed between the amplifier and the receiver.

In conclusion, remember that a preamp will not make up for a poor antenna installation. Adding an amplifier with +10 dB of gain will not compensate for an antenna with -10 dB of gain. Optimum performance from SDN500 can be achieved by using the best available antenna and good quality feedline.

Preamplifier Power

The SDN500 was designed for use with passive or active antennas, and does provide power for an active antenna. The default power available for active antennas is 3.3 Vdc at 50 mA. The SDN500 can be configured to supply up to 5 Vdc at 200 mA, but this would require a choice at the time of manufacture, and would be considered a special order.

Amplifier Manufacturers

If an amplifier is needed for systems integration and application, below is a list of amplifier manufacturers to contact for procurement.

JCA Technology, Inc.
2580 Junction Avenue
San Jose, CA 95134
Phone: 408-324-5700
FAX: 408-324-5705
email: **jca@jcatech.com**

Mini-Circuits
P.O. Box 350166
Brooklyn, NY 11235
Phone: (718) 934-4500
Fax: (718) 332-4661
www.mini-circuits.com

Miteq
100 David's Drive
Hauppauge, NY 11788
Phone: (516) 436-7400
www.miteq.com

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Chapter 6- Magnetometer Interface

Overview

The SDN500 can be integrated with an external magnetometer. Body-axis three dimensional magnetic vector data is input into the SDN500 via two methods, the industry standard ASCII NMEA protocol “XDR” message, and a proprietary Systron Donner Inertial message format known as message 3530. In both instances the data is sent into the SDN500 via the RS-232/RS-422 interface. Since the messages are coming in through the SDN500 RS-232/RS-422 interface, the receiving BAUD rate will be the same as for any input message, and is set when the choice is made to configure the BAUD rate on the SDN500 RS-232/RS-422 port (Please see Chapter 7- Software Integration). The body-axis magnetic data is transformed inside the SDN500 into heading reference data, which is then used by the GPS/INS algorithm to make heading significantly more stable under low dynamic situations. Note that SDN500 system heading is referenced to map north, and the reference magnetometer heading reference data is also converted to map north via an internal magnetic variation calculation. Magnetometer data alone is referenced necessarily to magnetic north, and the difference between magnetic north and map north is the magnetic variation. This calculation is a function of the location (Latitude and Longitude) of the system on the face of the earth, which is why the calculation can be accomplished via the GPS positioning information.

Magnetic Measurement

Three axes magnetometer systems use a set of sensitive magnetometers to measure the Earth's three-dimensional magnetic field vector. This vector data can be used to calculate magnetic heading. Because the earth’s field is very weak, small amounts of moving magnetic material near the magnetometer can have large effects on a magnetic heading calculation. The magnetometer should be isolated from magnetic material as much as possible. Magnetic material will distort the magnetic field near the sensing elements, which can then affect the accuracy of a heading calculation. A magnet can be used to test materials that will be near the magnetometer, such as iron, carbon steel, some stainless steels, nickel and cobalt. Essentially any material that will stick to a magnet should be avoided. The SDN500 contains magnetic disturbance compensation algorithms designed to correct for the effect of these disturbance magnetic fields as long as the disturbance is stationary. Materials that will not affect the magnetometer measurements include aluminum, brass, plastic, titanium, wood, and some high-quality stainless steels. Again, if in doubt, try to stick a magnet on the material. If the magnet doesn't stick then the material will not affect the magnetometer. Stationary magnetic objects will be compensated for by the compensation algorithms. Moving ferrous objects within 24 inches cannot be fully compensated by the algorithm, so the magnetometer should not be located within 24 inches of any large moving ferrous metal objects such as landing gear components, electric motors, control linkages, etc. Ferrous metal objects that may change position during flight operations, such as landing gear, flap actuators, and control linkages should not be within 24 inches of the magnetometer. The magnetometer should not be located close to high current DC power cables or 400 cycle AC power cables and their associated magnetic fields.

The magnetometer heading measurement is internally corrected for the magnetic variation term. This is done so that the Kalman filter can use magnetic heading as a heading reference by correcting magnetic heading for the local magnetic variation, and thus changing it from a magnetic north reference to a true map north reference. In this way the magnetic heading reference will provide a seamless heading reference for the Kalman filter which will coincide with the derived GPS velocity heading reference, which is only defined with regards to true map north. The magnetic variation model used inside the SDN500 is the World Magnetic Model (WMM-2005) published and documented by the National Geophysical Data Center (NGDC). A brief description of the WMM follows as published on the NGDC website: "The WMM consists of a degree and order 12 spherical-harmonic main (i.e., core-generated) field model comprised of 168 spherical-harmonic Gauss coefficients and degree and order 12 spherical-harmonic Secular-Variation (SV) (core-generated, slow temporal variation) field model (determined to degree and order 8). WMM2005 supersedes WMM2000 and should replace this model in navigation systems. Also included with the model is computer software (available in FORTRAN or C) for computing the magnetic field components X, Y, Z, F, D, I, and H in geodetic coordinates. The spherical-harmonic expansions used to compute the magnetic field components are described in the ***NOAA Technical Report: The US/UK World Magnetic Model for 2005-2010."***

Hardiron/Softiron Calibration

Magnetometer magnetic heading reference data will need to be calibrated for hard and soft iron compensation before use in any final installation. The SDN500 uses the magnetometer heading magnetic vector data to compute heading. Ideally, the magnetic sensors would be measuring only earth's magnetic field to compute the heading angle. In the real world, however, residual magnetism in your system will add to the magnetic field measured by the magnetometer.

Static magnetic disturbance behaves as a bias offset error in the magnetometer measurement if it is not compensated. This magnetic field bias offset is called hard iron magnetic error. In addition, magnetic material can change the direction of the magnetic field as a function of the input magnetic field. This dependence of the local magnetic field on input direction acts as a scale factor error on the magnetometer data, and is referred to as soft iron.

The SDN500 can measure any disturbance constant magnetic field that is associated with the SDN500 itself, or the user system, and corrects for it during the calibration procedure. The SDN500 also makes a correction for some soft iron effects. The process of measuring these non-ideal effects and correcting for them is called hard iron and soft iron calibration. Calibration corrects for magnetic fields that are fixed with respect to the user system. It cannot compensate for time varying fields, or fields created by parts that move with respect to the magnetometer.

The SDN500 accounts for the extra magnetic fields by making a series of measurements from the magnetic heading reference data. The SDN500 uses these measurements to model the hard iron and soft iron environment in the installation.

The magnetometer calibration mode should only be performed once the SDN500 system has been properly initialized and in Navigation Mode. The hard and soft iron calibration procedure control is performed using the SDN500 parameter control Message 3504 - SDN500 Parameter Control. The process is monitored using the system status Message 3500 - SDN500 System Status, and the status of the magnetometer calibration data present in non-volatile memory is observed using the Built-In-Test Results Message 3503 - SDN500 Built-In-Test Results.

Send the appropriate “Install Magnetometer Calibration Control” bits in Message 3504 - SDN500 Parameter Control to turn on the calibration process. Please ignore the “Launch Magnetometer Control” feature at this time. Once the SDN500 has received the calibration on command, Message 3500 - SDN500 System Status will display the proper “Install Calibration” bits signifying that the SDN500 is in magnetometer calibration mode. The user system will then need to be rotated through at least three complete circles. At this point, the SDN500 should have collected enough data for a good magnetometer compensation calibration. Send the appropriate control bits in Message 3504 - SDN500 Parameter Control to turn off the calibration process. Once the SDN500 has received the calibration off command, Message 3500 - SDN500 System Status will display the proper bits signifying that the SDN500 is no longer in magnetometer calibration mode, but in the mode prior to the start of calibration (Navigation Mode). The SDN500 will now store these as calibration constants in the EEPROM for use upon subsequent power cycles. Note that the process of storing this data in the EEPROM is the same as storing the system information into the EEPROM, as described in Message 3510 - SDN500 Control and Initialization, and there will be an interruption of data communications of approximately 2 seconds. The Built-In-Test Results Message 3503 - SDN500 Built-In-Test Results will now display the proper bits signifying that the magnetometer calibration has been stored properly.

Once the calibration process is complete, the SDN500 should be restarted through a power cycle to properly initialize the Kalman filter to the new calibrated heading reference. Once the SDN500 has entered “Air navigation” and is receiving proper magnetometer heading reference data, the magnetometer calibration can be then be tested by comparing the system heading output of the SDN500 with a known reference (compass or compass markers). Position the user system at each of the cardinal headings (0 degrees (north), 90 degrees (east), 180 degrees (south) and -90 degrees (west). At each cardinal position, allow the SDN500 at least 2 minutes to properly stabilize, and then observe the system heading parameter. It should be within +/- 2 degrees of the cardinal heading. If there is still some residual magnetic disturbance (as observed by a system heading error of more than +/- 2 degrees), then the magnetometer calibration can be performed again. All subsequent magnetometer calibrations build on the previous calibration by using the previously magnetometer calibration coefficients throughout the calibration process. It is this way that a “fine tuning” of the magnetometer calibration can be achieved. If the user desires to start over, or if a major configuration change to the installation is performed, such as moving the installation of the magnetometer or locating a new large magnetic ferrous disturbance near to the magnetometer, then the calibration coefficients can be erased from the SDN500 by sending the proper bits in Message 3504 - SDN500 Parameter Control. Send the appropriate “Install Magnetometer Calibration Control” bits in Message 3504 - SDN500 Parameter Control to erase the magnetometer calibration data, and restart the SDN500 system.

Magnetometer Data Interface

The SDN500 supports direct communications with an external magnetometer and will accept input magnetometer data via two message formats, the Systron Donner proprietary format Message 3530 - Heading Reference message, and the industry standard NMEA Protocol - XDR Heading Reference magnetometer transducer message. Please refer to Chapter 7- Software Integration for a complete description of these input messages. The SDN500 also provides a proprietary message output Message 3505 - Magnetometer Data, which contains information directly related to the input magnetometer data and the magnetic variation calculation. Message 3505 is designed to provide the user enough direct information about the magnetometer input data, and if requested, this message will be output at the same rate as the magnetometer message input rate. To connect to this message, please refer to the description in Chapter 7- Software Integration, regarding the proper method of connecting to a message type, and for a complete description of Message 3505 - Magnetometer Data.

Chapter 7- Software Integration

SDN500 to Host Vehicle Data Interface/Definitions

The SDN500 provides a bi-directional RS-232/RS-422 serial port (see Table 5-1, IONAV_RS232) to support serial interface between SDN500 and the *Host Vehicle* (*HV*). This allows the user to receive *output messages* describing the SDN500 status and navigation state, send *input messages* to the SDN500 to initialize it, and change its processing state.

The HV *Input/Output (I/O)* consists of various *data messages* that are identified by data message numbers. The detailed content and structure (definitions) of these data blocks will be specified in this chapter.

The transmit rate (data from the SDN500), and the reception rate (data from the HV) are currently both factory set at 115200 baud. Refer to Message 3504 in this chapter for information on selecting/reprogramming the SDN500–HV baud rate.

The SDN500 also provides a single directional (input) RS-232/RS-422 serial port (see Table 5-1, IO_RS232) to allow the HV to control the output data rate of the SDN500 IMU portion over the SDLC port. The high output rate IMU data available from the single directional (output) SDN500 SDLC high speed synchronous data port, available at three output rates (see SDN500 IMU SDLC Data).

Message Format

The data and commands transmitted over the SDN500-to-HV interface are formatted into *messages*. Each type of message is identified by a unique identification (ID) number. Messages contain a header portion and may or may not contain a data portion. *Header-only-messages* do not contain a data portion.

The maximum number of words a message can contain is 134 (five header words and 129 data words). The message header contains four header words, plus one header checksum word (Words 1 through 5). The message data portion contains a variable number of data words (Words 6 through 5+N ($0 < N \leq 128$)), plus one data checksum word (Word 6+N). For a header-only message, only the header portion (no data checksum) is sent.

A message word length is 16 bits on the SDN500–HV interface. However, the SDN500–HV protocol, which uses a standard *Universal Asynchronous Receiver Transmitter* (UART), transmits data in 8-bit groups (bytes). This means that two bytes are required in order to make up one message word.

A byte of information is transmitted as a sequence of 11 bits: one start bit, 8 bits of data (least significant bit (LSB) first), one parity bit (odd), and one stop bit. For each 16-bit data word, the least significant byte is transmitted first, followed by the most significant byte. Integer and floating point data types consisting of more than one word are transmitted from the lowest numbered word to the highest numbered word. The one exception to this rule is the time tag, which is output in words 6-9 of each HV output message. The four 16-bit data words are in the following order: 2,1,4,3, where 1 represents the most significant word and 4 the least significant word. Each word is separately byte-reversed.

Message Header Format

The five message words of the header portion of a message are summarized in Table 7-1.

Table 7-1. Message Header Word Definitions

Word Number	Description
1	Synchronization word (Value = DEL/SOH = $81FF_{16}$)
2	Message ID number
3	Word count (number of 16-bit words in data portion of message, excluding data checksum; legal range = 0 - 128; value = 0 for header-only messages)
4	Flags word (see description below)
5	Header checksum (2’s complement of 16-bit sum of header words 1 - 4)

Word 4 of the message header is a bit-coded *flags word* containing protocol and message related flags. The word’s bit definitions are defined in Table 7-2.

Table 7-2. Flag Word Bit Definitions

Bit	Description	Input to SDN500	Output to HV
0 (LSB)	Spare	Ignored	Always 0
1	Spare	Ignored	Always 0

2	Reserved	Reserved	Reserved
3	Reserved	Reserved	Reserved
4	Reserved	Reserved	Reserved
5	Disconnect	Commands the SDN500 “disconnect”, i.e. discontinue transmitting, the specified message. In addition, this flag, sent with a message ID (header word 2) of 0, causes the SDN500 to output only the default messages.	Always 0
6	Connect	Commands the SDN500 to “connect”, i.e., begin transmitting, the specified message to the HV at the scheduled update rate.	Always 0
7	Invalid Data	Ignored	Indicates that an error has rendered the data contained in the data portion of the SDN500 transmitted message to be questionable.
8	Command Reject	Ignored	Indicates that a command to the SDN500 from the HV has been rejected (“1”) or accepted (“0”).
9	Handshake	Indicates that the SDN500 must generate a handshake command accept/reject response to an input message.	Indicates that the SDN500-transmitted-message is a response to the HV command. The state of the Reject Flag indicates whether the command has been accepted or rejected.
10	NAK Message	Indicates that a SDN500-transmitted-message, with the Acknowledge Request Flag set, has been received by the HV with data errors. Receipt of a Negative Acknowledge Flag by SDN500 will cause SDN500 to re-transmit the message in error.	Indicates that the HV-transmitted-message, with the Acknowledge Request Flag set, has been received by the SDN500 with data errors.
11	ACK Message	Indicates that a SDN500 transmitted message, with the Acknowledge Request Flag set, has been received by the HV correctly.	Indicates that the HV-transmitted-message, with the Acknowledge Request Flag set, has been received by the SDN500 correctly.
12	ACK Request	Indicates that the message being transmitted by the HV requires acknowledgment from the SDN500.	Indicates that the message being transmitted by the SDN500 requires acknowledgment from the HV.
13	Reserved	Reserved	Reserved
14	Reserved	Reserved	Reserved
15 (MSB)	Ready	Indicates that the HV is ready to operate under the constraints of the SDN500–HV protocol. Whenever the HV is ready to receive a message, the Ready Flag is set to one (Ready = “1”, Not Ready = “0”).	Always 1

Message Data Format

The data portion may contain a maximum of 128 data words, plus one data checksum word (Words 6 through 134). These 16-bit data field message words are completely transparent to the protocol and have no restrictions on bit patterns or character groupings.

The number of data message words "N", is the same number of words specified in the message word count (message Word 3 in the header portion). When the message word count is zero, this field does not exist.

The 16-bit checksum field is used to validate the data portion of the message. It is transmitted as the last message word of any message containing data message words. It is computed as the 2's complement of the 16-bit sum of all message data words (words 6 to 5+N).

The data in the SDN500 messages is encoded in a variety of numerical data formats. These are summarized in Table 7-3 below.

Table 7-3. Numerical Data Formats

Data Format	Description
I	Integer (16 bits)
UI	Unsigned Integer (16 bits)
DI	Double integer (32 bits)
DUI	Double unsigned integer (32 bits)
BIT	Bit-coded 16-bit value
F	Single-precision binary-scaled fixed-point number (32 bits)
DF	Double-precision binary-scaled fixed-point number (64 bits)

For the binary-scaled fixed-point data formats, the encoding is described as F@S or DF@S, where S is the binary scaling. For both formats, the integer representation is a signed binary fraction (MSB = sign, binary point to the right of the sign bit) of the number 2^S.

For a single-precision binary-scaled number, the LSB is 2^{S-31}, and the range is from:
-2^S (= 80000000_{16}) to 2^S - 1 LSB (= $7FFFFFFF_{16}$).

For a double-precision binary-scaled number, the LSB is 2^{S-63}, and the range is from:
-2^S (= 8000000000000000_{16}) to 2^S -1 LSB

(= $7FFFFFFFFFFFFFFF_{16}$).

Example Illustrating Sample Message Data Byte Ordering and Data Conversion

The table below contains a sample message 3500 as transmitted to the Host Vehicle by SDN500. The byte number represents the time order of data bytes received by the Host Vehicle (i.e. byte 1 is the first byte received, byte 2 is the second byte received, etc.).
Examples of message header and data verification, and data conversion for the various types of numeric data follow.

BYTE #	MESSAGE DATA BYTES							
1	FF	81	AC	0D	10	00	00	80
9	45	F0	2D	78	BA	33	A0	FD
17	7F	D5	02	00	2B	04	00	00
25	00	00	00	00	31	19	34	24
33	00	00	99	19	00	00	F5	6C
41	37	00	A3	B8				

Integer and BIT coded data are sent byte-reversed: the message header data words are as follows:
Word 1 = $81FF_{16}$ (message synchronization value)
Word 2 = $0DAC_{16}$ (message identification = 3500_{10})
Word 3 = 0010_{16} (word count for data portion of message, not including the data checksum word = 16_{10})
Word 4 = 8000_{16} (flag word, indicating ‘ready’)
Word 5 = $F045_{16}$ (The 16-bit twos complement checksum of words 1-4 = 0 - LSW [$81FF_{16}$+ $0DAC_{16}$+ 0010_{16}+ 8000_{16}]).

Single-precision (32 bit) fixed-point quantities are sent in byte-reversed order. For example, the horizontal position error contained in the example message 3500, (words 16-17, bytes 31-34) is 00002434_{16} scaled at 15 (0.141418457) meters.

Double-precision (64 bit) fixed-point quantities are output byte-reversed and the most significant 32 bits of the double-precision quantity output first. For example, the time tag contained in this message 3500, (words 6-9, bytes 11-18) is $33BA782DD57FFDA0_{16}$ scaled at 20 (423759.0223798751140) seconds.

The message data checksum is $B8A3_{16}$ (The 16-bit twos complement checksum of message words 6 - 21 = 0 - LSW [+ $782D_{16}$ + $33BA_{16}$ + $FDA0_{16}$ + $D57F_{16}$ + 0002_{16} + $042B_{16}$ + 0000_{16} + 0000_{16} + 0000_{16} + 1931_{16} + 2434_{16} + 0000_{16} + 1999_{16} + $6CF5_{16}$ + 0037_{16}]).

Message Acknowledgment/Acceptance Protocol

Messages are grouped according to whether or not they must be *acknowledged* (ACKNOWLEDGE REQUEST flag, in header message word 4, is set or cleared). Commands are a subset of messages that must be acknowledged (since the ACKNOWLEDGE REQUEST flag is always set for commands). Any message not requiring acknowledgment is considered complete by the transmitting device as soon as it has been sent over the SDN500–HV interface.

The receiving device considers the message complete when it arrives successfully. If the message is received in error, it is ignored by the receiving device. Any message transaction requiring an acknowledgment is not considered complete by the transmitting device until a *message acknowledgment* is received.

The protocol for *acknowledge* (ACK) and *negative acknowledge* (NAK) messages are specified in the following paragraphs.

Acknowledge (ACK)

This message is a header-only message with a message ID that is the same as that of the message being acknowledged. The ACK bit is set in the flags word. The ACK message is transmitted in response to a message requiring acknowledgment which was received without word count or checksum errors. If the message is received without word count errors or checksum errors (the header and data checksums produce zero sums) the message is acknowledged within 100.0 msec. If the header checksum results in a non-zero sum, or the message had a framing or parity error, then the header will be assumed invalid (i.e., no flag information is available) and is not acknowledged.

Negative Acknowledge (NAK)

This message is a header-only message with a message ID that is the same as that of the message being acknowledged. The NAK bit is set in the flags word. The NAK message is transmitted in response to a message requiring acknowledgment whose header was received correctly but has a word count error or checksum error in the data portion of the message. If the message is received without word errors in the header, and the header checksum results in a zero sum (i.e., there are no checksum errors in the header or any framing or parity errors which would mean that the message would be ignored), and if there is a non-zero sum for the data checksum, then the message is negatively acknowledged within 100.0 msec.

Command Acceptance

All commands require acknowledgment (ACK or NAK*)*. The receiving device must always ACK or NAK the command to notify the transmitting device, whether or not the command was received in error. In addition to acknowledgment, any commands with the connect/disconnect/request flags or the handshake flag set require additional handshaking. The handshake needs to be performed for command completion.

If the handshake bit is set in a received command, the receiving device will indicate acceptance or rejection of the command by clearing or setting the command reject bit ("1"-- rejected, "0" -- accepted). SDN500 may reject a command because of the following system constraints:

- Additional messages requested by the command would cause the data rate of the interface to be exceeded.
- The SDN500's operations at the time of receipt of command do not allow the requested operation to be performed.
- The data content of the message had values that are out of range, or not allowed in current SDN500 operational mode.

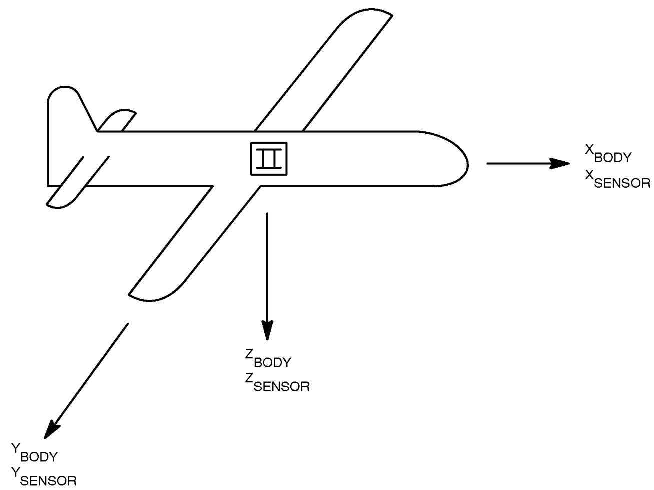
For 300 ms following SDN500 transmission of a command accept message, specific data messages being transmitted from SDN500 are not constrained to fall within the previous data output configuration or the requested data output configuration. In other words, the SDN500 is not required to output the previous sequence of messages nor the requested sequence of messages for a period of up to 300 msec. This condition occurs only after a command has been accepted by the SDN500 and the command modifies the current message output.

SDN500 Coordinate Frames

SDN500 utilizes several different coordinate reference frames.

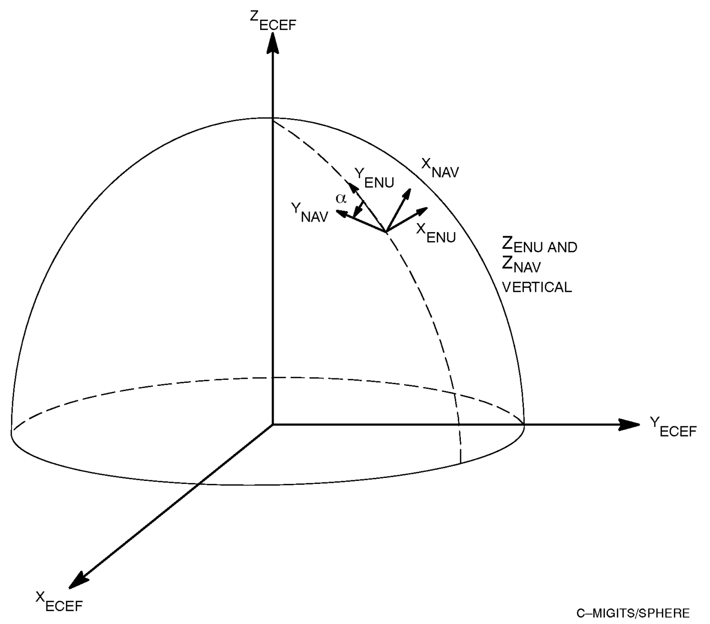
The *IMU* or *sensor coordinate frame* is fixed to the body of the SDN500, and its axes are nominally along the directions defined by the decal affixed to the can. The raw incremental inertial data received from the IMU portion is resolved along these axes, but none of the SDN500 HV output messages contain data resolved in this frame.

The *body coordinate frame* is also fixed to the body of the SDN500, but its orientation may be changed by user input (Message 3511). This is useful in making the SDN500 attitude outputs (pitch, roll, and heading) meaningful for different orientations of the SDN500 within a host vehicle. If body axes are defined such that the X_{BODY} axis points out the front end of the vehicle, the Y_{BODY} axis points out the right side, and the Z_{BODY} axis points downward through the floor, then the attitude angles will have their familiar meanings: i.e. pitch is a right-handed rotation about Y_{BODY}, roll is a right-handed rotation about $X\text{-}_{BODY}$, and heading is a right-handed rotation about Z_{BODY}. See illustration below.



The default orientation of the body frame is coincident with the sensor frame, so the default orientation of SDN500 (i.e. the orientation for which no message 3511 command is necessary to yield meaningful attitude outputs) has the decal X axis pointing out the nose of the vehicle and the decal Z axis pointing down. *(i.e. the SDN500 mounted with connector upwards)*

The *Earth-Centered Earth-Fixed (ECEF) coordinate frame* is fixed to the earth and rotates with it. The Z_{ECEF} axis is along the north polar axis of the earth, and the X_{ECEF} and Y_{ECEF} axes are in the equatorial plane, with the X axis pointing outward through the Greenwich meridian. The latitude and longitude angles output by the SDN500 are measured relative to the ECEF coordinate system. See illustration below.



The *locally-level east-north-up (ENU) coordinate frame* is centered at the SDN500 location and has its X_{ENU} axis pointing east, its Y_{ENU} axis pointing north, and its Z_{ENU} axis pointing up. The vehicle velocity is output in this coordinate system.

The *navigation coordinate frame* is also a locally level system centered on the SDN500 with its Z axis pointing vertically. It is displaced from the ENU coordinate system by an angular rotation about the Z axis by an angle α, called the *wander angle*. The wander angle is initialized to the negative of the initial heading of the vehicle, and in general changes very slowly during navigation, so that the navigation and ENU systems have a roughly constant orientation with respect to each other.

The navigation coordinate system is the fundamental system in which the SDN500 performs navigation, but none of the SDN500 output messages contain data resolved in this frame.

SDN500-HV Navigation Messages

Default Messages

Upon transition to *Initialization* mode, SDN500 will begin outputting the following default data messages on the HV interface automatically over the IONAV_RS232 port. Additional messages may be connected by issuing connect commands (described earlier in this chapter).

- SDN500 System Status (Message 3500). This message is output at 1 Hz.
- SDN500 Navigation Solution (Message 3501). This message is output at 10 Hz.
- GPS Processor Timemark Message (Message 3623). This passthrough message is output at 1 Hz as explained below.

SDN500-to-HV Data Messages

The messages output from the SDN500 to the HV fall into two categories: messages containing SDN500 status and navigation data, and a "passthrough" message containing data from the GPS processor, which contains status and navigation data.

Transmission of these messages may be enabled (connected) or disabled (disconnected) as described earlier in this chapter, and the output rate of some messages may be changed by HV input command. The data messages are summarized in Tables 7-4 and 7-5.

Table 7-4. SDN500- to- HV Data Messages

Message ID	Message Name	Description	Rate
3	SDN500 Timemark Message	System status and navigation data	1 Hz
3500	SDN500 System Status	System mode and processing status information	1 Hz
3501	SDN500 Navigation Solution	Position, velocity, attitude	10 Hz or 1 Hz
3502	SDN500 Delta Velocity and Delta Theta	Raw delta velocity and delta attitude data from the IMU	100 Hz, 10 Hz, or 1 Hz
3503	SDN500 Built-In Test Results	Built-In-Test results	Once at startup and at 1 Hz if requested
3505	Magnetometer Data	Magnetic Heading, Magnetometer Vector Data,	The same rate as the

		Magnetometer Hardiron/Softiron Data, Magnetic Variation	Magnetometer message rate
3512	SDN500 Flight Control	Delta velocity and delta attitude data compensated for IMU error estimates	100 Hz, 10 Hz, or 1 Hz

GPS Passthrough Message

Data from selected GPS messages received by the SDN500 is translated into the numerical formats used by the internal algorithms and grouped together into message 3623 output at 1Hz by the SDN500.

Table 7-5. GPS Message Passthrough ID Numbers

GPS	Raw Timemark ID	Translated Timemark ID
Pico	(1)	3623

HV-to-SDN500 Data Messages

The HV-to-SDN500 data messages are summarized in Table 7-6.

Table 7-6. HV-to-SDN500 Data Messages

Message ID	Message Name	Description
0	Universal Reset	Reset SDN500 output to default messages
3504	SDN500 Parameter Control	Set system baud rates; set message output rates and configuration; and storage of program data in FLASH
3510	SDN500 Control and Initialization	Mode commands and position/velocity/time initialization
3511	SDN500 Configuration Control	Set system configuration data: IMU orientation, lever arms
3530	SDN500 Magnetometer Interface	Provide magnetometer data input to the SDN500 to augment the heading solution

NMEA Protocol HV to SDN500 Data Messages

The NMEA protocol is provided to enable the user to configure the SDN500 to perform in an automatic manner and connect a NMEA capable magnetometer system directly into the RS-232 RX input of the SDN500. It is an ASCII message structure and a unique three upper case character string identifies each message. The three supported standard messages are summarized in Table 7-7.

Table 7-7 NMEA Protocol HV to SDN500 Data Messages	
Message ID	**Message Name**
"HDG"	Heading, Deviation and Variation
"HDT"	True Heading
"XDR"	Magnetometer Sensor Measurements

SDN500 Message Formats

The formats of the SDN500 messages are specified in the sections that follow.

Message 0 - Universal Reset

MSG NAME : Universal Reset (See Note)	
MSG ID : 0	
INVALID FLAG: Never set	Data Word Count: 0
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a

Note to Message 0 - Universal Reset:

To command SDN500 to output default messages only, Message 0 should be transmitted with the Disconnect Message Flag set to 1.

Message 3 – SDN500 Timemark Message

MSG NAME : SDN500 Timemark Message	
MSG ID: 3	
INVALID FLAG: Set when no nav solution	Data Word Count: 52 + (2 × Number of GPS Channels) (See Note 11)
I/O: Output	XMIT RATE: 1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
GPS Time	(Note 1)	6-9	DF@20	sec
UTC Time	(Note 2)	10-13	DF@17	sec
Latitude	(Note 3)	14-15	F@0	semicircles
Longitude	(Note 3)	16-17	F@0	semicircles
Altitude, Absolute	(Note 3)	18-19	F@15	meters
ECEF Position X	(Note 4)	20-21	F@23	meters
ECEF Position Y	(Note 4)	22-23	F@23	meters
ECEF Position Z	(Note 4)	24-25	F@23	meters
Velocity, East	(Note 5)	26-27	F@10	m/sec
Velocity, North	(Note 5)	28-29	F@10	m/sec
Velocity, Up	(Note 5)	30-31	F@10	m/sec
Acceleration, East	(Note 6)	32-33	F@6	m/sec/sec
Acceleration, North	(Note 6)	34-35	F@6	m/sec/sec
Acceleration, Up	(Note 6)	36-37	F@6	m/sec/sec
Attitude, Pitch	(Note 7)	38-39	F@0	semicircles
Attitude, Roll	(Note 7)	40-41	F@0	semicircles
True Heading	(Note 7)	42-43	F@0	semicircles
Current Mode	(Msg 3500, Note 2)	44	I	n/a
System Status Validity	(Msg 3500, Note 3)	45	BIT	n/a
Number Current SVs Tracked	(Msg 3500, Note 4)	46	I	n/a
Number of Position Measurements Processed	(Msg 3500, Note 5)	47	I	n/a

(continued next page)

SDN500 Timemark Message (cont.)

Number of Velocity Measurements Processed	(Msg 3500, Note 6)	48	I	n/a
FOM Information	(Msg 3500, Note 7)	49	BIT	n/a
Expected Horizontal Position Error	(Note 8)	50-51	F@15	meters
Expected Vertical Position Error	(Note 8)	52-53	F@15	meters
Expected Velocity Error	(Note 8)	54-55	F@10	m/sec
Equipment Available	(Note 9)	56	BIT	n/a
Equipment Used	(Note 10)	57	BIT	n/a
Channel 1 Measurement State	(Note 11)	58	BIT	n/a
Channel 1 C/No	(Note 11)	59	BIT	n/a
Channel 2 Measurement State	(Note 11)	60	BIT	n/a
Channel 2 C/No	(Note 11)	61	BIT	n/a
| |	| |	| |	| |	| |
| |	| |	| |	| |	| |
Channel N Measurement State	(Note 11)	56 + 2N	BIT	n/a
Channel N C/No	(Note 11)	57 + 2N	BIT	n/a
Data Checksum	-	58 + 2N	I	n/a

Notes to Message 3 – SDN500 Timemark Message

1. GPS TIME - GPS Sensor time (time of week in seconds, starting at Saturday 2400 hours/ Sunday 0000 hours) if GPS Time Valid Message 3500 is set to 1, otherwise SDN500 system time since power up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

2. UTC TIME - Universal Coordinated Time (seconds of day) - Not presently implemented.

3. LATITUDE/LONGITUDE - These words contain the SDN500 present position output in Latitude/Longitude coordinates referenced to WGS-84 map datum.

4. ECEF POSITION X, Y, and Z - These words contain the SDN500 present position output in WGS-84 Earth-Centered, Earth-Fixed (ECEF) coordinates.

5. VELOCITY EAST, NORTH, UP - These words contain the SDN500 present velocity in local tangent plane coordinate referenced to the WGS-84 ellipsoid.

6. ACCELERATION EAST, NORTH, UP - These words contain the SDN500 present acceleration. Compensated sensor delta velocity values are used.

7. ATTITUDE, PITCH and ROLL; TRUE HEADING - These words contain the SDN500 present attitude. Positive Pitch values represent nose up. Positive Roll values represent right wing down. Positive Heading values represent clockwise angles relative to North.

8. EXPECTED ERRORS - The expected horizontal and vertical position errors and velocity error are derived by taking the square root of the corresponding Kalman filter variances.

9. EQUIPMENT AVAILABLE - This word is structured as follows:

Bit Position	Definition
0-2	Reserved
3	External magnetometer heading reference data available
4-15	Reserved

10. EQUIPMENT USED - This word is structured as follows:

Bit Position	Definition
0-2	Reserved
3	External magnetometer heading reference data used
4-15	Reserved

11. GPS CHANNEL MEASUREMENT STATE and C/No - These words are provided for each channel of the GPS Receiver, so the length of the timemark block is dependent on the type of GPS receiver. These words are structured as follows:

Channel Measurement State Word

DATA ITEM	DATA BIT	DEFINITION
Satellite PRN Code	0-4	Range 0-31
Channel Activity	5-7	000=idle 001=C/A code search 101=C/A code tracking
Code Type	8	0= P-code, 1= C/A code
Encryption Type	9	0= P-code, 1= Y-code
Reserved	10	
Reserved	11-14	n/a
Channel Fault	15	1=Fault, 0=No Fault

Channel C/No Word

DATA ITEM	DATA BIT	DEFINITION
Reserved	0-7	n/a
C/No	8-13	Integer value of signal-to-noise ratio, range= 1 to 63 dB-Hz
Reserved	14-15	n/a

Message 3500 - SDN500 System Status

MSG NAME : SDN500 System Status	
MSG ID : 3500	
INVALID FLAG: Never set	Data Word Count: 16
I/O: Output	XMIT RATE: 1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 1)	6-9	DF@20	sec
Current Mode	(Note 2)	10	I	n/a
System Status Validity	(Note 3)	11	BIT	n/a
Number Current SVs Tracked	(Note 4)	12	I	n/a
Number of Position Measurements Processed	(Note 5)	13	I	n/a
Number of Velocity Measurements Processed	(Note 6)	14	I	n/a
FOM Information	(Note 7)	15	BIT	n/a
Expected Horizontal Position Error	(Note 8)	16-17	F@15	meters
Expected Vertical Position Error	(Note 8)	18-19	F@15	meters
Expected Velocity Error	(Note 8)	20-21	F@10	m/sec
Data Checksum	-	22	I	n/a

Notes to Message 3500 - SDN500 System Status

1. TIME TAG - Contains GPS Sensor time if valid (GPS Sensor has valid GPS time); otherwise, SDN500 system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
2. CURRENT MODE - The value of the CURRENT MODE word has the following definitions:

Value	Mode
1	Test
2	Initialization
3	(Not Used)
4	Fine Alignment
5	Air Alignment
6	Transfer Alignment
7	Air Navigation
8	(Not Used)
9	GPS Only

10	Install Magnetometer Calibration (Refer to Chapter 6- Magnetometer Interface)
11	Launch Magnetometer Calibration (Refer to Chapter 6- Magnetometer Interface)

3. SYSTEM STATUS VALIDITY - The bits of this word are defined as follows (where bit 0 = LSB):

- bit 0 GPS Measurements Available
  Set to 1 if GPS Sensor time is valid and GPS Sensor indicates that at least 4 SVs are being used.
- bit 1 INS Measurements Available
  Set to 1 when INS sensor data is being received from the INS.
- bit 2 GPS Data Late
  Set to 1 when GPS measurement data is not received for the current second.
- bit 3 GPS Time Valid
  Set to 1 when valid UTC data has been received from the GPS receiver.
- bit 4 Timemark Timeout
  Set to 1 when the 1-PPS timemark pulse from the GPS receiver is not detected.
- bit 5 BIT Failure
  Set to 1 when a failure of Built-In Test has occurred.
- bit 6 Constellation Change
  Set to 1 when the constellation (current set of SVs) has changed.
- bit 7 Time Bias Repartition
  Set to 1 when the GPS receiver resets the partitioning between the time bias estimate and the pseudorange values.
- bit 8 Coarse Air Alignment submode indicator
  Set to 1 when the system is in Coarse Air Alignment submode.
  Set to 0 when the system is not in Coarse Air Alignment submode.
- bit 9
  Reserved
- bits 10-12 GPS Receiver Type
  The following GPS receiver types are defined:

Value	Type
0	N/A
1	N/A
2	N/A
3	Jupiter Pico

- bit 13 Heading Hold Flag
  Set to 1 when in heading hold mode
  Set to 0 when not in the heading hold mode
- bits 14-15
  Reserved

4. NUMBER CURRENT SVs TRACKED - Number of SVs providing usable measurements during the current second. This is not necessarily the number of measurements processed. The following two words indicate how many measurements were actually used.

5. NUMBER OF POSITION MEASUREMENTS PROCESSED - Number of position measurements processed this second by the SDN500 Kalman filter.

6. NUMBER OF VELOCITY MEASUREMENTS PROCESSED - Number of velocity measurements processed this second by the SDN500 Kalman filter.

7. FOM INFORMATION - The following figure of merit (FOM) bit definitions have been defined for FOM information:

bits 0-3: Position FOM	
Value	$\sqrt{Variance}$ **(meters)**
1	< 25
2	< 50
3	< 75
4	< 100
5	< 200
6	< 500
7	< 1000
8	<5000
9	≥ 5000

bits 4-7: Velocity FOM	
Value	$\sqrt{Variance}$ **(m/sec)**
1	< 0.2
2	< 1
3	< 5
4	< 25
5	< 50
6	< 80

7	< 150
8	< 300
9	≥ 300

bits 8-11: Heading FOM	
Value	$\sqrt{Variance}$ **(mrad)**
1	< 0.5
2	< 1
3	< 1.73
4	< 5
5	< 8.66
6	< 10
7	< 17.3
8	< 86.6
9	≥ 86.6

bits 12-15: Time FOM	
Value	$\sqrt{Variance}$ **(μsec)**
1	< 0.001
2	< 0.01
3	< 0.1
4	< 1
5	< 10
6	< 100
7	< 1000
8	< 10000
9	≥ 10000

8. EXPECTED ERRORS - The expected horizontal and vertical position errors and velocity error are derived by taking the square root of the corresponding Kalman filter variances.

Message 3501 - SDN500 Navigation Solution

MSG NAME : SDN500 Navigation Solution	
MSG ID : 3501	
INVALID FLAG: Never set	Data Word Count: 22
I/O: Output	XMIT RATE: 1,10 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Latitude	(Note 3)	10-11	F@0	semicircles
Longitude	(Note 3)	12-13	F@0	semicircles
Altitude	(Note 3)	14-15	F@15	meters
Velocity North	-	16-17	F@10	m/sec
Velocity East	-	18-19	F@10	m/sec
Velocity Up	-	20-21	F@10	m/sec
Pitch	(Note 4)	22-23	F@0	semicircles
Roll	(Note 4)	24-25	F@0	semicircles
True Heading	(Note 4)	26-27	F@0	semicircles
Data Checksum	-	28	I	n/a

Notes to Message 3501 - SDN500 Navigation Solution:

1. Transmission rate programmable via Message 3504.
2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, SDN500 system time since power up is reported.. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
3. LATITUDE, LONGITUDE, ALTITUDE - Referenced to WGS-84 map datum.
4. PITCH, ROLL, TRUE HEADING - Positive pitch values represent nose up. Positive roll values represent right wing down. Positive heading values represent clockwise angle relative to North.

Message 3502 - SDN500 Delta Velocity and Delta Theta

MSG NAME : SDN500 Delta Velocity and Delta Theta	
MSG ID : 3502	
INVALID FLAG: Never set	Data Word Count: 16
I/O: Output	XMIT RATE: 1,10, 100 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Delta Theta X	(Note 3)	10-11	F@0	radians
Delta Theta Y	(Note 3)	12-13	F@0	radians
Delta Theta Z	(Note 3)	14-15	F@0	radians
Delta Velocity X	(Note 3)	16-17	F@10	m/sec
Delta Velocity Y	(Note 3)	18-19	F@10	m/sec
Delta Velocity Z	(Note 3)	20-21	F@10	m/sec
Data Checksum	-	22	I	n/a

Notes to Message 3502 - SDN500 Delta Velocity and Delta Theta:

1. Transmission rate programmable via Message 3504. The selected rate affects the data time interval. For example, if the message is requested at 10 Hz, the data represents 100 ms of ΔV and $\Delta\theta$.

Overflows may occur if high-dynamics data is output at low rates.

2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, SDN500 system time since power-up is reported.. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

3. Delta values are incremental sums reported in HV body axis coordinate system where the default orientation is as follows: X = nose, Y = right wing, Z = down. Sensor errors and gravity have not been compensated.

Message 3503 - SDN500 Built-In-Test Results

MSG NAME : SDN500 Built-In Test Results	
MSG ID : 3503	
INVALID FLAG: Never set	Data Word Count: 100
I/O: Output	XMIT RATE: Once at startup or completion of a commanded Built In Test, and at 1 Hz if connected for output. (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
BIT Summary	(Note 3)	10	BIT	n/a
Reserved	-	11	n/a	n/a
BIT Validity Word	(Note 4)	12	BIT	n/a
BIT Results Word	(Note 4)	13	BIT	n/a
SDN500 Memory Test Result	(Note 5)	14	BIT	n/a
SDN500 Hardware Test Result	(Note 6)	15	BIT	n/a
Reserved	-	16-33	n/a	n/a
SDI500 SW Version Number	(Note 7)	34-36	I	n/a
SDN500 SW Version Number	(Note 8)	37	I	n/a
SDI500 BIT Information	(Note 9)	38-47	BIT	n/a
SDN500 BIT Word	(Note 10)	48-49	BIT	n/a
SDI500 BIT Message Passthrough	(Note 11)	50 - 57	BIT	n/a
Reserved		58 - 71	n/a	n/a
GPS Receiver Self Test Results	(Notes 12)	72-105	n/a	n/a
Data Checksum	-	106	I	n/a

Message 3503 contains the results of all self test processing performed by SDN500: Power-On Self Test (POST), Commanded Built-In Test (BIT), and background BIT processing. Refer to the notes below for individual data items to determine when a particular message field is updated.

Notes to Message 3503 - SDN500 Built-In Test Results:

1. Message 3503 is transmitted once at start-up, after completion of Power-On Self Test (POST) and once upon each completion of a commanded Built In Test (BIT). It may also be connected for output in order to monitor the continuous background BIT processing, in which case it will be transmitted at a 1-Hz rate. In general, it is not necessary to have message 3503 connected for continuous output, as the system status message 3500 System Status Validity word, bit 5 indicates the BIT summary pass/fail status.

2. Time Tag - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, SDN500 system time since power-up is reported.

3. BIT Summary - Contains the overall pass/fail status and type of the current test. The overall test pass/fail status represents the overall test results on the sensor's input, temperature, power supply and flash memory. It is also reported in System Status message 3500, word 11 (System Status Validity), bit 5. The format of this word is as follows.

BIT	Description
0 (LSB) - 12	Reserved
13 - 14	Type of current BIT test: 0 - Background BIT 1 - Commanded BIT 2 - Power-On Self Test (POST)
15	Test pass/fail flag (0 = PASS, 1 = FAIL)

4. BIT Validity and BIT Result words - Bits in the BIT Validity word are Boolean indicators of whether the corresponding bits in the BIT Results word contain valid data. This word is updated each time message 3503 is output. A bit is set to '1' in the BIT Validity word to indicate that this particular subsystem test has been performed, or that this element contains valid data from a previous test. The BIT Results word contains summary test results for various subsystem tests, where a bit is set to '1' to indicate a failure in a particular subsystem test. The bits in these words are updated as indicated by their respective notes. The detailed test results may be examined to determine the exact nature of any failure noted by a subsystem summary test indicated in the BIT Results word. The format of the BIT Validity and BIT Results words are detailed in the following table.

BIT VALIDITY and BIT RESULTS

BIT	Note	Description
0 (LSB)		Reserved
1	(Note 4.1, B)	Memory test
2	(Note 4.2, A)	QRS fault
3	(Note 4.3, A)	Temperature fault
4	(Note 4.4, A)	VQA fault
5	(Note 4.5, A)	Voltage Level fault

6		Reserved
7	(Note 4.6, B, C)	FPGA BIT test
8	(Note 4.7, A)	IOP BIT test
9	(Note 4.8, C)	GPS receiver BIT test
10		Time mark synchronization test
11-15 (MSB)		Reserved

Notes to BIT VALIDITY and BIT RESULTS Words

4.1 Memory Test result represents the test result of the IMU portion's memory. It is performed at start up or when BIT is commanded.

4.2 QRS sensor test result represents summary test results of 3 QRS test results, including voltage supply to the sensors and sensor's current as well as ADC overflow test results.

4.3 Temperature sensors limit test summary result represents the composite test results of all temperature sensors limit test result. If this bit is set, then there is fault of sensed temperature out of range, or a temperature sensor is in fault.

4.4 VQA test result represents the composite test results of 3 accelerometers test result, including sensor data out of range and voltage supply out of range to the sensors.

4.5 Power supply out of range test summary result represents the composite test results of all parts of power supply to SDN500 and reference voltage.

4.6 FPGA Bit test represents the BIT test of FPGA component of the SDI500 IMU. The FPGA is used for fast digital signal processing of all sensor channels. The test is performed at start up or when the commanded BIT is requested.

4.7 IOP BIT test represents the SDI500 IMU I/O processor's bit test result. The I/O processor is used to output SDLC inertial data to the user and transmit inertial data to the navigation engine of the SDN500.

4.8 GPS Receiver BIT indicates the summary pass/fail status of the GPS receiver subsystem built-in test. This testing is performed by the GPS receiver subsystem when a built in test command is sent to the SDN500. A failure indicates that either: 1) a reply from the GPS receiver was not received within the time-out period when BIT was commanded, or 2) a reply from GPS receiver report fault in words 80, 81, 82,83 and low byte of 85. . See GPS receiver BIT test results for details (words 72 – 105).

5. SDN500 Memory Test Results Word – This word gives detailed memory test result. The format of the test results word is as follows:

BIT	Note	Description
0	Note B	Internal RAM test of IMU portion
1	Note B	Reserved
2	Note B	Cal file is valid
3	Note B	Filter coefficient file is valid
4	Note B	Stack overflow
5	Note B	Inertial data output exceed range specification
6	Note B	Saved navigation initialization data validity
7	Note B	Install Mag Cal data present
8	Note B	Launch Mag Cal data present
9 - 15	Note B	Reserved

6. SDN500 Hardware Test Results – This word gives the detailed test results on inertial sensors, temperature sensor, and power supply and reference voltage over limit test. The format of the test results are as follows:

BIT	Note	Description
0 (LSB)	Note A	X rate sensor status
1	Note A	Y rate sensor status
2	Note A	Z rate sensor status
3	Note A	X accelerometer status
4	Note A	Y accelerometer status
5	Note A	Z accelerometer status
6	Note A	Inertial Sensors temperature sensor status
7	Note A	Electronics temperature sensor status
8	Note A	DSP temperature sensor status
9	Note A	Power supply out of range status

7. SDI500 SW Version Number - Words 34, 35, 36 are the software version numbers for the SDI500 FPGA, DSP and IOP respectively. All software version numbers are 16 bit integers.

8. SDN500 SW Version Number – Word 37 is the SDN500 navigation software version number. All software version numbers are 16 bit integers.

9. SDI500 BIT Information – Words 38 – 47 pass through the SDI500 detailed BIT status. Word 38, 39 contain the details of the sensor fault status. Words 40, 41 contain the details of temperature sensor fault status. Words 42, 43 contain the details of memory fault and demodulation coefficient fault status. Word 44 is the IOP bit status. Word 45 is SDI500 BIT status word. Words 46, 47 are the IOP flash status words.

10. SDN500 BIT Word – Word 48, 49 are the BIT words of SDN500.

11. SDN500 BIT Message Passthrough – Words 50-57 are the pass through words from SDI500 Post BIT message. Words 50, 51 are Filter File ID. Words 52, 53 are the Cal File ID. Words 54, 55 are the SDI500 unit serial no. Words 56, 57 are the SDI500 production code and model no.

12. GPS receiver self test results - reflect the results of the GPS receiver subsystem self test performed by the Jupiter when a built in test command is received by the SDN500. These words are the data portion of the Jupiter BIT results message 1100, exactly as reported by the GPS receiver. It is defined in the following table:

Data	Notes	Word No	Data Type	Units
Set Time	(Note 12.1,C)	72-73	UDI	10 ms ticks
Sequence Number	(Note 12.2,C)	74	I	n/a
ROM Failure	(Note 12.3,C)	75	UI	n/a
RAM Failure	(Note 12.3,C)	76	UI	n/a
EEPROM Failure	(Note 12.3,C)	77	UI	n/a
Dual Port RAM Failure	(Note 12.3,C)	78	UI	n/a
Digital Signal Processor (DSP) Failure	(Note 12.3,C)	79	UI	n/a
Real-Time Clock (RTC) Failure	(Note 12.3,C)	80	UI	n/a
Serial Port 1 Receive Error Count		81	UI	# errors detected
Serial Port 2 Receive Error Count		82	UI	# errors detected
Serial Port 1 Receive Byte Count		83	UI	# errors detected
Serial Port 2 Receive Byte Count		84	UI	# errors detected
GPS Receiver Software Version		85	UI	0.01 resolution
Reserved		86-87	n/a	n/a

12.1 Set Time - This is an internal 10 ms count since power-on initialization enable the processor interrupts. It is not used to derive GPS time, but only serves to provide a sequence of events knowledge. The set time count references the receiver's internal time at which the message was created for output. The range is approximately 71 weeks.

12.2 Sequence Number – This is a count that indicates whether the data in this binary message has been updated or changed since the last message output.

12.3 A value of zero indicates a test has passed. A non-zero value indicates a device failure. Missing devices will be reported as failures. Therefore, the OEM's BIT pass/fail should ignore words for components that are not in the system under test.

Notes on update rates:
A. The data item in this field is updated continuously by background Built-In Test processing. The last update of this field is reported whenever message 3503 is output.

B. The data item in this field is updated once during Power-On Self-Test. Subsequent output of message 3503 report the results of this test.

C. The data item in this field is updated every time that a Built-In Test is commanded. Subsequent output of message 3503 report the results of the last commanded Built-In Test.

Message 3504 - SDN500 Parameter Control

Currently, the SDN500-HV transmit and receive baud rate is factory set to 115,200.

MSG NAME : SDN500 Parameter Control	
MSG ID: 3504	
INVALID FLAG: Never set	Data Word Count: 5
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Host Vehicle Baud Rate and Magnetometer Calibration Control (Refer to Chapter 6- Magnetometer Interface)	(Note 2)	7	BIT	n/a
Heading Hold Control (Refer to Chapter 4 - Heading Hold Mode)	(Note 3)	8	BIT	n/a
Reserved		9	BIT	n/a
Message Control	(Note 4)	10	BIT	n/a
Data Checksum	-	11	I	n/a

Notes to Message 3504 - SDN500 Parameter Control:

1. DATA VALIDITY - This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
Host Vehicle XMIT Rate Valid (See Note 2)	0	0=No data specified 1=Valid XMIT baud rate data
Host Vehicle RCV Rate Valid (See Note 2)	1	0=No data specified 1=Valid RCV baud rate data
Reserved	2	Set to zero
Reserved	3	Set to zero
Reserved	4	Set to zero
Message 3501 XMIT Rate Valid	5	0=No data specified 1=Valid XMIT rate for Message 3501
Message 3502 XMIT Rate Valid	6	0=No data specified 1=Valid XMIT rate for Message 3502
Message 3512 XMIT Rate Valid	7	0=No data specified 1=Valid XMIT rate for Message 3512
Message 3512 Configuration Specification Valid	8	0=No data specified 1=Valid configuration for Message 3512
Reserved	9	Set to zero
Reserved	10	Set to zero

Magnetometer Calibration Control Valid	11	0=No data specified 1=Valid magnetometer calibration control data
Heading Hold control valid	12	0=No data specified 1 = Valid heading hold control data
Reserved	13	Set to zero
Pass through Control Valid	14	0=No data specified 1=Valid pass through control data
Save Configuration Command Valid	15	0=No data specified 1=Save configuration command valid

Refer to Appendix A- Frequently Asked Questions, for explanation of the Save Configuration command

2. BAUD RATE and Magnetometer Calibration Control - Baud rate changes are only processed when the CURRENT MODE (Message 3500) is Initialization. The Magnetometer Calibration Control parameters will be accepted in any mode. This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
XMIT Baud Rate	0-3	0=No Change 1=115200 2=57600 3=38400 4=19200 5=9600
Install Magnetometer Calibration Control	4-5	0=No Change 1=Start Mag Cal 2=End Mag Cal 3=Erase Mag Cal
XMIT Parity	6-7	0=No Change 1=No parity 2=Even parity 3=Odd parity
RCV Baud Rate	8-11	0=No Change 1=115200 2=57600 3=38400 4=19200 5=9600 6=4800
Launch Magnetometer Calibration Control	12-13	0=No Change 1=Start Mag Cal 2=End Mag Cal 3=Erase Mag Cal
RCV Parity	14-15	0=No Change 1=No parity 2=Even parity 3=Odd parity

The default setting for the Host Vehicle interface is 38400 baud, odd parity.

3. Heading Hold Control – The heading hold control is accepted only when in air navigation mode. This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
Reserved	0-3	
Heading Hold control	4	0=heading hold off 1=heading hold on
Reserved	5-15	

4. MESSAGE CONTROL - This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
Message 3501 Transmit Rate	0-1	0=No Change 1=1 Hz 2=10 Hz (Default)
Message 3502 Transmit Rate	2-3	0=No Change 1=1 Hz 2=10 Hz (Default) 3=100 Hz
Message 3512 Transmit Rate	4-5	0=No Change 1=1 Hz 2=10 Hz (Default) 3=100 Hz
Message 3512 Configuration	6-9	Bit 6=Delta attitude Bit 7=Delta velocity Bit 8=Attitude Bit 9=Velocity
Reserved	10-13	Set to zero
Passthrough control	14	0=Pass raw GPS messages 1=Pass translated GPS messages
Save configuration command	15	0=Erase 1=Save

Message 3505 - Magnetometer Data

MSG NAME : SDN500 Navigation Solution	
MSG ID : 3505	
INVALID FLAG: Never set	Data Word Count: 38
I/O: Output	Same as the Magnetometer data input rate

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Magnetic Heading	(Note 3)	10-11	F@0	semicircles
Magnetometer X	(Note 4)	12-13	F@2	gauss
Magnetometer Y	(Note 4)	14-15	F@2	gauss
Magnetometer Z	(Note 4)	16-17	F@2	gauss
Magnetometer X Hardiron	(Note 5)	18-19	F@2	gauss
Magnetometer Y Hardiron	(Note 5)	20-21	F@2	gauss
Magnetometer Z Hardiron	(Note 5)	22-23	F@2	gauss
Magnetometer X Softiron	(Note 6)	24-25	F@4	ratio
Magnetometer Y Softiron	(Note 6)	26-27	F@4	ratio
Magnetometer Z Softiron	(Note 6)	28-29	F@4	ratio
Launch Magnetometer X Hardiron	(Note 7)	30-31	F@2	gauss
Launch Magnetometer Y Hardiron	(Note 7)	32-33	F@2	gauss
Launch Magnetometer Z Hardiron	(Note 7)	34-35	F@2	gauss
Launch Magnetometer X Softiron	(Note 8)	36-37	F@4	ratio
Launch Magnetometer Y Softiron	(Note 8)	38-39	F@4	ratio
Launch Magnetometer Z Softiron	(Note 8)	40-41	F@4	ratio
Magnetic Variation	(Note 9)	42-43	F@0	semicircles
Data Checksum	-	44	I	n/a

Notes to Message 3505 – Magnetometer Data:

1. Transmission rate is the same as the magnetometer heading reference input message rate, such as message 3530 or XDR. Output available upon connect request.
2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, SDN500 system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
3. Calculated magnetic heading data in semi-circles corrected for magnetic variation (see note 9) used as reference data input for the Kalman filter.
4. Magnetometer vector data in units of gauss. Maximum range is 1.0 gauss.

5. Magnetometer hardiron data in units of gauss. The "install" magnetometer hardiron data is output in these fields after an "install" magnetometer calibration has been conducted.

6. Magnetometer softiron data in unitless ratio data. The "install" magnetometer softiron data is output in these fields after an "install" magnetometer calibration has been conducted.

7. Magnetometer hardiron data in units of gauss. The "launch" magnetometer hardiron data is output in these fields after a "launch" magnetometer calibration has been conducted. Please ignore this portion of message 3505.

8. Magnetometer softiron data in unitless ratio data. The "launch" magnetometer softiron data is output in these fields after a "launch" magnetometer calibration has been conducted. Please ignore this portion of message 3505.

9. Calculated magnetic variation data in semi-circles used to change magnetic north heading data into true map north data for use as reference data input for the Kalman filter.

Message 3510 - SDN500 Control and Initialization

MSG NAME : SDN500 Control and Initialization	
MSG ID : 3510	
INVALID FLAG: Never set	Data Word Count: 21
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Mode Command	(Note 2)	7	I	n/a
Latitude – Degrees	(Note 3)	8	I	degrees
Latitude – Minutes	(Note 3)	9	I	minutes
Latitude – Seconds	(Note 3)	10	I	seconds
Longitude – Degrees	(Note 3)	11	I	degrees
Longitude – Minutes	(Note 3)	12	I	minutes
Longitude – Seconds	(Note 3)	13	I	seconds
Altitude	(Note 3)	14-15	DI	meters
Ground Speed	(Note 4)	16	I	m/sec
Ground Track	(Note 4)	17	I	degrees
Year	(Note 5)	18	I	years
Day of Year	(Note 5)	19	I	days
Hours	(Note 5)	20	I	hours
Minutes	(Note 5)	21	I	minutes
Seconds	(Note 5)	22	I	seconds
True Heading	(Note 6)	23	I	degrees/100
Auto Align/Nav Sequence	(Note 7)	24	BIT	n/a
Reserved	Set to zero	25-26	n/a	n/a
Data Checksum	-	27	I	n/a

Notes to Message 3510 - SDN500 Control and Initialization:

1. DATA VALIDITY - The bits of this word are defined in the table below. A mode command may be issued in any mode, subject to the limitations of Table 4-1.

Refer to Appendix A- Frequently Asked Questions, for an explanation of various initialization options. The other initialization data will be acted upon only in initialization mode.

DATA ITEM	DATA BIT	DEFINITION
Mode Command Data	0	0=invalid, 1=valid
Position Data (lat/long/altitude)	1	0=invalid, 1=valid
Velocity Data	2	0=invalid, 1=valid
Date/Time Data	3	0=invalid, 1=valid
Heading Data	4	0=invalid, 1=valid
Auto Align/Nav Sequence Data	5	0=invalid, 1=valid
Auto GPS Init Valid	6	0=invalid, 1=valid
Reserved	7-15	Set to zero

2. MODE COMMAND - A value of zero enables automatic mode sequencing through alignment into navigation mode, as defined by the Auto Align/Nav sequence word. A value corresponding to a valid mode (see notes for message 3500) will cause a transition to that mode, if necessary through intervening modes as specified by the Mode Transition Table, Table 4-1. A commanded mode will remain in effect until another mode command is processed. The special mode command values -99 and +99 allow enabling of an "INS-Only" mode where GPS measurements processing is disabled and navigation is performed using only INS data. The value -99 enables INS-Only mode, and the value +99 disables it, i.e. returns to INS/GPS operation.

3. LATITUDE, LONGITUDE, ALTITUDE - For latitude, northern hemisphere values are indicated with positive degree, minute, second values; southern hemisphere values are represented with negative degree, minute, and second values. For instance, a southern latitude of 34 degrees, 15 minutes, 25 seconds would be input with a degrees value of -34, a minute value of -15, and a second value of -25. Similarly, for longitude, eastern hemisphere values are indicated with positive degree, minute, and second values; western hemisphere values are represented with negative degree, minute, and second values.

Latitude, longitude, and altitude are geodetic values referenced to WGS-84 datum. The default location at turn-on is the position saved in FLASH by the Save Configuration command of Message 3504, or, if this does not exist, the location is Concord, CA (Lat = 37:57:50, Lon = -122:01:47, Alt = 1.0).

4. VELOCITY - A vertical velocity of 0 (level flight) is assumed. Ground track is measured clockwise relative to North. The default is a velocity of zero.

5. DATE, TIME - UTC (Paris) date and time. The year is encoded as years since 1900 (1=1901). The day of year starts at one (1=Jan 1). The hour is encoded in 24-hour time (0=midnight; 13=1 pm).

6. TRUE HEADING - Represents actual pointing direction of HV, measured clockwise from North. The value must be specified in the range -180 to +180 degrees in units of deg/100, so the input integer must be between -18000 and +18000. The default heading is zero.

7. AUTO ALIGN/NAV SEQUENCE - This word is used to define default sequencing through an alignment mode and into a navigation mode after initialization. If this data is not provided, default sequencing is through Fine Alignment mode into Air Navigation mode. The bit definitions (where 0=LSB) for this word are shown in the table below. The numerical definitions of the modes are found in the notes for message 3500.

DATA ITEM	DATA BITS	DEFINITION
Auto Alignment Sequence	0-3	Alignment mode for automatic sequencing
Auto Navigation Sequence	4-7	Navigation mode for automatic sequencing
Auto GPS Initialization	8	0 = Initialize from user-provided data (default) 1 = Initialize from GPS processor nav solution as soon as GPS processor enters navigation mode
Reserved	9-15	Set to zero

Message 3511 - SDN500 Configuration Control

MSG NAME: SDN500 Configuration Control	
MSG ID : 3511	
INVALID FLAG: Never set	Data Word Count: 22
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Sensor-to-Body Transformation Cbs (1,1)	(Note 2)	7-8	F@1	Unitless
Sensor-to-Body Transformation Cbs (1,2)	(Note 2)	9-10	F@1	Unitless
Sensor-to-Body Transformation Cbs (1,3)	(Note 2)	11-12	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,1)	(Note 2)	13-14	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,2)	(Note 2)	15-16	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,3)	(Note 2)	17-18	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,1)	(Note 2)	19-20	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,2)	(Note 2)	21-22	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,3)	(Note 2)	23-24	F@1	Unitless
Lever Arm X	(Note 3)	25	I	cm
Lever Arm Y	(Note 3)	26	I	cm
Lever Arm Z	(Note 3)	27	I	cm
Data Checksum	-	28	I	n/a

Notes to Message 3511 - SDN500 Configuration Control:

1. DATA VALIDITY - The bits of this word are defined in the table below:

DATA ITEM	DATA BIT	DEFINITION
Sensor-to-Body Transformation Data	0	0=invalid, 1=valid
Lever Arm Data	1	0=invalid, 1=valid
Reserved	2-15	Set to zero

2. SENSOR-TO-BODY TRANSFORMATION - This matrix provides the means of transforming delta-velocity and delta attitude data from IMU axes to host-vehicle body axes. This affects the incremental data reported in messages 3502 and 3512 and the attitude data (pitch, roll, and heading) reported in messages 3501 and 3512 available on the IONAV_RS232 port. It does not affect the SDN500 high output rate IMU data available from the SDLC port, that data will always be output in the IMU axes.

3. LEVER ARM - The lever arm is the distance to the GPS antenna from the SDN500 center of gravity along the SDN500 body axes.

Message 3512 - SDN500 Flight Control

MSG NAME : SDN500 Flight Control	
MSG ID : 3512	
INVALID FLAG: Never set	Data Word Count: Note 3
I/O: Output	XMIT RATE: 1,10, 100 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Configurable Flight Control Data	(Note 3)	10 - N		
Data Checksum	-	N+1	I	n/a

Notes to Message 3512 - SDN500 Flight Control:

1. Transmission rate programmable via Message 3504. The selected rate affects the data time interval. For example, if the message is requested at 10 Hz, the data represents 100 ms of ΔV and $\Delta\Theta$.

Overflows may occur if high-dynamics data is output at low rates.

2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, SDN500 system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

3. The format of Message 3512 is configurable via Message 3504. Message 3512 may be specified to contain any or all of the following data items.

Notes to Message 3512 - SDN500 Flight Control (cont.)

DATA	NUMBER OF 16-BIT WORDS	DATA TYPE	UNITS
Compensated Delta Theta (Body coordinates - X,Y,Z)	6	F@0	radians
Compensated Delta Velocity (Body coordinates - X,Y,Z)	6	F@10	m/sec
Attitude (Pitch, roll, heading)	6	F@0	semicircles
Velocity (North, east, up)	6	F@10	m/sec

Included data items appear in the order shown. The size of the data block will vary with the included data items. The default content of message 3512 is the delta-attitude and delta-velocity data. Unlike message 3502, the delta-attitude and delta-velocity values are compensated for estimated IMU errors.

Message 3530 - Heading Reference

MSG NAME : Heading Reference	
MSG ID : 3530	
INVALID FLAG:	Data Word Count: 6
I/O: Input	XMIT RATE: 1 to 10 Hz

Data	Word No	Data Type	Units
Message Header	1-4	n/a	n/a
Header Checksum	5	I	n/a
Flag	6	n/a	n/a
Data	7-12		
Data Checksum	13	I	n/a

Message 3530 is a host vehicle input message to SDN500. It provides heading reference information via magnetometer vector data for the SDN500. The heading reference is therefore an extra navigation aid. The data packet must be sent down to the SDN500 at a 1Hz or higher rate. Receiving message 3530 at a 10Hz input rate has been tested thoroughly, but any input rate between 1Hz and 10Hz is acceptable.

Message 3530 contains 13 words with a 5 word header, a 1 word flag, 6 words of data and a 1 word data checksum as shown in the above table. Here 1 word equals 16 bits. The header format is the same as for other messages, such as message 3504. The flag word contains various flags to indicate the meaning of the data included and its validation. The flag word is defined as follows:

BIT	Notes	Description
0 (LSB) - 2	010 – Magnetometer Measurement	Message Subtype
3 - 6	Reserved	Not Used
7	1	Measurement Valid
8-15 (MSB)	Reserved	Not Used

The data types and units are as follows:

Data	Word No	Data Type	Units
Reserved	7-8	N/A	
Mag X measurement	9	I	13 nanoTesla/Count
Mag Y measurement	10	I	13 nanoTesla/Count
Mag Z measurement	11	I	13 nanoTesla/Count
Reserved	12	N/A	

Message 3623 - Jupiter Timemark Message

MSG NAME: Jupiter Timemark Message (Note 1)	
MSG ID : 3623	
INVALID FLAG: Never set	Data Word Count: 117
I/O: Output	XMIT RATE: 1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	(Note 1)	5	I	n/a
GPS Time of Week	(Note 2)	6-9	DF@20	sec
UTC Time	(Note 3)	10-13	DF@17	sec
Reserved	-	14	n/a	n/a
Reserved	(Note 4)	15	BIT	n/a
Number of SV's Used	-	16	I	n/a
Reserved	-	17-18	n/a	n/a
UTC Day	-	19	UI	days (1-31)
UTC Month	-	20	UI	months (1-12)
UTC Year	-	21	UI	years (1980-2079)
Latitude	(Note 5)	22-23	F@0	semicircles
Longitude	(Note 5)	24-25	F@0	semicircles
Altitude	(Note 5)	26-27	F@15	meters
Velocity, East	(Note 6)	28-29	F@10	m/sec
Velocity, North	(Note 6)	30-31	F@10	m/sec
Velocity, Up	(Note 6)	32-33	F@10	m/sec
Expected Horizontal Position Error	-	34-35	UDI	cm
Expected Vertical Position Error	-	36-37	UDI	cm
Expected Time Error	-	38-39	UDI	cm
Expected Horizontal Velocity Error	-	40	UI	cm/sec
Clock Bias	-	41-42	DI	cm
Clock Drift	-	43-44	DI	cm
Channel 1 CSW	(Note 7)	45	I	n/a
Channel 2 CSW	(Note 7)	46	I	n/a
Channel 3 CSW	(Note 7)	47	I	n/a
Channel 4 CSW	(Note 7)	48	I	n/a
Channel 5 CSW	(Note 7)	49	I	n/a
Channel 6 CSW	(Note 7)	50	I	n/a
Channel 7 CSW	(Note 7)	51	I	n/a
Channel 8 CSW	(Note 7)	52	I	n/a
Channel 9 CSW	(Note 7)	53	I	n/a
Channel 10 CSW	(Note 7)	54	I	n/a

Channel 11 CSW	(Note 7)	55	I	n/a
Channel 12 CSW	(Note 7)	56	I	n/a
Channel 1 Measurement State Info	(Note 8)	57	BIT	n/a
Channel 2 Measurement State Info	(Note 8)	58	BIT	n/a
Channel 3 Measurement State Info	(Note 8)	59	BIT	n/a
Channel 4 Measurement State Info	(Note 8)	60	BIT	n/a
Channel 5 Measurement State Info	(Note 8)	61	BIT	n/a
Channel 6 Measurement State Info	(Note 8)	62	BIT	n/a
Channel 7 Measurement State Info	(Note 8)	63	BIT	n/a
Channel 8 Measurement State Info	(Note 8)	64	BIT	n/a
Channel 9 Measurement State Info	(Note 8)	65	BIT	n/a
Channel 10 Measurement State Info	(Note 8)	66	BIT	n/a
Channel 11 Measurement State Info	(Note 8)	67	BIT	n/a
Channel 12 Measurement State Info	(Note 8)	68	BIT	n/a
Channel 1 Pseudorange	(Note 9)	69-70	F@26	meters
Channel 1 Deltarange	(Note 10)	71-72	F@14	m/sec
Channel 2 Pseudorange	(Note 9)	73-74	F@26	meters
Channel 2 Deltarange	(Note 10)	75-76	F@14	m/sec
Channel 3 Pseudorange	(Note 9)	77-78	F@26	meters
Channel 3 Deltarange	(Note 10)	79-80	F@14	m/sec
Channel 4 Pseudorange	(Note 9)	81-82	F@26	meters
Channel 4 Deltarange	(Note 10)	83-84	F@14	m/sec
Channel 5 Pseudorange	(Note 9)	85-86	F@26	meters
Channel 5 Deltarange	(Note 10)	87-88	F@14	m/sec
Channel 6 Pseudorange	(Note 9)	89-90	F@26	meters
Channel 6 Deltarange	(Note 10)	91-92	F@14	m/sec
Channel 7 Pseudorange	(Note 9)	93-94	F@26	meters
Channel 7 Deltarange	(Note 10)	95-96	F@14	m/sec
Channel 8 Pseudorange	(Note 9)	97-98	F@26	meters
Channel 8 Deltarange	(Note 10)	99-100	F@14	m/sec
Channel 9 Pseudorange	(Note 9)	101-102	F@26	meters
Channel 9 Deltarange	(Note10)	103-104	F@14	m/sec
Channel 10 Pseudorange	(Note 9)	105-106	F@26	meters
Channel 10 Deltarange	(Note 10)	107-108	F@14	m/sec
Channel 11 Pseudorange	(Note 9)	109-110	F@26	meters
Channel 11 Deltarange	(Note 10)	111-112	F@14	m/sec
Channel 12 Pseudorange	(Note 9)	113-114	F@26	meters
Channel 12 Deltarange	(Note 10)	115-116	F@14	m/sec
ECEF Position X	(Note 11)	117-118	F@23	meters
ECEF Position Y	(Note 11)	119-120	F@23	meters
ECEF Position Z	(Note 11)	121-122	F@23	meters
Data Checksum	-	123	I	n/a

Notes to Message 3623 - Jupiter Timemark Message:

1. Message 3623 represents a re-packaging of various Jupiter messages (Jupiter Messages 1000, 1002, 1007, 1009, and 1102) internal to the SDN500. Passthrough translation is enabled, i.e., data formats have been changed to those used by SDN500. The message size and checksum values differ from those of any Jupiter message.

2. GPS TIME - GPS Sensor time (time of week in seconds, starting at Saturday 2400 hours/ Sunday 0000 hours) if GPS Time Valid Message 3500 is set to 1, otherwise SDN500system time since power up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

3. UTC TIME - Universal Coordinated Time (seconds of day).

4. Reserved

5. LATITUDE, LONGITUDE, ALTITUDE - Referenced to WGS-84 map datum. WGS-84 coordinates are ellipsoidal coordinates, hence given in latitude, longitude and altitude above the ellipsoid. Note: In some locations, a WGS-84 altitude of 0 meters above the ellipsoidal surface can differ by as much as 100 meters from actual sea level.

6. VELOCITY EAST/NORTH/UP - Local tangent plane coordinates referenced to the WGS-84 ellipsoid, where velocities are referenced clockwise with respect to true North.

7. CHANNEL STATUS WORD
These words have the following structure:

Channel Status Word

DATA ITEM	DATA BIT	DEFINITION
Weak Signal	0	1 = Weak
High $\Delta\theta$	1	1 = High
Parity Error(s)	2	1 = Errors
Pre-Position Data (not used)	3	1 = Data propositioned
Propagated Track	4	1 = Propagated
Bit Sync Flag	5	1 = Data bit sync not achieved
Frame Sync Flag	6	1 = Frame sync not achieved
Z Count Flag	7	1 = Z Count not recovered

Reserved	8 - 15	N/a

8. CHANNEL 1, 2, ..., 12 MEASUREMENT STATE INFO These words are structured as follows:

Channel Measurement State Word

DATA ITEM	DATA BIT	DEFINITION
Channel Used	0	1 = Used
Ephemeris Available	1	1 = Available
Measurement Validity	2	1 = Valid
Reserved	3	
SVID	4-9	Satellite PRN, Range 0 to 32
C/No	10-15	Integer value of signal-to-noise ratio, range = 0 to 60 dBHz

9. CHANNEL 1, 2, ..., 12 PSEUDORANGE - The apparent range from the receiver antenna to a GPS satellite, calculated from the signal transmission time, the time of signal reception, and the speed of light.

10. CHANNEL 1,2, ..., 12 DELTARANGE – The time rate of change of pseudorange.

11. ECEF POSITION X/Y/Z - WGS-84 ECEF coordinates. ECEF coordinates are rectangular, Cartesian and are fixed to the earth, hence a rotating coordinate system.

NMEA Protocol - XDR Heading Reference

The NMEA protocol is an industry standard messaging scheme designed to allow simple terminal observation of the input/output data for basic avionics system. The serial protocol is ASCII, which enables any terminal emulation software to visibly display the ASCII data. Each message is made up of several components, which are discussed below. The main advantage of this interface, is that if the magnetometer device the user is using supports this NMEA "XDR" message output, then the user can either simply transfer the data bits directly down to the SDN500 without any further manipulation, or the magnetometer may be directly wired to the SDN500's receive RS-232 channel (Please see Chapter 5- Hardware Integration). It should be noted that the SDN500 would have to be configured to initialize in an automatic manner if this approach is desired, since the magnetometer would directly be sending data down to the SDN500, and the user host computer would no longer be able to.

NMEA Message "XDR" then is a host vehicle input message to the SDN500. It provides heading reference information via magnetometer vector data for the SDN500. The heading reference is therefore an extra navigation aid.

NMEA Protocol Checksum Field
This absolute value is calculated by exclusive OR operation on the 8 data bits (ASCII code) (no start or stop bits) of each character in the message, between, but excluding "$" and "*" characters. The hexadecimal value of the most significant and the least significant 4 bits of the result is converted to two ASCII characters (0-9, A-F) for transmission of the data packet. The most significant character is transmitted first. These characters fill the "hh" positions in each message described below.

The format defined below is an industry standard NMEA protocol message format. If the magnetometer device supports data output in the NMEA standard, then the following message will be correctly interpreted by the SDN500.

Format of NMEA XDR Output Message

XDR Transducer Measurements:

$HCXDR,A,x.x,D,PITCH,A,x.x,D,ROLL,G,x.x,,MAGX,G,x.x,,MAGY,G,x.x,,MAGZ,G,x.x,,MAGT*hh<cr><lf>

The “Data” field of an included measurement will be null if its contents cannot be determined due to saturated measurements. Only units of degrees are allowed by NMEA for pitch and roll measurements. Magnetic measurements are transmitted in engineering units (nanoTesla). MAGX aligns with the compass board north-south axis, and MAGZ is perpendicular to the plane of the compass board. MAGT is the total magnetic field strength. It is determined by calculating the square root of the sum of the squares of MAGX, MAGY, and MAGZ.

Example:

$HCXDR,A,-0.8,D,PITCH,A,0.8,D,ROLL,G,122,,MAGX,G,2045,,MAGY,G,-4950,,MAGZ,G,5357.2,,MAGT*11

SDN500 IMU SDLC Data

The SDN500 provides a high rate synchronous output port (see Table 5-1, IO_SDLC) using the SDLC protocol, which is an output only port to support a serial interface between the SDN500 IMU portion and the Host Vehicle (HV). This allows the user to receive output messages containing the SDN500 IMU portion status and sensor data used for flight control and navigation. IMU data can be output as 600, 1200 or 2400 Hz Flight Control Data with 100 Hz Inertial Data. The control of which rate and the ability to store the choice of output rate into non-volatile memory is performed through the SDN500 IMU portion asynchronous RS-232/RS-422 port (see Table 5-1, IO_RS232).

Flight Control Data is comprised of 3 axes of acceleration data and 3 axes of gyro rate of turn data. Inertial Data is comprised of the 3 axes delta velocity data and 3 axes delta angle data. Flight control data is contained in all data messages and is available at 600, 1200 or 2400 Hz. A subset of the messages also includes inertial data. These longer messages occur at 100 Hz. The terms “Flight Control Message” and “Inertial Message” will be used to distinguish between the short and long message types respectively.

SDN500 IMU SDLC Messages

The Flight Control Data Message contains the Flight Control Data values and the other information shown in Table 7-8 below. The message is transmitted at 600, 1200 or 2400 Hz from the SDLC port. The Normal Mode Inertial Data Message contains the Flight Control Data values, the Inertial Navigation Data values and the other information shown in Table 7-9 below. The message is transmitted at 100 Hz from the SDLC port. All values are 2’s complement integer 8, 16, or 32-bit values as defined in the tables. All values are sent LSByte first and LSBit first. The total size of the message, including header and checksum, is 36 bytes for the Flight Control Message and 60 bytes for the Inertial Message.

The SDLC hardware employs bit-stuffing, if necessary, but this is transparent to the user. The sensor data scaling is defined by the terminology “S6.25 rad/s”, where “S” indicates it is a signed value, “6” indicates that 6 bits are used to represent the portion of the value to the left of the decimal and “25” indicates that 25 bits are used to represent the fractional part of the value. In effect this just means the user must divide the received value (interpreted as a 32 bit signed integer) by 2^{25} (33554432) to get the output in the engineering units indicated (rad/s).

Table 7-8 SDN500 SDLC Flight Control Message 600, 1200 or 2400 Hz				
Byte Offset	Meaning	Length	Scaling	Range
0	SDLC Flag	8 Bits		0x7E
1	Address	8 Bits		0x0A
2	Message ID	8 Bits		1
3	Comp X Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
7	Comp Y Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
11	Comp Z Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
15	Comp X Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
19	Comp Y Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
23	Comp Z Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
27	BIT Status Word	16 Bits		Table 7-10
29	Revolving Parameter Index	16 Bits		Table 7-11
31	Revolving Parameter	16 Bits		Table 7-11
33	CRC	16 Bits		
35	SDLC Flag	8 Bits		0x7E

Table 7-9 SDN500 SDLC Inertial Navigation Message 100 Hz				
Byte Offset	Meaning	Length	Scaling	Range
0	SDLC Flag	8 Bits		0x7E
1	Address	8 Bits		0x0A
2	Message ID	8 Bits		2
3	Comp X Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
7	Comp Y Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
11	Comp Z Rate	32 Bits	S6.25 rad/s	+/- 1000 °/sec
15	Comp X Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
19	Comp Y Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
23	Comp Z Accelerometer	32 Bits	S10.21 meters/sec^2	+/- 50 G
27	BIT Status Word	16 Bits		Table 7-10
29	Delta Theta X	32 Bits	S2.29 rad	
33	Delta Theta Y	32 Bits	S2.29 rad	
37	Delta Theta Z	32 Bits	S2.29 rad	
41	Delta Velocity X	32 Bits	S6.25 meters/sec	
45	Delta Velocity Y	32 Bits	S6.25 meters/sec	
49	Delta Velocity Z	32 Bits	S6.25 meters/sec	
53	Revolving Parameter Index	16 Bits		Table 7-11
55	Revolving Parameter	16 Bits		Table 7-11
57	CRC	16 Bits		
59	SDLC Flag	8 Bits		0x7E

SDLC Flag

This value, present at the beginning and end of the messages, is the same for all SDLC messages. (This is typically stripped off by receiving SDLC hardware devices; however it is still part of the SDLC format.)

Address

The Address field is 0x0A for all message types. (This is typically stripped off by receiving SDLC hardware devices; however it is still part of the SDLC format.)

Message ID

The Message ID field is 1 (Flight Control Message) or 2 (Inertial Message).

BIT Status Word

The BIT (Built-In Test) status word is a 16-bit field that is part of every output message. It is decoded in Table 7-10 below. The SDI500 has extensive BIT reporting capacity. The BIT processing is separated into three functions:

- Power-Up BIT
- Continuous BIT
- Initiated BIT

The *Power-Up BIT* function is performed after each power-up. The *Initiated BIT* occurs at the request of the user via input message control (see Message 3504 - SDN500 Parameter Control). The *Continuous BIT* function provides continuous monitoring of a subset of the BIT measurements for constant updates to the navigation message and flight control message in normal mode. Table 7-10 also details in which function each bit is calculated or monitored.

Hard BIT signifies a serious BIT error and is sticky (i.e. once set, it remains set until a system reset occurs). It may be set by a either a one-time serious failure or a persistent failure of some other condition.

Soft BIT is simply an OR of the present condition of bits 6 through 14.

Flight Control Data Invalid indicates that initialization is not complete after a reset or mode change for the Flight Control Data portion of the output message, or that the data is not valid, but does not necessarily denote a fault condition. Inertial Data Invalid indicates that initialization is not complete after a reset or mode change for the Inertial Data portion of the output message, or that the data is not valid, but does not necessarily denote a fault condition.

Table 7-10 SDN500 SDLC Status Word		
BIT	Meaning	Function
0	Hard BIT	Continuous BIT
1	Soft BIT	Continuous BIT
2	Flight Control Data Invalid	Continuous BIT
3	Output Message Rate	Power-Up BIT
4	Output Message Rate	Power-Up BIT
5	Output Message Rate	Power-Up BIT
6	IOP fault	Power-Up BIT, Initiated BIT
7	IOP P/S Out Of Range	Continuous BIT
8	Gyro Sensor Failure	Continuous BIT
9	Accelerometer Sensor Failure	Continuous BIT
10	Temperature over range	Continuous BIT
11	FPGA Filter failure	Continuous BIT
12	DSP Memory Failure	Power-Up BIT, Initiated BIT
13	Demodulation Coefficient Fault	Power-Up BIT, Initiated BIT
14	IOP Watchdog Timeout	Continuous BIT
15	Inertial Data Invalid	Continuous BIT

Output Message Rate (bits 3, 4 and 5) is encoded as:

2	600 Hz / 100 Hz
3	1200 Hz / 100 Hz
5	2400 Hz / 100 Hz

Revolving Parameter

The Revolving Parameter Index marks which parameter from Table 7-11 is being output in the Revolving Parameter position in the message. It will reset every 16 counts.

Table 7-11 Revolving Parameter Index	
Index	Revolving Parameter
0	DSP 3.3V
1	DSP 2.5V
2	DSP 1.2V
3	IOP 3.3V
4	IOP +6.0V
5	IOP -6.0V
6	*Not Used*
7	Message Rate Stored in Flash (see Table 7-10)
8	0 = SDLC Internal Clock, 1 = SDLC External Clock
9	0 = Using Checksums, 1 = Using CRCs
10	0 = RS422 mode, 1 = RS232 mode
11	*Not Used*
12	*Not Used*
13	*Not Used*
14	*Not Used*
15	CPU Load Percentage – as a percentage from 0 to 100

CRC

The 16-bitCRC is generated automatically by the SDLC signal processor. (This is typically stripped off by receiving SDLC hardware devices; however it is still part of the SDLC format.)

SDI500 Input Command Messages

Input commands are received only over the SDN500 IO_RS232 port which is an asynchronous IO_RS-232/RS-422 port. This port is configured to use 8-bit data, no parity, 1 stop bit, and 57.6 KBaud data rate. There must be at least 10 ms between successive commands.

Seven input commands are available for the user. Three commands allow selection of the three message rates defined above. Two commands select either internal or external SDLC clock usage. There is a command that allows the storing of message rate and SDLC clock configuration information to the Flash EEPROM, and there is a command to erase the Flash EEPROM returning the system to the default factory configuration.

The format of all user commands consists of a 16-bit Command ID, a 32-bit argument, and a 16-bit checksum. The least significant byte of each word is sent first. The Transform command definition is presented below in Table 7-12.

Table 7-12 SDI500 Command Input Format			
Byte Offset	Meaning	Length	Value
0	Command ID	16 Bits	See Below
2	Argument	32 Bits	See Below
4	Checksum	16 Bits	Not 2's Comp!

Command ID

CMD_MESSAGE_RATE	0x225a
CMD_SDLC_CLOCK	0x335a
CMD_FLASH	0x555a

Arguments

ARG_MSGRATE_600_100	0x33333333
ARG_MSGRATE_1200_100	0x44444444
ARG_MSGRATE_2400_100	0x66666666
ARG_INT_SDLC_CLK	0x11111111
ARG_EXT_SDLC_CLK	0x22222222
ARG_SAVE_TO_FLASH	0x11111111
ARG_ERASE_FLASH	0x22222222

Checksum

The checksum is the sum of the Command ID and the argument, treated as 3 unsigned 16-bit words. Do not take the two's complement of the sum.

Chapter 8- End Product Applications

Overview

SDN500 can be used for a variety of applications. Use of the various system features and interfaces varies widely from customer to customer. The information presented here is designed to guide the first-time user on what might be required for his/her specific application.

Regardless of the application, *power* must be supplied to the SDN500 unit. A *GPS antenna* is a necessity if integrated INS/GPS performance is desired.

The system will operate in *INS only* navigation if a GPS antenna is not present. However, it will <u>not</u> meet specified SDN500 performance, and the system navigation solution will drift over time.

All users will need to communicate with the system's asynchronous RS-232 *serial interface*. This interface provides navigation solution data to the user, and accepts initialization and control data from the user.

Use of other SDN500 interfaces and features beyond those just mentioned requires consideration of specific application needs. The sections that follow provide examples of specific application needs and how they should be addressed by the system integrator.

Specific Application Examples

If an application has a limited capability to supply SDN500 with initialization data, providing *battery power* to the unit may solve this potential problem. Providing external battery input to the SDN500 will allow it to store the last known position and time data.

Presence of this data will improve GPS TTFF. In applications using dynamic alignment, this may reduce the time required to complete alignment and transition to integrated INS/GPS navigation.

If an application needs to time-synchronize SDN500 data with other external systems, use of the *Timemark* (RS-232) output is required. This discrete output will provide a pulse that corresponds to valid GPS time in output block 3.

If the application control loops can accept 100-Hz data (inertial data), the user may be able to utilize block 3502 on the system serial port. Considerations when using 3502 data at 100 Hz include:

* The system serial port bandwidth, (a function of the baud rate).
* The number of output data blocks connected and/or requested.

Product Application Examples

The SDN500 can be implemented in many end-product solutions. Some examples of SDN500 use and applications are described below.

Use: Navigation System

* *Applications*: Manned or remote controlled dynamic platforms.
* *Examples*: Airplanes, Helicopters, remote controlled Unmanned Aerial Vehicles (UAVs), Mobile Land Vehicles, and Mobile Marine Vehicles.

Use: Guidance, Navigation, and Control

* *Applications*: Unmanned Vehicles.
* *Examples*: Autonomous UAVs, Missiles, Targets, Drones, Guided Munitions.

Use: Pointing

* *Applications*: Camera and other pointing applications.
* *Examples*: Aerial Photomapping, Radar Pointing/Steering, Land/Sea Launched Weapon Platforms.

Since SDN500 can be integrated into a wide range of end-product solutions, each unique system requires different inputs and outputs to satisfy the application. The system integrator should help the development team determine how to use SDN500 features and software data sets within the specific product or application.

Appendix A- Frequently Asked Questions

I apply power to the unit and the unit doesn’t run. What can I do?

Inspect the power supply and cabling to the unit. Verify the proper voltage level at the power supply and at the unit connector pins.

* The DC power supply that you are using may not have an adequate current capacity for the unit. Although the unit draws +250mA steady state current at 15 volts, turn-on inrush current can be as high as 3 amps at 15 volts power during the first half second. It’s a good idea to use a power supply rated to at least 4 amps.

I can’t communicate with the unit via the RS-232 port. Why?

Generally, if you are having troubles communicating with the unit and are sure that your RS-232 communications parameters are set correctly; try viewing the data using an RS-232 monitor program. This will verify the communications parameters, as well as the message data content, handshaking, and timing. Remember that the data on the RS-232 port is binary, not ASCII coded numbers. See Chapter 7- Software Integration for data formats. Also, verify the following:

* Check that the serial data connections are complete in the cable that you are using. (Can you see data on an oscilloscope or via an RS-232 monitor program right at the data pins on the unit connector?)
* Verify that a null modem cable configuration is being used (i.e., is your system’s Transmit data line going to the unit’s receive data line and your system’s

Receive data line going to the unit's transmit data line).

* Check that the proper baud rate, data bits, stop bits, and parity are being used. You should be using the proper baud rate, eight data bits, one stop bit, and odd parity.
* Verify that you have set up your UART correctly. On a PC, the UART's OUT 2 signal must be asserted for the UART to function properly.
* If your program is interrupt-driven, verify that the interrupt handling routine functions correctly using a dumb terminal or simulated message input.

Why am I getting unintelligible data over the RS-232 port?

The RS-232 data is sending byte information in reverse order from the unit. (At your PC, observe the message traffic, or at your printer, if you are using one, get a sample printout.) If you're using a PC to receive data, you must be sure to place the data in memory in the correct order for your program to interpret the data.

* Verify that poor cable connections are not causing RS-232 signal degradation. If the received data bytes have parity, break, or framing errors, then you are either using the wrong communications parameters, or there is a problem with the cabling.

My program can't detect the start of a new message block, but there appears to be data being sent by the unit. Why?

The message start identification word "81FF" is sent LSB first, so a program should check that an "FF" is received, then that an "81" is received to indicate the start of an incoming message.

I can receive data from the unit, but I can't send data to the unit. What should I do?

* Verify that the unit transmit cable connection is complete to your processor.

* Verify that the message format for the data that you are sending the unit is proper. (Are the checksums for the header and data portions of the message correct?) If the handshake protocol indicates that your message has been rejected, chances are that your message format is in error.

Messages are output with non-sequential timestamps, or seem to be output sporadically or stop being output altogether. What can I do?

Check to see if the messages that are 'CONNECTED' fit the bandwidth RS-232 bus at the baud rate you are using. The unit will behave unpredictably if the data bandwidth is exceeded.

The unit stays in Initialization mode when I turn it on. Why?

When the unit is turned on, it will remain in Initialization mode until it has received a valid initialization data message. If you have sent an initialization message and the unit remains in Initialization mode, the message you are sending the unit may have a data or format error.

The unit exhibits poor performance upon sequencing to INS/GPS Navigation mode. Why?

* The unit may not have been stationary during the Ground Alignment mode. The Ground Alignment mechanization assumes that the unit is stationary, and will behave unpredictably if this is not the case.
* You may be experiencing problems with GPS operation. See the next question regarding GPS operation.

The unit will not sequence into INS/GPS Navigation mode. What should I do?

* Check that the GPS satellite signal strengths (C/No) appear normal in the GPS data message. If all signal strengths indicate 0 or are low (< 30 dBHz), then the antenna may not be connected to the unit or the antenna connector, cable, or antenna itself may be broken. If an active antenna, it may not be the proper power it needs from the SDN500. Please verify that the 3.3 Vdc at 50 mA power supplied by the SDN500 is enough. The antenna may also be indoors or otherwise significantly obscured (buildings, trees, people, improper orientation), or the cable run to the antenna may be too long. Typically for the Jupiter Pico receiver, indoor reception will not be available. For full accurate performance, a clear view of the sky is recommended.

* You may have sent erroneous initialization information to the unit. In this case, signal strengths for all channels probably indicate 0. Check that the initialization data you have sent is accurate. The GPS initialization process is very sensitive to errors in time initialization. Be sure that you are using UTC (GMT) and not local time. Position data must be in decimal degrees (not radians), in WGS-84 coordinates (not NAD-27), and should be within 100 km of your actual location. Remember that west longitudes (e.g. USA) and south latitudes must be entered as negative numbers.

* If the unit has not been run for several months, the GPS almanac data stored by the GPS processor may be too old to provide quick GPS satellite acquisition. In this case, power the unit up with the antenna connected and let the unit remain in Initialization mode for about 1 minute after the GPS indicates that it is tracking

satellites. This will allow time for the GPS almanac to be updated.

The unit sequences to INS-Only Navigation mode, but after a little while the position data starts changing erratically. What's wrong?

The unit is not receiving GPS data or there is a problem with the GPS initialization. The unit depends on receiving GPS data for proper operation. The mode sequencing time line provides adequate time for the GPS subsystem to acquire satellites and begin GPS navigation before Ground Alignment mode is complete.

The unit cannot function as an unaided inertial navigation system for long periods of time. The errors inherent in the inertial instruments will eventually grow unbounded without GPS data available to provide corrections.

What is saved by the Save Configuration command?

The Save Configuration command in message 3504 is used to save a number of system parameters to FLASH so that the parameters will be initialized to the saved values at subsequent turn-ons. These parameters are:

* *Position (Latitude, longitude, altitude)*
* *Sensor-to-body coordinate transformation (see notes on message 3511)*
* *Lever-arm body-frame components*
* *Auto align/nav sequence specifiers*
* *Auto GPS init flag*
* *Baud rates (HV Communication)*
* *Message 3501, 3502, and 3512 output rates*
* *Message 3512 output configuration*
* *Message connect/disconnect states*
* *Magnetometer Calibration Hard Iron Vector*
* *Magnetometer Calibration Soft Iron Vector*

All of these parameters are saved at once as a group, so it is not possible to save certain parameters while leaving other parameters at their previously saved or default values. In general, it is useful to save the configuration so that the SDN500 comes up in the desired configuration at turn-on. Care should be taken, however, that the state of the system is known when the Save Configuration command is issued. In particular, the position can become corrupted if the SDN500 is operated for a long period without GPS available, and the IMU parameter estimates can become corrupted if the unit is moved during Fine Alignment mode. The configuration should not be saved in either of these situations. If it is desired to erase a saved configuration, the Save Configuration with the Erase option specified can be used.

Notes: The Save and Erase commands can only be issued when SDN500 is in initialization mode. If the unit is not in initialization, send a mode command of initialization to command the unit to the initialization.

It is recommended to only use the save command for system configuration changes.

What is the difference between the Mode Command and the Auto Align/Nav sequence word in message 3510?

The Mode Command word in Message 3510 is a command to the SDN500 to sequence to the specified mode, if necessary through intervening modes, while the Auto Align/Nav sequence word defines the default sequencing through an alignment mode to a nav mode, but does not trigger this sequencing. The Mode Command tells the SDN500 to sequence to the specified mode and no further, so, if the commanded mode is an alignment mode, the system will go to that mode and stay there, regardless of the alignment mode's exit criteria. A mode command of Automatic (0) tells the SDN500 to go through the mode sequence defined by the Auto Align/Nav sequence word. Generally, for normal upmoding, it is best to send a 3510 message containing a mode command of Automatic and an Auto Align/Nav sequence word specifying the desired sequencing. Only in special situations would commanded upmoding to specific modes be appropriate.

One such situation would be a case where the SDN500 was to remain stationary for a long period of time; in this case, it would make sense to command Fine Alignment mode to allow the unit to stay in Fine Alignment as long as it was stationary, and then command Automatic mode before start of motion to enable transition to a navigation mode.

Mode commands are also used to command mode transitions, either to command Test mode to perform Built In Test, or to return to Initialization mode. It is possible, for instance, after having been in navigation mode, to return to initialization mode, and upmode again through a different sequence.

An alignment/navigation sequencing specified in message 3510 becomes the default for subsequent re-upmodes if power to the unit is not turned off. This sequencing can be saved even across power cycles using the Save Configuration command.

How do I initialize the unit?

Message 3510 offers a number of options for initializing the SDN500. The SDN500 software allows two possible paths for sequencing from startup into navigation:

* *Initialization --> Fine Alignment --> Air Navigation*
* *Initialization --> Air Alignment --> Air Navigation*

In general, the Fine Alignment route is the appropriate option to use if SDN500 can be kept stationary for three minutes or more after startup. The Air Alignment route is the appropriate option to use if SDN500 will be moving from the time it is turned on.

One of the parameters which can be specified in the 3510 message is the Auto GPS Initialization flag. This indicator tells SDN500 whether it should get its position and velocity initialization data from the user or from the GPS receiver when it acquires satellites and begins tracking. In general, the set of data which must be provided by the user to fully initialize SDN500 will depend on whether this flag is set or not.

Position and velocity data may be provided in the 3510 message even if the Auto GPS Initialization flag is set, but they will not be used to initialize SDN500; they instead will be used to initialize the GPS receiver if it is not already tracking satellites.

The behavior of the initialization sequence is somewhat different for the case in which Auto GPS Initialization is specified and the case in which it is not. If Auto GPS Initialization is not specified, the transition to alignment mode will take place immediately upon acceptance of the 3510 message regardless of whether the GPS is tracking satellites.

If Auto GPS Initialization is specified, the SDN500 will continue to report Initialization mode until the GPS receiver acquires and tracks four satellites, at which time the unit will transition to alignment mode.

1. Fine Alignment Initialization - Fine alignment performs an initial estimation of the IMU parameters, primarily gyro bias and the vertical component of accelerometer bias, using the known fact that the IMU is stationary. In order for this estimation to be valid, the SDN500 must have a reasonably good idea of its position and heading, so these quantities must be provided to it before entry to Fine Alignment.

The initial position should be valid to within about 100 miles, and the initial heading should be good to within about 10 degrees. In general, though, the more accurate these values are, the better the IMU calibration will be. Vehicle heading cannot be estimated during Fine Alignment since it is not observable in a stationary situation, so the heading during Fine Alignment will stay at very nearly the initial value provided by the user. Heading can only be estimated via GPS measurements during subsequent motion.

The paragraphs below summarize the data which must be provided for initialization of Fine Alignment both without and with auto-initialization from GPS.

* Without auto-initialization from GPS - In order to initialize Fine Alignment without auto-initialization from GPS, position, time, and heading must be supplied in the 3510 message. Velocity will be ignored even if it is given a non-zero value.

- With auto-initialization from GPS - In order to initialize Fine Alignment with auto-initialization from GPS, only heading must be supplied in the 3510 message. It is helpful to supply position and time also, especially if the GPS receiver has not yet begun tracking satellites. Position will be reinitialized from GPS. Again, velocity will be ignored even if it is given a non-zero value.

2. Air Alignment Initialization- Air alignment performs an initial estimate of heading using GPS measurements, and then exits automatically to a navigation mode. Since, as mentioned before, heading is not observable in a stationary situation, movement, in particular acceleration, of the SDN500 is necessary to get out of Air Alignment mode.

Either linear acceleration in a straight line or a turn from one course to another is required for exit. Air Alignment generally does not estimate IMU parameters nearly as well as does Fine Alignment; it is left up to subsequent motion during Air Navigation mode to do this.

* Without auto-initialization from GPS - In order to initialize Air Alignment without auto-initialization from GPS, position, velocity, time, and heading must be supplied in the 3510 message. In general, this mode of initialization is not recommended since it may give unreliable results depending on the relative timing of the 3510 message and GPS satellite acquisition.

* With auto-initialization from GPS - The parameters which must be supplied in order to initialize Air Alignment with auto-initialization from GPS depend on how fast the SDN500 host vehicle is traveling. If the vehicle speed is less than 5 meters/sec, then at least the heading must be supplied in the 3510 message. If the speed is greater than 5 meters/sec, then no parameters are required for initialization.

- If heading is not specified, it is computed from the course over ground of the vehicle as seen by GPS, and position and velocity are also initialized from GPS values. As before, it is helpful to supply position, velocity, and time in the initialization message if the GPS receiver has not yet begun tracking satellites. Use of auto-initialization from GPS is the recommended method of initialization for Air Alignment mode.

Appendix B- Getting Started

Setup

The following information will guide the system integrator in effectively integrating the SDN500 system with the HV. For commonly asked questions regarding system integration, refer to Appendix A- Frequently Asked Questions. For questions concerning your specific application, refer to Chapter 8- End Product Applications. Otherwise, contact an SDI applications engineer.

Support Equipment Required

Power Supply

SDN500 requires a power input of +10 to +42 volts as measured at the input. The typical steady-state current drawn by SDN500 is +250mA at +/24 Vdc. Turn-on (inrush) current during the first half second can be as high as 3 Amps at 15 volts on the power supply. It's a good idea to use a power supply rated at least 4 amps for the supply.

The battery input voltage to SDN500 should be in the range of +2.5 to +3.5Vdc (3V nominal), as measured at the input, referenced to power return/ground (IO_SIG_COM). Current draw is less than 1 microampere.

The optional battery input to SDN500 accepts a voltage in the range of +2.5 to +3.5Vdc (3V nominal), as measured at the input (referenced IO_SIG_COM), to maintain position, time, and ephemeris data when primary power is removed. The typical steady-state current drawn from the battery is 1 micro-amp. In remote applications where using an unlimited power source is not convenient, a lithium battery is recommended to provide long life and voltage stability. If an unlimited power source is needed or desired, care should be taken to ensure that the supply voltage is free of unwanted noise or transients in excess of the input requirements.

Antenna

SDN500 requires L1 GPS SPS signals (1575.42 MHz), either from a passive or active antenna. The signal level input shall be between -163 to -130 dBW for normal operation. Signal-to-noise (C/No density measured by

SDN500) should range approximately between 35 to 45 dBHz on all channels. Additional information on the type of antenna to use, and whether a preamplifier is needed is given in Chapter 5- Hardware Integration.

Connectors/Cables

The Main Data Interface connector and cable requirements are defined in Chapter 5- Hardware Integration. If used in a hostile electromagnetic environment, care should be given to overbraid the interface cable to obtain the best overall EMI protection.

The straight RF input mating connector is a standard male SMA type of the MIL-C-39012 series. A 50-ohm coaxial cable and antenna is required for the RF input.

Communication Via RS-232 Asynchronous Port

As part of getting started, a Windows compatible computer equipped with a RS-232 COM port supporting up to 115.2kBd can be used as the Host Vehicle system. The host vehicle I/O interface will enable the user to send initialization and control data to SDN500, as well as display or record its navigation information. Refer to Chapter 5- Hardware Integration for information on the data rates and frame format selection of the serial data.

Additional Support for Integration

SDN500 provides a Time Mark pulse at one pulse-per-second (PPS) for synchronization of external equipment. The leading edge of the pulse represents the instant in time when the navigation solution is valid. The navigation solution and status at this instant of time is reported in Timemark output message 3 and 4. See Chapter 7- Software Integration for discussion of time validity at the various solutions.
PC-based integration software, MIGICOM is available with SDN500. This software will aid the user in the configuration, initialization, and communication through the host vehicle port. The software serves only as a guide in helping the user get started using SDN500 and to observe the contents of each data message. However, it is the responsibility of the user to develop software to meet his specific application.

Installation

It is recommended that SDN500 be mounted using three #6 socket cap screws, tightened to a torque at dry of 24 In-Lbs, and lubricated at 18 In-Lbs. The mounting hole pattern is shown in Figure 3-4.

SDN500 can be initialized in any orientation. In order for its attitude outputs (pitch, roll, heading) to be meaningful in the coordinate reference frame of the host vehicle, the sensor-to-host vehicle transformation may need to be reset, using data message 3511**.** See Chapter 7- Software Integration for more details.

Using SDN500

This section is intended as an operational overview of SDN500. Examples are provided using the MIGICOM software, running on a standard PC computer. The following section will provide information necessary to help the user set up their system to make use of the various interfaces and features of SDN500.

SDN500 Operational Overview

Once power is applied, SDN500 will go through power-on initialization, and will sequence up to Initialization mode. This entire process takes approximately 5 seconds to complete.

Also at this time, the GPS receiver subsystem will begin searching for a satellite, based on GPS almanac data stored in the receiver's non-volatile memory, together with time and position data from the optional battery backed RAM. The GPS receiver will sequence up into navigation mode once it can track enough satellites. This can take up to 15 minutes, depending on the condition of the receiver's stored data and RF signal quality. SDN500 will remain in initialization mode until it receives an initialization (message 3510) from the host vehicle.

As a minimum, SDN500 requires time, position, and heading information for initialization. The GPS receiver acquisition time is directly related to the accuracy of data that is provided to SDN500, which uses the data to initialize the GPS receiver. Proper, repeatable operation of the SDN500 depends on reasonable input data.

SDN500 is most sensitive to time initialization data (which should be accurate to within 10 minutes), followed by heading initialization data (which should be accurate to within 10 degrees). SDN500 is less sensitive to position data, which should be accurate to within 100 kilometers of actual location. Once initialized, the SDN500 will sequence to one of two possible alignment modes: *Fine Alignment* and *Air Alignment*.

Specification of the alignment mode is done via input message 3510 as described above.
The purpose of each alignment mode is to use a known velocity reference to perform initial estimation of vehicle attitude and of IMU error parameters (biases and scale factor errors of the gyros and accelerometers).

Fine Alignment - The default alignment mode if no mode-up sequence is specified, assumes SDN500 is stationary for the purpose of estimating IMU parameters. It is thus important that the unit be kept stationary during this mode, which has a duration of two minutes. Movement during this time will result in mis-estimation of IMU parameters and erratic subsequent behavior.

Air Alignment - This mode uses GPS measurements as the velocity reference for its estimation process, and it performs estimation of the GPS antenna lever arm (i.e. the distance between the GPS antenna and SDN500) as well as of the other parameters.

It is advantageous to move SDN500 during this mode. In fact, the exit criteria from Air Alignment mode is determined by whether or not the heading and the lever arms have been estimated to a particular level of precision. Note that the lever arms are only estimated during Air Alignment mode and do not continued to be estimated during normal Air Navigation mode operation. This generally makes it necessary to move through a trajectory with several changes of direction before this mode can be exited.

After completing the alignment mode, sequencing continues to the navigation mode: *Air Navigation*. Choice of sequencing is made via input message 3510. *Air Navigation* mode continues to estimate attitude and IMU parameters that were begun during alignment mode, and also estimates position and velocity errors using GPS data as a reference.

If available, measurements can be processed from a heading reference, such as a compass, or from earth magnetic field vector information from a digital magnetometer. In *Air Navigation* mode, if the GPS receiver is navigating (GPS Measurements Available bit = 1 in message 3500), the navigation solution will represent a combined INS/GPS navigation solution. Once the *INS/GPS* mode is reached, the SDN500 can be moved, tested or flown. If GPS measurements are not available, the navigation solution represents an "INS-only" navigation solution.

The use of INS data allows SDN500 to navigate through temporary GPS outages due to the effects of antenna obscuration, jamming, or loss of GPS. The SDN500 is not intended to be operated as an INS-only system over extended periods of time (several minutes). As with any unaided inertial system, if SDN500 is left in an INS-only state indefinitely, navigation errors will grow unbounded. The actual performance of SDN500 during INS-only operation depends on the state of the internal navigation filter when the INS-only state is entered.

Assuming that SDN500 is operating properly and in a static position, the user should observe the measurement variances (message 3500) and the system velocities (message 3501) decrease during alignment. During this time, the GPS receiver should also acquire satellites and begin navigating. This can be verified by observing the signal strengths and tracking state information provided in the GPS data block (message 3).

Signal strengths (C/No density ratio) should range from the mid 30's to mid 40's dBHz on all channels. If the antenna signals are satisfactory and the initialization data provided was accurate, the GPS receiver will reach navigation mode within 30 seconds.

C/No values that are less than 30 dBHz indicate a problem with signal strength or noise, and will prevent the GPS receiver from acquiring satellites. Types of problems that could cause this result are the wrong type of antenna, excessive cable length, obscuration of antenna, or poor cable connection. If the signal strength measurements are too high (C/No > 46 dBHz), then the signal should be attenuated. Excessive signal strengths can confuse the GPS receiver and will result in very erratic operation.

Once SDN500 is navigating, the system heading will be observed to drift when the unit remains stationary for a period of time, or if the vehicle is constant non changing velocity (such as straight and level flight). This happens when the navigation filter cannot accurately estimate heading without changes in motion. The inherent accuracy of the inertial instruments do not allow for unaided heading determination.

Before You Begin

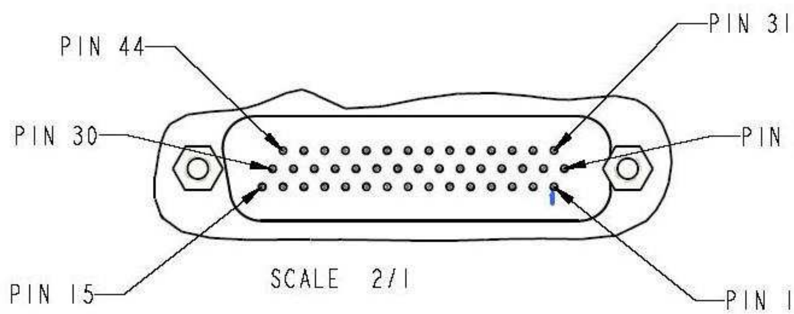
Warning

Improper wiring of the user cable connecting to SDN500 can cause irreversible damage that is not covered under product warranty.

Common mistakes include incorrectly identifying pin assignments (e.g., mirror image wiring assignments), resulting in power being applied to the wrong pins.

Before applying power, verify that it is being supplied to the correct pins; see the table and figure below (outside view of SDN500 Main Data Interface connector).

Signal	Pin
+10 to +42 Vdc	31 and 44
+4 to +12 Vdc “keep alive” power (optional)	12
Power Return (Ground)	1 and 30
Case Ground (Unfiltered pin connected to case)	16 and 15



The cable’s RF noise environment and shielding requirements should be taken into consideration prior to fabrication.

Verify that the cable configuration of RS-232 port is correct. Your system’s transmit data line should go to the SDN500 receive line and your system’s receive line should go to the SDN500 transmit line (null modem connection).

For reference, Table B-1 provides the standard pin assignments for the relevant RS-232 signals typically found on a PC with an RS-232 serial port. SDN500 requires only use of the **Transmit** and **Receive** data signals (**TD**, **RD**) and **Signal Ground**.

Table B-1. RS-232 Pin Assignments			
Description	**Computer Pin # (25-Pin)**	**Computer Pin # (9-Pin)**	**Abbreviation**
Transmit Data	2	3	TD
Receive Data	3	2	RD
Signal Ground	7	5	SG
Protective Ground	1	-	FG

Verify that the cable configuration of +10 to +42 Vdc main power and +2.5 to +3.5Vdc battery input (optional) are correct.

Insert the available MIGICOM CD in the CD drive, and install MIGICOM on your computer. The MIGICOM software will provide the ability to interface between SDN500 and a Windows-based PC simulating the user's host vehicle communication device. Refer to the MIGICOM User's Guide for the details of the installation.

Create a short cut on screen for easy access. Double click on the MIGICOM shortcut, the MIGICOM command and control window should appear on the screen.

Configuring Host Vehicle Communication Port

The default I/O configuration of SDN500 as delivered has input and output baud rates set to 115200 bits per second with an odd parity, 8 data bits, one start bit, and one stop bit. These parameters may be changed via message 3504 described in Chapter 7- Software Integration. Verify that your PC's COM port capability is compatible with the SDN500 I/O baud rate settings.

Using MIGICOM, set the baud rate to the SDN500 baud rate. On setup pull down menu, select communication parameters. When the communication parameters dialog box appears (as shown below), choose the COM port your computer uses, and set the baud rate as, 115200, odd parity, 1 stop bit, and then click OK. MIGICOM is now ready to communicate with SDN500.

Powering Up the System

1. Before connecting the cabling and test equipment to SDN500, apply power to the test setup and verify that the correct voltages are seen at the 44-pin Main Data Interface connector (+10 to +42 Vdc on pin 31 and 44, +2.5 to +3.5Vdc optional "keep-alive battery power" on pin 12, all referenced to Power Return on pins1 and 30).
2. If the above is not the case, troubleshoot the cable and test equipment to resolve the problem before continuing.
3. With power off, connect the 44-pin I/O connector to SDN500 and all required cabling to the test equipment. Apply power to the SDN500.
4. Verify that the correct amount of current is being drawn according to the specifications given by the power supply requirements.

Note: An excessive or inadequate power reading may be due to miswiring; the unit should be shut off immediately to avoid permanent damage.

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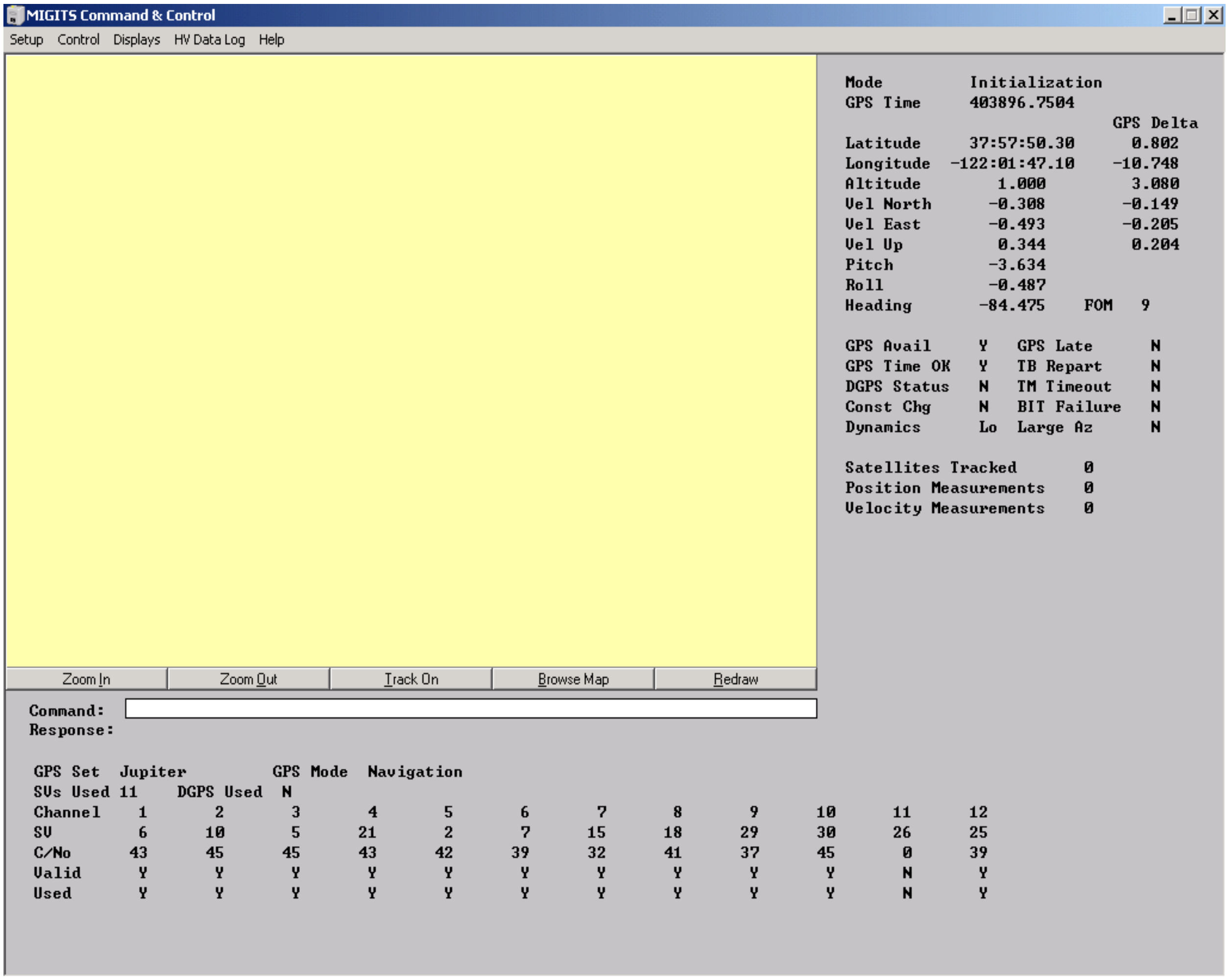
5. Data should appear on the MIGICOM window as shown below. Please verify that the PC Windows is set to a maximum screen resolution of 1024x768. Data from message 3500 and 3501 is displayed at the right side of the window, and data from message

3623 is displayed at the bottom of the window. Message 3500, 3501 and 3623 should continuously update the display.



6. If no data appears and only parameter labels are shown, then the serial port may need to be reconfigured.

Data Display

By default, SDN500 will display data messages 3500, 3501 and 3623. See Chapter 7- Software Integration for description of the contents of these messages. The following function keys are available and will display each of the above messages:

F1

Message ID 3500 - SDN500 System Status
Displayed are the current mode (initialization, fine align, etc.), GPS and INS availability and the current number of satellites tracked. The current mode will be initialization until the unit is properly initialized as demonstrated later in this section.

F2 Message ID 3501 - SDN500 Navigation Solution
Current position, velocity, and attitude are displayed.

F4 Message ID 3623 - GPS Timemark message
Navigation information is provided, including position, time, the satellites tracked and the carrier-to-noise ratios.

Note: Message 3623 reports the navigation solution of the GPS processor alone, while message 3501 reports the combined INS/GPS solution. Message 3624 will not be displayed by MIGICOM in the display screen.

While viewing any of the data messages, typing map in the command prompt will exit the display.

In addition to the function keys, data messages can be displayed by using the **display** command. To display message 3500, at the command prompt, type the following:

display 3500 <return>

Message ID 3500 will be displayed as seen earlier. The **display** command may be abbreviated as **db.**

To exit the MIGICOM program, close the MIGICOM command and control window.

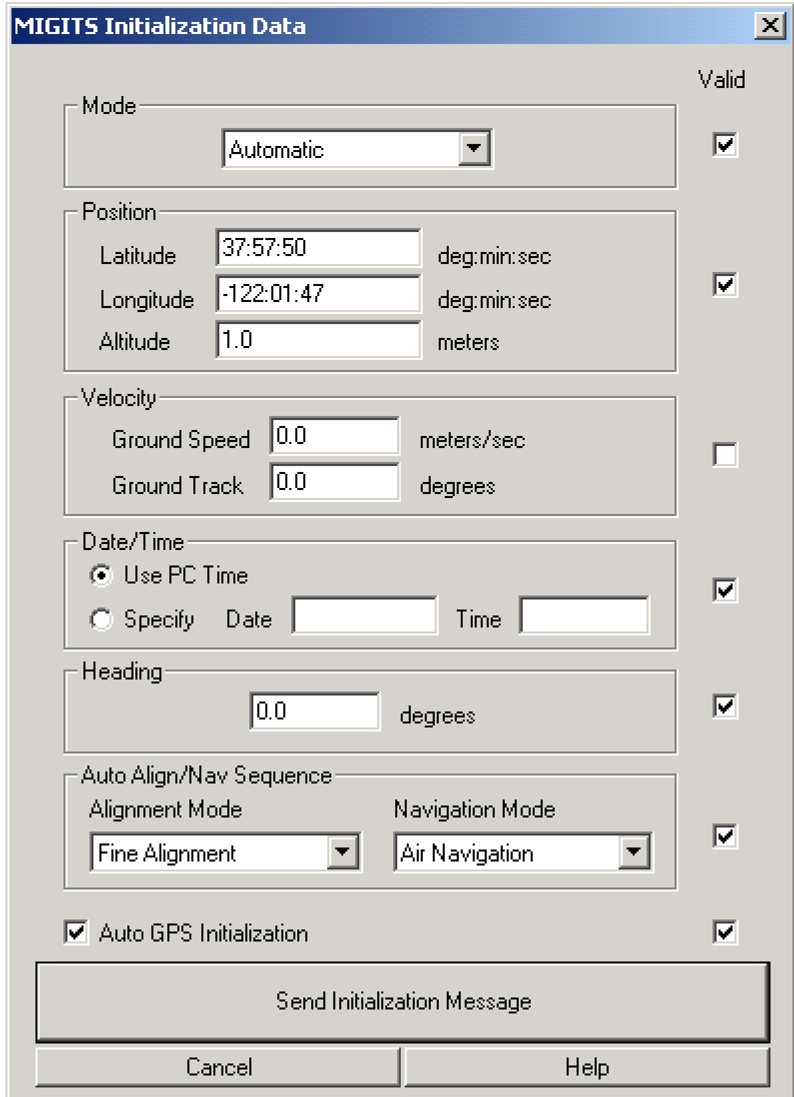
System Initialization

The system initialization is accomplished by transmitting message 3510, SDN500 Control and Initialization. A detailed description of message 3510 can be found in Chapter 7- Software Integration. Using MIGICOM to initialize SDN500 as follows:

1. On the MIGICOM command and control window, click on the control pull down menu, select initialization, a MIGITS initialization data dialog box will appear.

2. On the MIGITS initialization data dialog box, fill in the correct position, time and heading data of the SDN500 and select the mode sequence your application needs, then click on the send initialization tab. The 3510 message is sent to the SDN500.

   A typical 3510 message screen can be found below:



After sending message 3510 to the SDN500, an acknowledgement message will be displayed, e.g. 3510 command accepted. If this is not displayed then the RX connection on the computer serial COM port must be tested for proper operation. The unit will move to Fine Alignment once GPS measurement is available, i.e., when the GPS available field in the message 3500 display turns from N to Y. Refer to Chapter 2 of the MIGICOM User's Guide for more details on the initialization.

A restricted version of the 3510 message, containing just a mode command, may be sent by using control pull down menu with mode command option. The user can select any of the available modes: Initialization, Fine Alignment, Air Alignment, and Air Navigation. This will cause SDN500 to sequence to the commanded mode, if necessary through intervening modes. One use of this command is to send the SDN500 back to initialization mode after it is in an alignment or navigation mode. Another use is to force SDN500 to remain in a particular mode. For instance, if the system is commanded to Fine Alignment mode from Initialization, it will remain in Fine Alignment until commanded out, possibly beyond the default two minutes.

Message Connection and Disconnection

Host vehicle messages may be connected and disconnected by typing the “**connect”** and “**disconnect’** in the command prompt as shown below:

connect 3502 3512 <return>

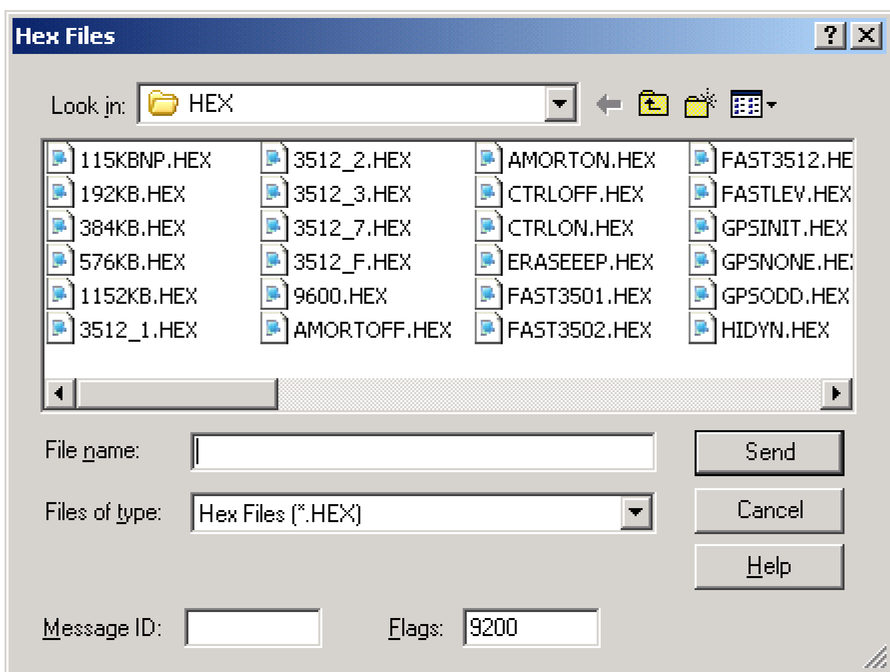
disconnect 3623 <return>

The first command connects messages 3502 and 3512, and the second command disconnects message **3623**.

Connecting an already connected message, or disconnecting an already disconnected message, has no effect. Up to seven message numbers may be specified with either command. The “**connect**” command may be abbreviated as **c**, and the “**disconnect**” command may be abbreviated as **d**. Please refer to Chapter 2 of the MIGICOM User’s Guide for more details.

Sending Other Commands

Other commands to the system, for example, message 3504 and 3511, may be issued using “Control” pull down menu under the option of “Send Hex File.” A Hex Files dialog box as below will appear. Select the Hex file and then click send.



By convention, the files which are used have a filename extension of ".hex". They reside in the directory c:\cm2\hex. The hex files are ASCII files containing the successive words of the data portion of the message as four-nibble hexadecimal numbers. The functions of the various hex files which are distributed with the MIGICOM software are summarized below.

1. Baud Rate – ***(default is 115200 baud).*** The following hex files may be sent to set the SDN500 HV interface to the indicated baud rates:

Hex File	Baud Rate
1152kb.hex	115200 baud
576kb.hex	57600 baud
384kb.hex	38400 baud
192kb.hex	19200 baud
9600.hex	9600 baud

After transmission of any of these commands, the baud rate at which MIGICOM is operating needs to be changed in order to communicate at the new baud rate. This may be done by setting up communication parameters via MIGICOM setup pull down menu.

2. Message Rates –Host vehicle output messages 3501, 3502, and 3512 have selectable output rates which may be set using the following hex files:

Hex File	Action
slow3501.hex	Block 3501 @ 1 Hz
med3501.hex	Block 3501 @ 10 Hz
slow3502.hex	Block 3502 @ 1 Hz
med3502.hex	Block 3502 @ 10 Hz (default)
fast3502.hex	Block 3502 @ 100 Hz
slow3512.hex	Block 3512 @ 1 Hz
med3512.hex*)*	Block 3512 @ 10 Hz (default)
fast3512.hex	Block 3512 @ 100 Hz

Care should be taken, especially when using the 100Hz transmissions that the requested message rates do not exceed the communication channel bandwidth at the current baud rate.

3. Flight Control Message Configuration - The data contained in the flight control message 3512 may be

configured using the following hex files with a message-number of 3504:

Hex File	Message 3512 Data
3512_1.hex	Delta-attitude
3512_2.hex	Delta-velocity
3512_3.hex	Delta-attitude and Delta-velocity
3512_7.hex	Delta-attitude, Delta-velocity, and Attitude
3512_f.hex	Delta-attitude, Delta-velocity, Attitude, and Velocity

The other ten possible configurations of the 3512 message may be selected by appropriate modifications to the hex files.

4. Save Configuration Command –The Save Configuration command is used to save a number of system parameters to FLASH so that the parameters will be initialized to the saved values at subsequent turn-ons. The parameters saved are summarized in Appendix A-Frequently Asked Questions. The current set of parameters may be saved by sending saveeep.hex. The parameters may be erased by sending eraseeep.hex

SDN500 can only accept these commands when the unit is in Initialization mode.

5. Message Passthrough Translation - The state of the program flag which determines whether GPS passthrough messages are translated to SDN500 format may be set by sending passtran.hex to turn passthrough translation on, and sending notran.hex to turn it off.

6. Body Frame Orientation - The sensor-to-body coordinate transformation may be changed by message 3511, to whatever orientation is desired. One transformation is to turn the default transformation "upside down" to accommodate the situation where SDN500 is oriented with the sensor Z axis pointing up (i.e. the plug is facing down). In this orientation, the default coordinate transformation yields a roll value of about 180 degrees. A reorientation of the body axes to yield a roll value of approximately 0 may be accomplished by sending upside.hex.

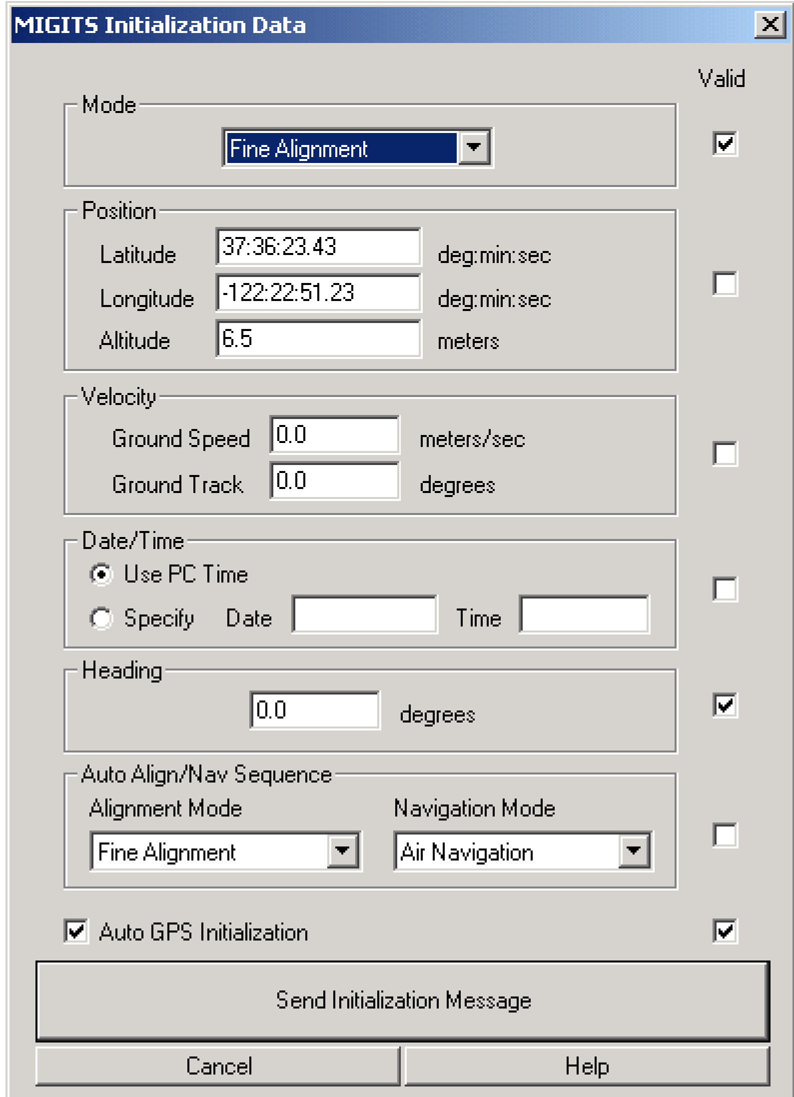
7. Lever Arm Specification - The body-frame components of the lever arm from SDN500 to the GPS antenna may also be set using message 3511. Knowledge of the lever arm is important in accounting for the offset and the motion of the antenna relative to the SDN500. The SDN500

mechanization assumes that the GPS antenna is rigidly attached to SDN500 and rotates with it. If this is not the case (e.g. if a rooftop antenna is being used), it is best to leave the lever arm components at their default value of zero. A sample lever arm specification file [specifying body-frame components of (X,Y,Z) = (100, 49, -84)] is included in the hex directory. It would be invoked by sending levarm.hex.

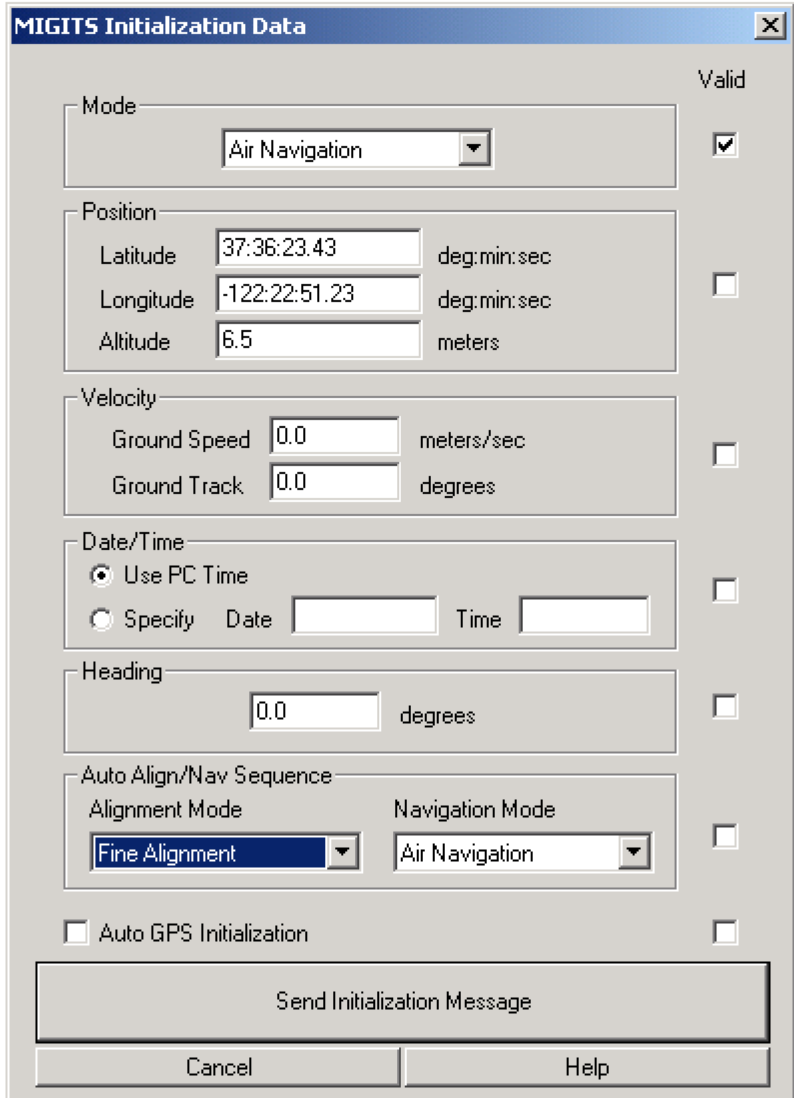
8. INS-Only Operation - The SDN500 can be commanded into an "INS-Only" mode in which GPS measurements are not processed even though they may be available from the GPS receiver. This may be useful in assessing the performance of the SDN500 when the GPS signal is lost. This option is more convenient than the alternative of disconnecting the GPS antenna, since the GPS receiver continues to track satellites. This mode is entered by sending insonly.hex and exited by sending ninsonly.hex.

If your application requires the longer Fine Alignment time, you can do so as follows. First send a 3510 message commanding the SDN500 to the Fine Alignment mode, then send another 3510 message to the SDN500 commanding the unit to Air Navigation mode when you are ready to launch. The following shows the two 3510 messages using MIGICOM.

Send a 3510 message commanding the unit into Fine Alignment as shown: (specify the true heading of the unit - the unit will move into Fine Alignment mode after GPS is locked and will stay in Fine Alignment).



Send a 3510 message when you want to move the unit to Air Navigation mode as shown below. The unit will move to the Air Navigation mode once the 3510 message is received. Keep in mind that the minimum time of the Fine Alignment mode is 2 minutes. If the “Command to Air Navigation” message is sent to the unit within the 2 minutes of the Fine Alignment period, then the unit will move into the Air Navigation mode at the end of 2 minutes of Fine Alignment. If the “Command to Air Navigation” message is sent to the unit after 2 minutes of Fine Alignment, then the unit will move into the Air Navigation mode immediately. The system must then be launched within 5 hours to prevent large drift in heading.


MIGITS Initialization Data
Valid
Mode
Air Navigation
Position
Latitude
37:36:23.43
deg:min:sec
Longitude
-122:22:51.23
deg:min:sec
Altitude
6.5
meters
Velocity
Ground Speed
0.0
meters/sec
Ground Track
0.0
degrees
Date/Time
Use PC Time
Specify
Date
Time
Heading
0.0
degrees
Auto Align/Nav Sequence
Alignment Mode
Navigation Mode
Fine Alignment
Air Navigation
Auto GPS Initialization
Send Initialization Message
Cancel
Help

Appendix C- SDN500 to CMIGITS Pin-out Migration

SDN500 Pin-Out Migration

The following information compares the outputs of a Systron Donner CMIGITS-3 (Part# CMIG-310) to that of the SDN500, in order to make the migration from one product to the other as easy as possible. Users who purchased the SDN500-CB01 product (SDN500 with CMIGITS adaptor kit) will also find it useful as it defines the pass-through connections present in the adapter cable.

Table C-1 contains the pin-out translation from the SDN500 connector pins to the CMIGITS-3 connector pins.

Table C-1 SDN500 to CMIGITS Pin Migration

SDN500 Main 44 Pin Connector Pin Assignment			CMIGITS 37 Pin Connector Pin Assignment		
Pin #	**SDN500 Name**	**SDN500 Description**	**Pin #**	**CMIGITS Name**	**SDN500 Description**
16	CASE_GND	Unfiltered pin is connected to case	19	GND_CHASSIS	Unfiltered pin is connected to case
1	VINRTN	Input power return voltage	17	PWR GND	Input power return voltage
31	VIN	Positive Power supply voltage. Nom 28V. Range 10V to 42V.	6	+28V	Positive Power supply voltage. Nom 28V. Range 12V to 42V.
17	IO_R232/RS422TX-	**RS232** Async Xmt Data (or RS422- when pins 5 and 35 tied)			
2	IO_RS422TX+	**RS422+** Async Xmt Data when pins 5 and 35 tied			
32	IO_RS232/422RX+	**RS232** Async Rcv Data (or RS422+ when pins 5 and 35 tied)			
18	IO_RS422RX-	**RS422-** Async Rcv Data when pins 5 and 35 tied			
3	IO_BTLD	Boot Load Control (when low) for IO processor			
33	IO_RESET	IO Reset Control (when low) for IO processor			
19	IO_SDLC_TX_DTA+	**RS422+** SDLC Transmit Data output	13	SERDATP	**RS422+** SDLC Transmit Data output
4	IO_SDLC_TX_DTA-	**RS422-** SDLC Transmit Data output	12	SERDATN	**RS422-** SDLC Transmit Data output
34	IO_SDLC_TX_CLK+	**RS422+** SDLC Transmit Data Clock (Input or output)	25	DATSFTCKP	**RS422+** SDLC Transmit Data Clock (Input or output)
20	IO_SDLC_TX_CLK-	**RS422-** SDLC Transmit Data Clock (Input or output)	24	DATSFTCKN	**RS422-** SDLC Transmit Data Clock (Input or output)
24	NC				
9	NC				
21	IO_FRAME_SYNC+	**RS422+** SDLC Frame Sync (Not currently implemented)			

6	IO_FRAME_SYNC-	**RS422**- SDLC Frame Sync (Not currently implemented)			
36	IO_BIT_HARD	Open Drain output. Latches (low) when Hard BIT asserted			
22	IO_BIT_SOFT	Open Drain output. Sets (low) during Soft BIT condition			
7	IO_USB_DTA+	Universal Serial Bus Data output. (Not currently implemented)			
37	IO_USB_DTA-	Universal Serial Bus Data output. (Not currently implemented)			
23	IO_HRD_RST_L	System reset. (Cycles internal power)			
8	IO_SIG_COM	Circuit or Signal common (or GND)			
38	IO_SIG_COM		30	GND_DIG	Circuit or Signal common (or Gnd)
5	**IONAV_RS422SEL_L**	**Select RS422 Mode when tied to pin 35**			
35	**IO_SIG_COM**	**Circuit or Signal common (GND)**			
39	IONAV_RS232/422TX-	**RS232** Navigation TX Data (RS422- when Pin 5 and 35 tied)	32	RS232OUT	**RS232** Navigation TX Data
25	IONAV_RS422TX+	**RS422+** Navigation TX Data when Pin5 and 35 are tied			
10	IONAV_RS232/422RX+	**RS232** Navigation RX Data (RS422+ when Pin 5 and 35 tied)	28	RS232IN	**RS232** Navigation RX Data
40	IONAV_RS422RX-	**RS422-** Navigation RX Data when Pin5 and 35 are tied			
26	IONAV_BTLD_L	Boot Load Control for Navigation Processor (when < 0.5V)	35	BLMODE	Boot Load Control for Nav Processor (when < 0.5V)
11	NAV_RESET_L	Navigation processor and GPS Rcvr Reset (Cycles Nav Pwr)			
41	F_1PPS_RS232/422TX-	**RS232** 1PPS pulse from GPS Rcvr (RS422- when pins 5, 35 tied	34	TIMEMARK	**RS232** 1PPS pulse from GPS Rcvr
27	F_1PPS_RS2422TX+	**RS422+** 1PPS pulse from GPS Rcvr (RS422- when pins 5, 35 tied			
12	F_NAVGPS_BATT_BU	Battery backup to GPS Rcvr. 5V nominal. Min 4V max 12V	31	BATTERY	Battery backup to GPS Rcvr. 5V nominal. Min 4V max 12V
42	NC				
28	IONAV_BIT_CMD	Built in Test Command to Nav Processor. (>02.5V)	14	BIT_REQ	Built in Test Command to Nav Processor. (>02.5V)
13	NC				
43	NC				
29	NC				
14	NC				
44	VIN	Positive Power supply voltage. Nom 28V. Range 10V to 42V.	27	+28V	Positive Power supply voltage. Nom 28V. Range 10V to 42V.
30	VINRTN	Input power return voltage	18	PWR GND	Input power return voltage
15	CASE_GND	Unfiltered pin is connected to case			

Glossary of Terms

Abbreviations and Acronyms

The following is a list of abbreviations and acronyms used in this guide and their definitions.

$\Delta\theta$
: *Attitude change*

Δv
: *Velocity change*

2-D
: *Two Dimensional*

2-Drms
: *Two-Dimensional root mean square*

3-D
: *Three Dimensional*

3-Drms
: *Three-Dimensional root mean square*

AAMP
: *Advanced Architecture Microprocessor*

AMRAAM
: *Advanced Medium Range Air-to-Air Missile*

A/D
: *Analog-to-Digital*

AFSC
: *Air Force System Command*

AP
: *Application Processor*

AS
: *Anti-Spoofing*

ASIC
: *Application Specific Integrated Circuit*

AWGN
: *Additive White Gaussian Noise*

B
: *Boolean*

BIT
: *Built-In-Test*

bps
: *Bits Per Second*

cg
: *Center of Gravity*

C
: *Celsius*

C/A

Coarse/Acquisition

SDN500

C/A-code Miniature Integrated GPS/INS Tactical System (Digital Quartz Inertial Measurement Unit coupled with a 50-channel C/A code GPS receiver)

C/No

Carrier-to-Noise density ratio

COMSEC

Communications Security

cw

Continuous Wave

dBm

Decibels Milliwatt (measure of power relative to one milliwatt)

dBW

Decibel-Watt (measure of power relative to one watt)

DC

Direct Current

deg

Degrees

DETF

Double Ended Tuning Fork

DI

Double precision Integer

DIG

Digital

DoD

Department of Defense

DOP

Dilution of Precision

DQI

Digital Quartz Inertial Measurement Unit Systron Donner Inertial trade name)

DSP

Digital Signal Processor

DTR

Data Terminal Ready

EEPROM

Electrically Erasable Programmable Read Only Memory

EFP

Extended Floating Point

EMC

Electromagnetic Compatibility

EMI

Electromagnetic Interference

EPROM

Erasable Programmable Read Only Memory

EU

Electronics Unit

FFC

Flex Cable

FLASH

Electrically Programmable and Erasable Memory

FP

Floating Point

g

Gravity

GaAs

Gallium Arsenide

GDOP

Geometric Dilution of Precision

GHz.

Gigahertz (10^9)

GMT

Greenwich Mean Time

GN&C

Guidance, Navigation and Control

GND

Ground

GPS

Global Positioning System

GPSRE

GPS Receiver Engine

Grms

G's root mean squared

HDK

Hardware Developer's Kit

HDOP

Horizontal Dilution of Precision

HVIO

Host Vehicle Input/Output

Hz

Hertz

ICD

Interface Control Document

I

Integer

I/O

Input/Output

IF

Intermediate Frequency

IMU

Inertial Measurement Unit

INIT

Initialization (mode)

INS

Inertial Navigation System

IODE

Issue of Data Ephemeris

ISA

Inertial Sensor Assembly

kbaud

Kilobaud (10^3)

kHz

KiloHertz (10^3)

km

Kilometer

kohms

Kilohms

LD/LR

Line Driver/Line Receiver

LPTS

Low Power Time Source

LRU

Lowest Replaceable Unit, Line Replaceable Unit

LSB

Least Significant Bit

mA

Milliamp (10^{-3})

MFI

Multi-Function Interface

MHz

Megahertz

MR

Master Reset

mrad

Milliradian (10^{-3})

MSB

Most Significant Bit

ms

Millisecond (10^{-3})

m/sec

Meters per Second (units of velocity)

m/sec/sec

Meters per Second per Second (units of acceleration)

m/sec/sec/sec

Meters per Second per Second per Second (units of impulse or "jerk")

MSL

Mean Sea Level

MTBF

Mean Time Between Failure

MTTR

Mean Time to Repair

MUX

Multiplex (bus)

mV

Millivolt

mW

Milliwatt

nS

Nanoseconds

NAV

Navigation

NAVSTAR

Navigation Satellite Timing and Ranging

NF

Noise Factor

NMEA

National Marine Electronics Association

NSA

National Security Agency

nsec

Nanosecond (10^{-9})

OEM

Original Equipment Manufacturer

ρ

Pseudo-range

P/N

Part Number

PDOP

Position Dilution of Precision

PSD

Power Spectral Density

P-P

Peak-to-Peak

ppm

Parts Per Million

PPS

Precise Positioning Service; also, Pulse-Per-Second

PPS-SM

Precise Position Service Security Module

PRN

Pseudorandom Number

PSF

Post Select Filter

psia

Pounds Per Square Inch Absolute

PVT

Position, Velocity, and Time

PWB

Printed Wiring Board

QFS

Quartz Flexure Suspension

QRS

Quartz Rate Sensor

RAM

Random Access Memory

RF

Radio Frequency

RFI

Radio Frequency Interference

rms

Root Mean Squared

ROM

Read Only Memory

RSS

Root Sum of Squares

RTCA

Radio Technical Commission for Aeronautics

RTCM

Radio Technical Commission for Maritime Services

rt-hr

Root-Hour

RT

Remote Terminal

RTC

Real-Time Clock

RTN

Return

RTV

Room Temperature Vulcanizing

SA

Selective Availability

SA/AS

Selective Availability, Anti-Spoofing

SDLC

Synchronous Data Link Control

sec

Seconds

SEP

Spherical Error Probable

SNR

Signal-To-Noise ratio (expressed in decibels).

SPS

Standard Positioning Service

SRAM

Static Random Access Memory

SRU

Shop Replaceable Unit

SV

Space Vehicle

TDOP

Time Dilution of Precision

TSP

Twisted Shielded Pair

TTFF

Time to First Fix

TTL

Transistor -Transistor Logic

TWINAX

Two conductor coaxial cable

TwPr

Twisted Pair

UART

Universal Asynchronous Receiver /Transmitter

μsec

Microsecond (10^{-6})

UBER

Undetected Bit Error Rate

UDRE

User Differential Range Error

URA

User Range Accuracy

UTC

Universal Coordinated Time

VCO

Voltage Controlled Oscillator

Vdc

Volts Direct Current

VDOP

Vertical Dilution of Precision

VQA

Vibrating Quartz Accelerometer

VSWR

Voltage Standing Wave Ratio

ZIF

Zero Insertion Force

Terms

The following is a list of selected terms used in this document, together with their associated meaning.

Algorithm

A set of rules for finding a solution to a problem in a finite number of steps.

Almanac

A set of orbital parameters that allows calculation of approximate GPS satellite positions and velocities. The almanac is used by a GPS receiver to determine satellite visibility and as an aid during acquisition of GPS satellite signals. The almanac is a subset of satellite ephemeris data and is updated weekly by GPS Control.

Analog Sinusoidal

A curve having ordinates proportional to the sine (or cosine) of an angle that is a linear function of time, distance, or both.

Application Processor

The processor connected to the Host Vehicle receiver port which controls SDN500 with command messages and uses data from output messages.

Attenuation

The decrease in amplitude of a signal during its transmission from one point to another. It may be expressed as a ratio, or, by extension of the term, in decibels.

Attitude

A ship, aircraft, or other vehicle's state in terms of pitch, roll and heading.

Baud

bits per second (also referred to as baud rate)

Block I Satellite

Satellites designed and built to support GPS development and testing. A total of 10 Block I satellites were successfully launched between February 1978 and October 1989.

Block II Satellite

Satellites designed and built to support GPS Space Segment operation. A total of 28 Block II satellites have been built and launched.

Block IIR Satellite

Satellites being designed to eventually replace Block II satellites. The first Block IIR satellite was launched in 1997.

Coarse/Acquisition Code

A spread spectrum direct sequence code that is used primarily by commercial GPS receivers to determine the range to the transmitting GPS satellite.

Circular Error Probable

The radius of a circle, centered at the user's true location, that contains 50 percent of the individual position measurements made using a particular navigation system.

Clock Error

The uncompensated difference between synchronous GPS system time and time best known within the GPS receiver.

Cold Start

A condition in which the GPS receiver can arrive at a navigation solution without initial position, time, current ephemeris, and almanac data.

Control Segment

The Master Control Station and the globally dispersed Monitor Stations used to manage the GPS satellites, determine their precise orbital parameters, and synchronize their clocks.

Coriolis Force

An apparent force that as a result of the earth's rotation deflects moving objects (such as missiles) to the right in the northern hemisphere and to the left in the southern hemisphere.

Decibel-Isometric-Circular

Measure of power relative to an isometric antenna with circular polarization.

Dielectric

The insulating (non-conducting) medium between the two plates of a capacitor. Typical dielectrics include air, plastic, mica, and ceramic. A vacuum is the only perfect dielectric.

Differential GPS

Doppler Aiding

A signal processing strategy, which uses a measured Doppler shift to help a receiver smoothly track the GPS signal to allow a more precise velocity and position measurement.

Doppler Effect

The observed change of frequency of a wave caused by a time rate of change of the effective distance traveled by the wave between the source and the point of observation.

Doppler Shift

The change observed in the frequency of a wave due to the Doppler effect.

Drift Angle

The angle measured in the horizontal plane between the horizontal velocity projection and the horizontal projection of the vehicle's longitudinal axis. In an example of an aircraft, the drift angle is generated from cross-winds, causing the aircraft to point into the direction of the relative wind, rather than along the ground-referenced velocity direction.

Earth-Centered Earth-Fixed

A Cartesian coordinate system with its origin located at the center of the Earth. The coordinate system used by SDN500 to describe three-dimensional location. For the WGS-84 reference ellipsoid, ECEF coordinates have the Z-axis aligned with the Earth's spin axis, the X-axis through the intersection of the Prime Meridian and the Equator and the Y-axis is rotated 90 degrees East of the X-axis about the Z-axis.

Ephemeris

A set of satellite orbital parameters that is used by a GPS receiver to calculate precise GPS satellite positions and velocities. The ephemeris is used to determine the navigation solution and is updated frequently to maintain the accuracy of GPS receivers.

Federal Radio Navigation Plan

The U.S. Government document which contains the official policy on the commercial use of GPS.

Gauss

A unit of measure of magnetic flux density or magnetic field strength.

Geometric Dilution of Precision

A factor used to describe the effect of the satellite geometry on the position and time accuracy of the SDN500 solution. The lower the value of the GDOP parameter, the less the error in the position solution. Related indicators include PDOP, HDOP, TDOP, and VDOP.

Global Positioning System

A space-based radio positioning system which provides suitably equipped users with accurate position, velocity, and time data. When fully operational, GPS will provide this data free of direct user charge worldwide, continuously, and under all weather conditions. The GPS constellation will consist of 24 orbiting satellites, four equally spaced around each of six different orbital planes.

GPS Time

The number of seconds since Saturday/Sunday Midnight UTC, with time zero being this midnight. Used with GPS Week to determine a specific point in GPS time.

GPS Week

The number of weeks since January 6, 1980, with week zero being the week of January 6, 1980. Used with GPS Time to determine a specific point in GPS time.

Gradient

Change in the value of a quantity (for example, Gravity) with respect to the change in a given variable (for example, Position).

Horizontal Dilution of Precision

A measure of how much the geometry of the satellites affects the position estimate (computed from the satellite range measurements) in the horizontal (East, North) plane.

Interface

The physical terminating points of a data link.

Kalman Filter

Sequential estimation filter which combines measurements of satellite range and range rate to determine the position, velocity, and time at the GPS receiver antenna.

Ll Band

The 1575.42 MHz GPS carrier frequency which contains the C/A code, P-code, and navigation messages used by commercial GPS receivers.

L2 Band

A secondary GPS carrier, containing only P-code, used primarily to calculate signal delays caused by the atmosphere. The L2 frequency is 1227.60 MHz.

Mask Angle

The minimum GPS satellite elevation angle permitted by a particular GPS receiver design.

Measurement Error Variance

The square of the standard deviation of a measurement quantity. The standard deviation is representative of the error typically expected in a measured value of that quantity.

Multipath Errors

GPS positioning errors caused by the interaction of the GPS satellite signal and its reflections.

Obscuration

Term used to describe periods of time when a GPS receiver's line-of-sight to GPS satellites is blocked by natural or man-made objects.

Overdetermined Solution

The solution of a system of equations containing more equations than unknowns. The GPS receiver computes, when possible, an overdetermined solution using the measurements from five GPS satellites, instead of the four necessary for a three-dimensional position solution.

Piezoelectric

A property of crystals which produce a voltage when subject to a mechanical stress, or undergo mechanical stress when subjected to a voltage

Port

Access point for data input or output

Precision Code

A spread spectrum direct sequence code that is used primarily by military GPS receivers to determine the range to the transmitting GPS satellite.

Parallel Receiver

A receiver that monitors four or more satellites simultaneously.

Position Dilution of Precision

A measure of how much the error in the position estimate produced from satellite range measurements is amplified by a poor arrangement of the satellites with respect to the receiver antenna.

Pi (or π)

The mathematical constant having a value of approximately 3.14159.

Precise Positioning Service

The GPS positioning, velocity, and time service which will be available on a continuous, worldwide basis to users authorized by the DoD.

Pseudorandom Number

The identity of the GPS satellites as determined by a GPS receiver. Since all GPS satellites must transmit on the same frequency, they are distinguished by their pseudorandom noise codes.

Q Factor

A measure of sharpness of resonance or frequency selectivity of a mechanical or electrical system.

Radome

Also called a radar dome. The housing that protects a radar antenna from the elements, but does not block radio frequencies.

Real Time

Refers to Greenwich Mean Time.

Selective Availability

The method used by the DoD to control access to the full accuracy achievable with the C/A code.

Satellite Elevation

The angle of the satellite above the horizon.

Sequential Receiver

A GPS receiver in which the number of satellite signals to be tracked exceeds the number of available hardware channels. Sequential receivers periodically reassign hardware channels to particular satellite signals in a predetermined sequence.

Spherical Error Probable

The radius of a sphere, centered at the user's true location, that contains 50 percent of the individual three-dimensional position measurements made using a particular navigation system.

Standard Positioning Service

A positioning service available to all GPS users on a continuous, worldwide basis with no direct charge. SPS uses the C/A code to provide a minimum dynamic and static positioning capability.

Standby SRAM

Portion of the SRAM that is powered by a "keep-alive" power supply when prime power is removed to preserve important data and allow faster entry into the Navigation Mode when prime power is restored. All of the SRAM in the receiver is "keep-alive" SRAM.

Strapdown Inertial Navigation System

A system in which the accelerometers are directly connected to the vehicle's frame (in the example of an aircraft, the airframe). The accelerometers measure the components of vehicle-specific force acceleration in the body (in this example, the airframe) axes.

Time Dilution of Precision

A measure of how much the geometry of the satellites affects the time estimate computed from the satellite range measurements.

Three-Dimensional Coverage (Hours)

The number of hours-per-day with four or more satellites visible. Four visible satellites are required to determine location and altitude.

Three-Dimensional (3-D) Navigation

Navigation mode in which altitude and horizontal position are determined from satellite range measurements.

Time Mark Message

Output message of the receiver that provides the current estimate of position, velocity, and time as well as other data related to the state of the receiver.

Time Mark Pulse

A positive going pulse output by the receiver at the instant to which the next solution output will be referenced. The position, velocity, and time values in the next message were the estimated values at the rising edge of the pulse.

Time-To-First-Fix.

The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix, and the specific receiver design.

Update Rate

The GPS receiver specification which indicates the solution rate provided by the receiver when operating normally.

Universal Coordinated Time

This time system uses the second defined true angular rotation of the Earth measured as if the Earth rotated about its Conventional Terrestrial Pole. However, UTC is adjusted only in increments of one second. The time zone of UTC is that of Greenwich Mean Time (GMT).

Velocity

A vector quantity indicating both direction of motion and magnitude of speed.

Vertical Dilution of Precision

A measure of how much the geometry of the satellites affects the position estimate (computed from the satellite range measurements) in the vertical (perpendicular to the plane of the user) direction.

WGS-84

World Geodetic System (1984). A mathematical ellipsoid designed to fit the shape of the entire Earth. It is often used as a reference on a worldwide basis, while other ellipsoids are used locally to provide a better fit to the Earth in a local region. GPS uses the center of the WGS-84 ellipsoid as the center of the GPS ECEF reference frame.

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