Y207A277 REV D
CAGE CODE 88818

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DATE 4 AUG 03

Interface Control Document

for the

INTEGRATED DVL INS

Workhorse Navigator Doppler Velocity Log (DVL)

and

Seaborne Navigation System (SEANAV)

Inertial Navigation System (INS)

(SEA*DeViL*)

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DRR K0055P **TOTAL PAGES** 77

REVISION RECORD

REV	DESCRIPTION	APPROVAL AND DATE
-		01-08-14
A	Revised to incorporate embedded DGPS receiver and updated software	02-10-17
B	Revised to include initialization of the embedded DGPS receiver	03-01-20
C	Revised to update descriptions of DVL and DVL INS mounting	03-02-03
D	Revised to add RS-232 communication to DVL, update GPS messages	03-08-04

REV	D	D		D
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1. SCOPE

1.1 Purpose

This document defines and provides the means to control the interfaces for the Integrated RD Instruments Workhorse Doppler Velocity Log (DVL) and the Kearfott Guidance & Navigation Corporation Seaborne Navigation (SEANAV) Inertial Navigation System (INS) kit. The DVL RS-422 interface is defined in the RD Instruments Workhorse Navigator Technical Manual. This document defines the mechanical and electrical interface of the Integrated DVL INS. It defines the INS RS-422 operational interface, the RS-422 or RS-232 external GPS interface, and the embedded GPS receiver interface. This ICD reflects tailoring for a hybrid navigation system integrated with the DVL and a GPS receiver.

The DVL INS operates with either an embedded Differential GPS receiver (DGPS), or an external GPS/DGPS receiver [with a NMEA 183 interface], or a DoD Military standard GPS receiver [with a DoD Time Mark Block interface]. The embedded DGPS receiver is a Thales Navigation Ashtech DG16 DGPS board that incorporates signals from Satellite Based Augmentation Systems (SBAS) such as WAAS, EGNOS & MSAS. The DG16 is a 16-channel receiver with 12 GPS L1 code and carrier channels, 2 SBAS channels and 2 300 KHz DGPS Beacon channels. The DG16 is implemented with two RS-232 ports, one providing data to the INS and one duplex port available for control and additional data that is application dependent. Interface to the embedded DGPS receiver's RS-232 ports is described in the Thales Navigation DG16 and DG14 OEM Receiver Reference Manual.

Contained herein is the message protocol and format definition of the:

DVL RS-422 interface intended for operational use (i.e. mission computer and INS interface),

INS RS-422 interface intended for operational use (i.e. mission computer interface), and

RS-232 interface (NMEA 183 or DoD ICD-GPS-150) providing GPS data to the INS.

2. APPLICABLE DOCUMENTS

The following documents of the exact issue shown form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superceding requirement.

2.1 Government Documents

ICD-GPS-150 9 Aug 1991	GPS User Equipment Control Document For Instrumentation Port Data Link Of The DoD Standard GPS UE Radio Receivers

2.2 Non-Government Documents

STANDARDS

RS-422 Apr 1975	Electronic Industries Association (EIA) Standard RS-422, Electrical Characteristics of Balanced Voltage Digital Interface Circuits
RS-232-D Jan 1987	Standard Interface between Data Terminal Equipment and Data Communication Equipment employing Serial Binary Data Interchange
IEC 1010-1 Part 1	International Engineering Consortium Standard General Requirements

NON-KEARFOTT DOCUMENTS

Navigator Technical Manual October 1997	RD Instruments Workhorse Navigator Doppler Velocity Log Acoustic Doppler Current Profilers Technical Manual
NMEA 0183 Version 2.20 January 1, 1997	Standard For Interfacing Marine Electronic Devices
Thales Navigation 630851 Rev. A December 2001	DG16 and DG14 OEM Receiver Reference Manual

2.3 Order of Precedence

In the event of a conflict between the text of this document and the references cited herein (except for related associated detail specifications or specification sheets, the text of this document shall take precedence. Nothing in this specification, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

3. INTERFACE REQUIREMENTS

3.1 Interface Definition

3.1.1 System Overview

The DVL INS provides navigational data (position, velocity and orientation) in geodetic coordinates to the system user. This document provides a description of the DVL INS interfaces. Figure 1 shows a typical DVL INS operational block diagram. Figure 2 shows a typical system configuration.

3.1.1.1 System Functions

The DVL INS is a self-contained inertial system for use in multiple sea navigation applications. The DVL INS provides, depending on the application, all or part of the following:

a. horizontal position in geodetic coordinates of latitude and longitude
b. altitude (depth), referenced to the local datum
c. angular orientation consisting of geodetic azimuth, pitch and roll
d. geographic (N, E, D) or body axis x, y, z (vehicle reference frame) velocities
e. body axis x, y z (vehicle reference frame) linear acceleration
f. vehicular angular rates for three axes (vehicle reference coordinates)

Coordinate and reference frames are defined in paragraph 3.1.2.

Coordinate and reference frames are defined in paragraph 3.1.2.

The DVL INS accepts the following types of aiding to improve inertial survey accuracy:

a. Global Positioning System (GPS) information
b. Zero Velocity Updates (ZUPT's) when vehicle is stopped and when commanded on the mission computer interface.
c. Position Updates.

3.1.1.2 System Application

Illustrated in Figure 2 is a GPS aided inertial system with a Computer on the RS-422 interface. The Computer is used for system control, data entry, and data display. Figure 1 illustrates a Computer or PC connected to the primary interface to perform these functions.

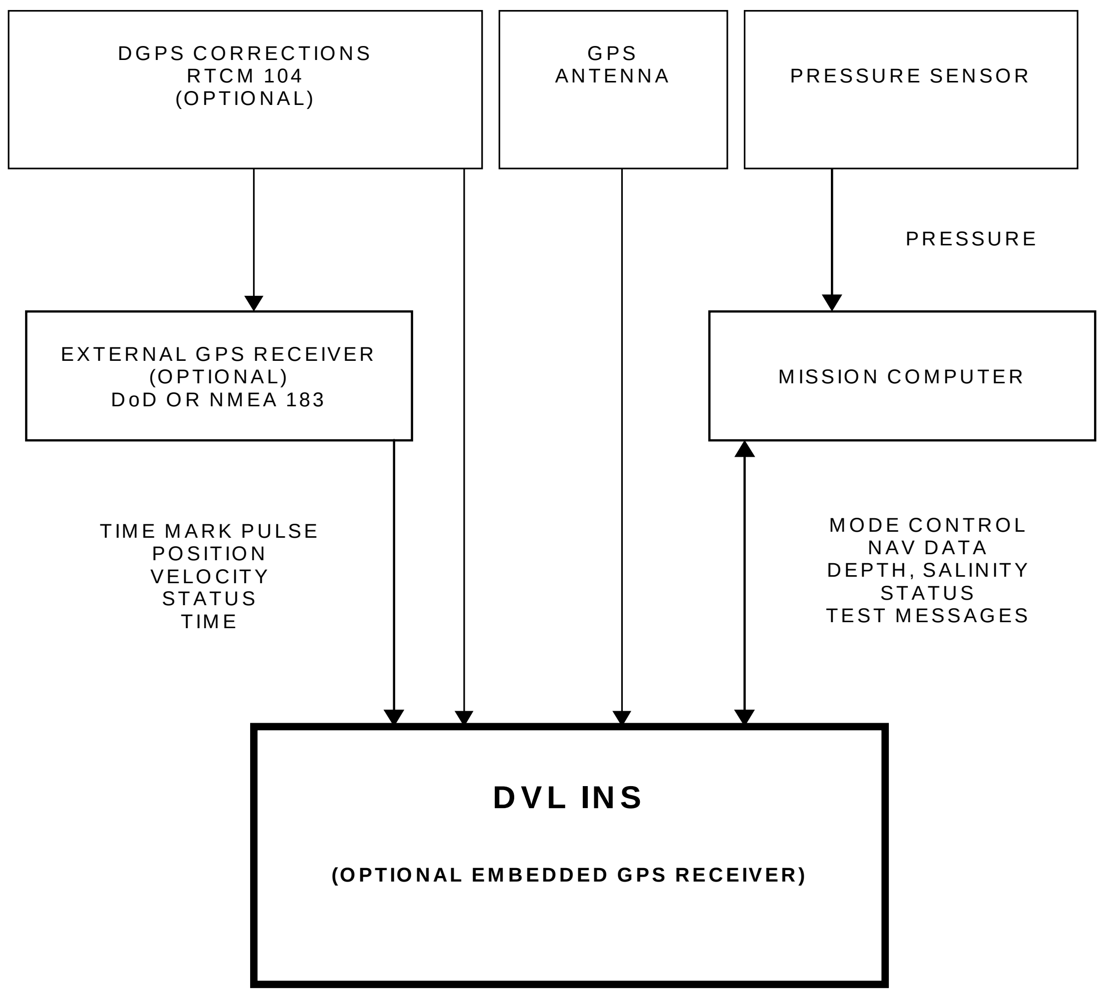


Figure 1: Typical DVL INS Operational Block Diagram

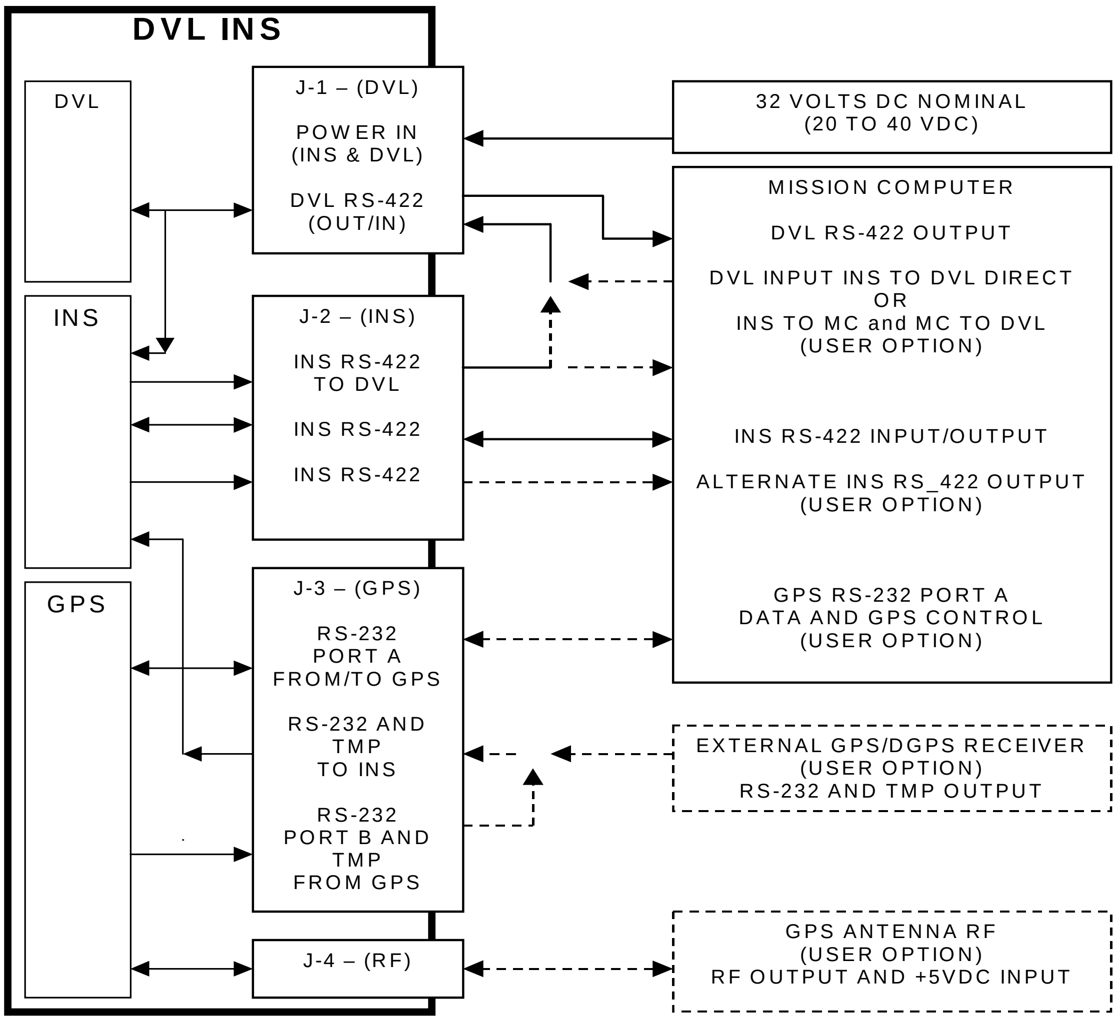


Figure 2: DVL INS Application

3.1.2 System Coordinate and Reference Frames

3.1.2.1 Orientation.

Vehicle orientation is defined by the relationship of the vehicle reference frame (Figure 3) to an earth referenced coordinate frame. A suitable set of SEANAV boresight angles should be selected for each installation to insure proper definition of orientation parameters during deployment.

3.1.2.1.1 Earth reference coordinate frame.

The earth reference coordinate frame is an orthogonal coordinate set (X_E, Y_E, Z_E), X_E points to north, Y_E to east and Z_E downward along the local vertical.

3.1.2.1.2 Vehicle reference coordinate frame.

The vehicle reference frame is a set of right hand orthogonal axes, X_v, Y_v, Z_v shown in Figure 3. The vehicle reference axes convention is + X_v (fore), + Y_v (port side), + Z_v (up).

3.1.2.1.3 Vehicle reference orientation parameters

The vehicle reference orientation parameters are defined in terms of rotations between the earth reference and vehicle reference coordinate frames as shown in Figure 3.

Azimuth is the angle between north and the projection of the vehicle X-axis onto the horizontal plane. Azimuth is measured clockwise from north and is always positive.

Pitch is the angle between the vehicle X-axis and the horizontal plane. Pitch is positive when the X-axis points above the horizontal plane and negative when below.

Roll is the angle between the horizontal plane and the vehicle (minus) Y-axis, measured in the Y, Z plane. Roll is positive when the vehicle (minus) Y-axis points below the X, Y plane, negative when above.

3.1.2.2 Configuration parameters

The configuration parameters ("Accept Configuration Data" message) does not take effect until a shutdown command is given, and power reapplied. The return configuration command/message allows verification of the data. If the configuration is not changed from the previous mission, the "Accept Configuration Data" message is not required.

3.1.2.2.1 Vehicle Boresight Angles.

A set of vehicle boresight angles (VALPHA, VBETA and VGAMMA) are used to rotate the SEANAV case coordinate frame (X_c, Y_c, Z_c) (Figure 5 and Figure 6) into the vehicle's coordinate frame (X_v, Y_v, Z_v) (Figure 6).

3.1.2.2.2 GPS antenna lever arms

The GPS antenna lever arms, defined in the vehicle frame, are measured from the location of the inertial sensors in the SEANAV to the antenna. The accuracy required of the GPS antenna lever arms is < 25 cm. If these vary from mission to mission, they should be reset accordingly.

3.1.2.2.3 DVL lever arms

The DVL lever arms, defined in the vehicle frame, are fixed (see Section 4.1.1) for the DVL INS and are also referenced to the vehicle axes. The accuracy required of the DVL lever arms is < 5 cm.

3.1.2.2.4 Ship's EM Log Boresight Angles

A set of EM Log boresight angles (EMLAZIM, EMLPITCH, and EMLROLL) are used to rotate the ship's EM Log data into vehicle's coordinate frame (X_v, Y_v, Z_v) when the vehicle frame is not aligned with the ship's frame. The angles are measured in the ship's coordinate frame as the Euler angles of the vehicle with respect to the mother ship.

$$\begin{bmatrix} X_V \\ -Y_V \\ -Z_V \end{bmatrix} = \Phi * \Theta * \Psi \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix}$$

$$\Psi = \begin{bmatrix} \cos\Psi & \sin\Psi & 0 \\ -\sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\Theta = \begin{bmatrix} \cos\Theta & 0 & -\sin\Theta \\ 0 & 1 & 0 \\ \sin\Theta & 0 & \cos\Theta \end{bmatrix}$$

$$\Phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{bmatrix}$$

Ψ = AZIMUTH

Θ = PITCH

Φ = ROLL

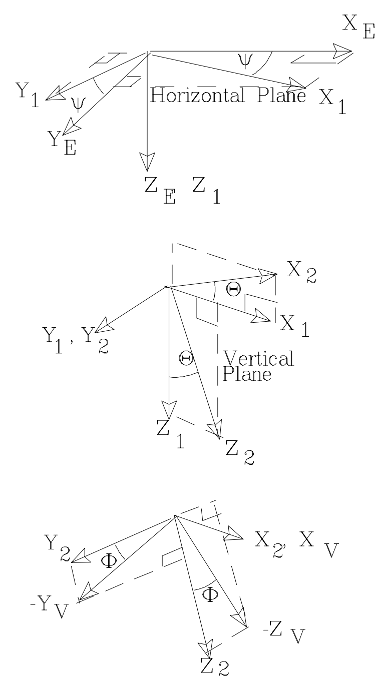
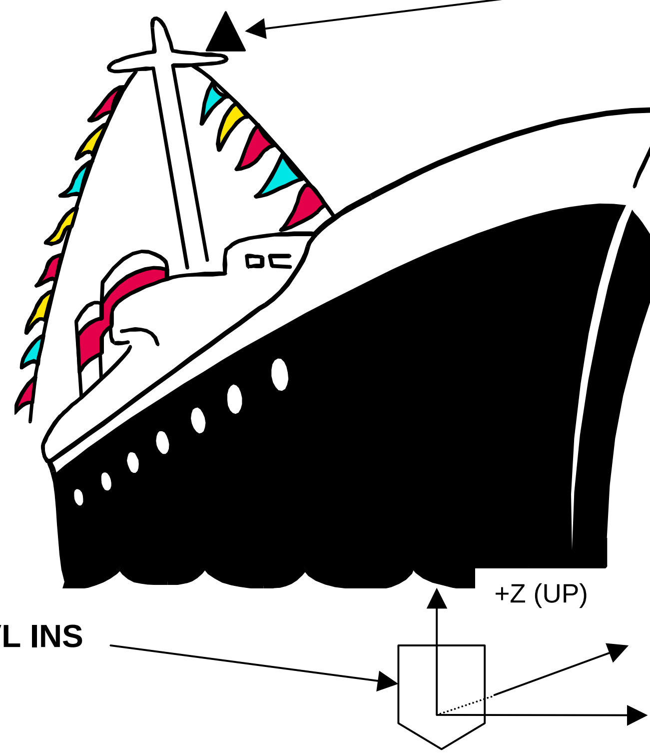


Figure 3: Orientation Parameter Definition



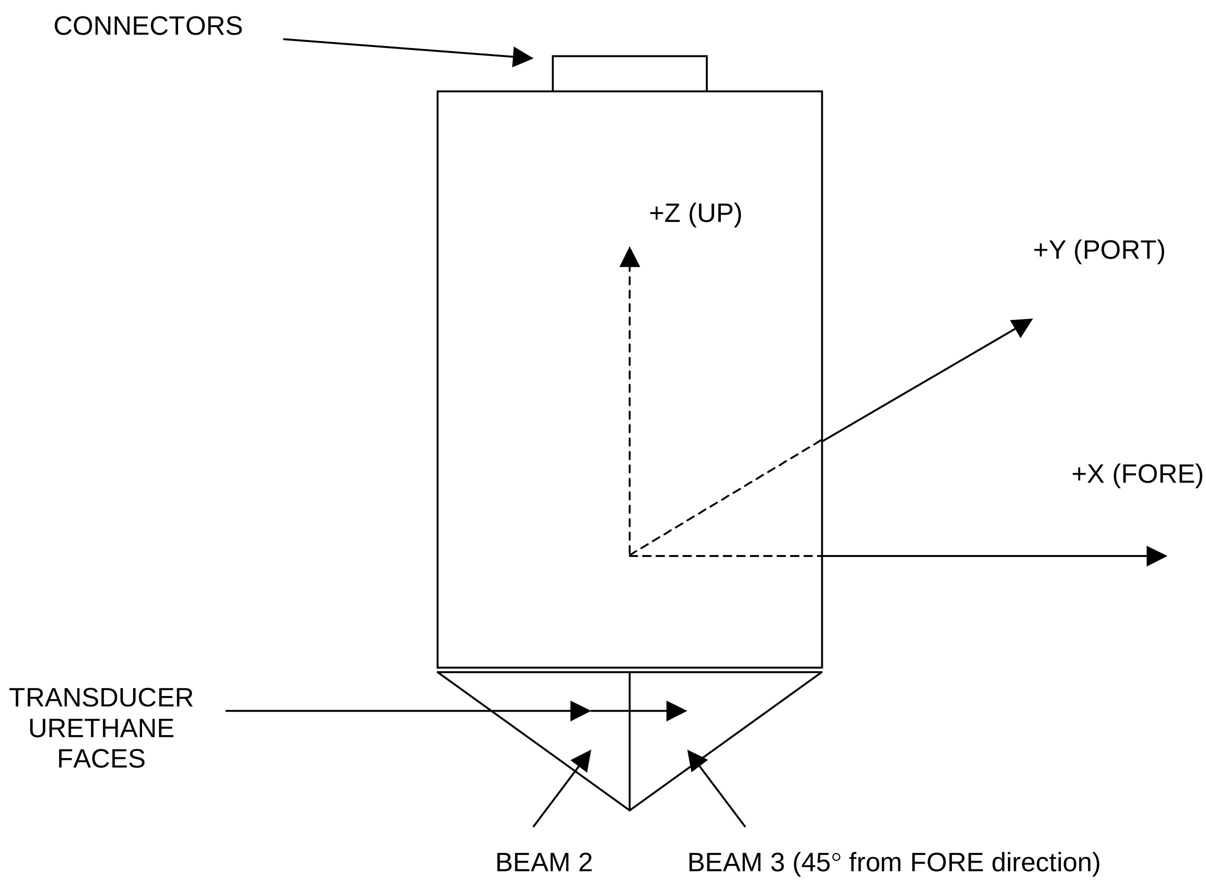
DVL INS on center line, forward at bottom of hull

GPS Antenna on port yard arm of super structure

GPS ANTENNA AFT OF DVL INS	X is Negative
GPS ANTENNA PORT OF DVL INS	Y is Positive
GPS ANTENNA ABOVE DVL INS	Z is Positive

Note: Accuracy required ≈ 25 cm.

Figure 4: GPS Antenna Lever Arm Offsets

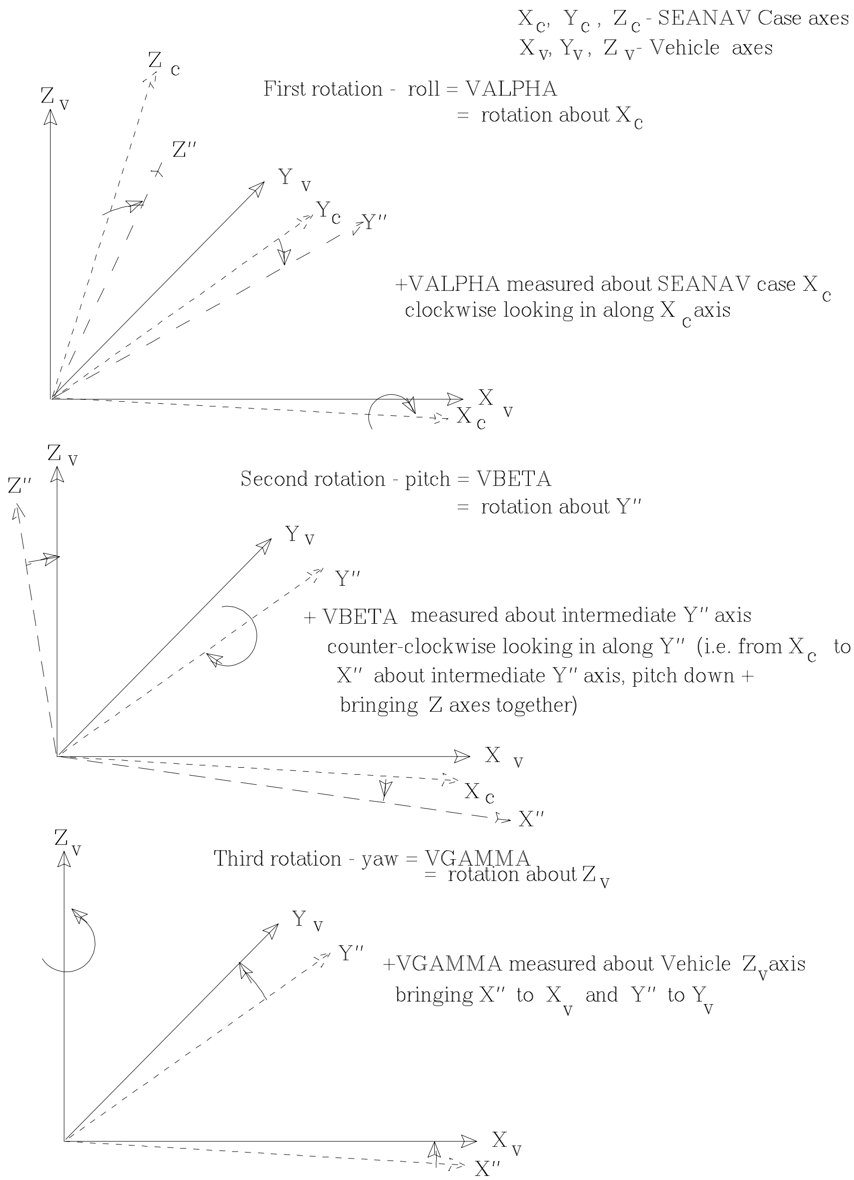


Note: Normal configuration diagram - Viewed from starboard facing port – fore to right.
DVL beams 1 and 3 are oriented at 45 degrees either side of the vehicle “fore” direction

Special operation configuration - All attitude operation
DVL beam 2 oriented along the vehicle “fore” direction
See Table 3: DVL Configuration Parameters

DVL beam numbers are viewable on the transducer faces (along with the serial numbers)

Figure 5: DVL INS Case Coordinates



(Note: For Navigation Performance, SEANAV must be boresighted to DVL "vehicle" frame to within 3 degrees, with mission-to-mission repeatability of 0.025 degrees after a doppler calibration mission has been performed)

Figure 6: DVL INS to Vehicle Boresight Configuration Angles

3.2 DVL Operational Procedures

This section describes the DVL interface with the INS over an RS-422 serial port. It defines the input and output data transmission utilized by the integrated DVL INS. It includes DVL clock synchronization, configuration/mode commands, and DVL output data. Format and protocol are described only for clarity and general understanding of the interface in the context of this ICD. Details are deferred to the DVL technical manual appendices referenced below.

Data transmission (DVL to INS) is internal to the DVL INS in accordance with Table 1 (J1 pins 1 and 2). Data transmission (INS to DVL) is external to the DVL INS in accordance with Table 1 (J1 pins 5 and 6 and J2 pins 1 and 5). In baseline DVL INS operation, the user connects the INS outputs to the DVL inputs in the system interconnect in accordance with Figure 10. The absence of this connection permits the user to assume control of the DVL from the INS if necessary in the application. In this case, see section 3.2.3 for the user requirements.

3.2.1 INS to DVL I/O (baseline)

The message traffic and timing during a mission from the INS to the DVL is described when the INS directly controls the DVL communication. Immediately following system power-up and start-up processing, the INS establishes communication with the DVL via a "break" command. The "break" command is recognized as a logic-low line voltage maintained for a contiguous interval > 300ms. This is the "wake-up" command to the DVL which puts it into an I/O mode. The DVL I/O mode suspends DVL ping and velocity data acquisition) and allows configuration and mode commands to be entered with echo verification.

The DVL responds to the "wake-up" with an ASCII ">" output indicating it is ready to receive input commands. When the “>” has been received by the INS, the INS transmits a "CR0" command that restores configuration/mode settings preset in EEPROM to RAM.

Following the configuration command sequence, the DVL clock used to time-tag pings is initialized (synchronized) to the INS internal time, including hour, minute, second. The DVL echo of the input time is verified and if a discrepancy detected, the time input is commanded again. The DVL time is re-synched to the INS once every 30 minutes. This requires suspension of the "autonomous" mode and commanding the DVL into I/O mode via a "break" command, with the DVL response of a ">" character. When the DVL INS has received this response, the INS issues a clock reset command per the initial clock synch scenario. The DVL is commanded back to the operational "autonomous" mode, immediately following the DVL re-synch echo, unless a discrepancy is detected in which case a retry is performed.

3.2.2 PING Control by the user mission computer via the INS

The DVL is maintained in the I/O mode (no pinging) until the INS receives a "doppler ping" command from the mission computer (Section 4.1.1, Table 15: Accept Operation Data Message, Note 2, BIT # 0). When the "doppler ping" command is received for the first time, the DVL is commanded into "autonomous" mode. In this mode the DVL suspends Command I/O, pings at a variable rate determined by the DVL for maximum data under current conditions, and outputs velocity data messages without request at a rate consistent with the ping rate. This mode of operation is commanded via a "CS" command (start pinging) and maintained except for occasional periodic re-synchronization of the DVL clock. The DVL is commanded out of this mode via a "break" if the "doppler ping" command is cleared (toggles off from the mission computer). The DVL can be commanded out of "autonomous" mode and into "Water Track" mode only if the DVL Water Track Mode command is enabled. It can be returned to "autonomous" mode if the DVL Water Track Mode Command is disabled.

The DVL "water-track" and "bottom-track" modes are configured (Section 4.1.1, Table 15: Accept Operation Data Message, Note 2, BIT # 0) as follows. To command DVL to bottom track only mode requires the INS to transmit a "BK0" ASCII command to the DVL to command DVL to alternate water-track/bottom-track mode requires transmitting to DVL a "BK1" command. To command DVL to "Autonomous mode" requires transmitting to DVL a "BK2" command. To command DVL into "Water Track" only mode requires transmitting to DVL a "BK3" command.

3.2.3 User control of the DVL (Optional)

If the user chooses to control operation of the DVL, the INS I/O requirements to the DVL must be maintained per sections 3.2.1 and 3.2.2. The communication that the user must provide includes “wake-up”, configuration/mode commands, establishment of communication and time synchronization followed by re-synchronization every 30 minutes (as initiated by the INS). Additional latency in time synchronization introduced by the user implementation shall be less than 0.1 sec. The RD Instrument "workhorse" Technical Manual Appendix C describes in detail the input protocol, format, and input commands used by the DVL. Appendix D describes in detail the output data available from the DVL, including protocol and message format. This option is utilized if the user must control timing of “ping” or if the user requires additional outputs from the DVL.

3.2.4 DVL to INS alignment calibration (For information only)

The DVL to INS misalignments are calibrated in the factory in a static or dynamic environment prior to shipment. For the integrated system configuration, doppler calibration is not required. The misalignments are fine adjusted during normal missions (i.e. filtered with an EEPROM stored weighting factor on any change from turn-on to shutdown). The capability for the user to calibrate the misalignments is retained in the INS software and its use is optional but not recommended.

3.2.4.1 Doppler calibration requirements (Not utilized – for information only)

For the integrated system configuration, doppler calibration is not required. The DVL to INS misalignments are calibrated in the factory in a static or dynamic environment prior to shipment. This is one of the major improvements achieved by utilizing an integrated DVL INS. In a system configuration where the DVL and INS are located in separate structures, it is required for the INS to determine (calibrate) the misalignments between the DVL and the INS coordinate frames to transform velocity data from the DVL. The capability to calibrate the misalignments is retained in the INS software and its use is optional, but not recommended, to the user. This permits the INS system (via Kalman filter) to update estimates of the DVL misalignments relative to the INS (and DVL scale factors). These initial estimates are subsequently stored in EEPROM (at shutdown command) for operational missions. If the user selects Doppler Calibration, the INS will discard the previously stored values and store the current mission estimates.

3.2.4.2 Doppler calibration run (Not utilized – for information only)

A doppler calibration run must contain appropriate features in the mission to effectively provide observability to the Kalman filter. This includes an accurate alignment followed by doppler aided navigation with distinct periods having motion that exercise each DVL axis (i.e. velocity component along vehicle x, y, and z) to the extent that is practicable as well as periods at differing speeds, attitude, and heading. In other words, a trajectory with down-track, cross-track, and normal-to-deck motion if possible, and also differing geographic frame direction, speeds (intermittent commanded ZUPT's as well), roll, and pitch. Bottom track doppler data is essential, and any water track data should exclude (via doppler aiding enable command) zones with high variability of water currents, temperature, and salinity.

The entire run should be of sufficient duration - of the order of two hours in bottom track mode. The alignment should include GPS aiding with at least one turn > 60°, cruising steady along each track angle at as large a velocity as possible for at least 10 minutes each (a stationary alignment is not required, but is acceptable). It is useful to enable slow test messages during a calibration so that the covariances on the doppler states can be monitored; they provide information as to whether the states have been observable during the mission. It may be that some states are not observable by virtue of the dynamics that can be realized with the vehicle. These parameters will not be important during normal operation and will simply be "inert".

The DOPPLER CALIBRATION logical must be pre-set, followed by a shutdown, prior to calibration, and must be reset (cleared), prior to shutdown during the calibration run (otherwise the calibration results will not be retained during the next mission).

3.3 INS Operational Procedures

3.3.1 INS Initialization data

The INS maintains a history of data in an EEPROM to permit rapid initialization of the INS at power turn on without the requirement of entering data that does not change between missions. The EEPROM is initialized at Kearfott, prior to shipment, to default values based on nominal mission requirements.

3.3.1.1 Configured for installation and operation.

The INS must be configured for the installation and operation scenario prior to the first mission via the "Accept Configuration" message as defined in Table 14. This message allows setting of boresight angles from the physical INS case axes to the vehicle reference axis desired for output attitude, rate, and acceleration data (i.e. the vehicle longitudinal, lateral, and normal).

Byte D7 of the "Accept Configuration Data" message configures the system for "surface" ship or underwater vehicle; enables test messages ("turns on" output of special diagnostic messages); sets the mission scenario for sonar Doppler or EM Log calibration (discussed in paragraph 3.2.4.1). The SATIME (dockside stationary align time) byte D8, is set in minutes - this align mode completes and transitions to aided navigation after this time duration; a longer time increases alignment performance (5 minutes is a short time; 15 minutes the longest. beyond which there is diminishing return). Similarly the LSATIME (land stationary align time) byte D33, is set in minutes. Land stationary align time is used when Land/Dock Side switch, LANDFLAG, in "Accept Operational Data Message" is set 1 (land).

3.3.1.2 Shutdown Command function

The INS has the capability to retain system operational conditions during periods when no power is applied to the unit. Prior to removing power, the INS can be commanded to store operational data into the EEPROM by use of the Shutdown command. This is found in the ACCEPT OPERATIONAL DATA message of paragraph 4.1.2 as specified in Table 15. Following the INS being commanded to shutdown, the INS stores relevant data into the EEPROM and then transitions into an Idle mode. Power must then be removed from the INS.

3.3.2 Normal Operation

It is assumed that the above configuration and calibration for the particular assemblage of vehicle, INS, DVL, and GPS lever arm geometry have been achieved. A normal mission requires an alignment (includes "leveling" - roll/pitch determination, and heading alignment - true heading with respect to geographic north determination) prior to navigation operation. Following alignment, the navigation portion of the mission requires observing procedural guidelines to optimize performance.

3.3.3 Alignment

The INS can be aligned in three ways (stationary, moving base and heading initialized fine moving base) In addition, there are two sequence control procedures (extended and restart) during alignment.

3.3.3.1 Stationary Alignment

Stationary Alignment, requires initial position either entered manually or received from the GPS. The reference data consists of Zero Velocity Updates (ZUPT). This form of alignment is less accurate above 60° latitude because it depends solely on sensing the horizontal component of earth's rotational rate. The duration is fixed by the configuration SATIME or LSATIME and the SYSTEM MODE (NAVIGATION DATA MESSAGE) will indicate FINE STATIONARY ALIGN – COMPLETE. The system will continue to align if ZUPT is commanded and enabled. A coarse gyrocompass alignment, taking 1-2 minutes, precedes the fine alignment, as reported in the SYSTEM MODE. No meaningful inertial data are output during the coarse alignment. During fine alignment the inertial data output, though not meeting navigation accuracy requirements, will be output with qualitatively correct values (i.e. heading error < 1°). Zero velocity is regarded as "truth", and therefore the vehicle motion must be limited to small "noise" oscillations (the software assumes a 1 σ noise motion of 0.2 ft over a 2-second Kalman cycle for a DOCK SIDE Stationary Alignment and less for LAND Stationary Alignment).

3.3.3.2 Moving Base Alignment (MBA)

Moving-Base Alignment with full coarse heading determination requires no manual operational input data other than the "GPS AIDING ENABLE" flag set (Operational Data Message). This mode is the "normal" operational alignment mode, starting automatically when GPS Position, Velocity, Time (PVT) data become available and GPS aiding is enabled. During this mode both GPS position and velocity data are utilized by the Kalman filter; for the first 1-2 minutes of active alignment, a coarse heading is determined, during which time no meaningful inertial data are output.

Moving-Base Alignment with full coarse heading determination can be achieved, as discussed above, using EM Log or DVL or Velocity Log data after initial position is inserted and the “DOPPLER/EM LOG AIDING ENABLE” flag is set (Operational Data Message).

Moving-Base fine align continues until the performance level of the system (primarily driven by heading alignment) is determined by the Kalman filter covariance model to be ready for navigation requirements. This is not a fixed time, and will be influenced by latitude if turning and accelerations are minimal, and by the level of sensed acceleration (including turns at a steady speed) if the vehicle dynamics provide such. The latter allows alignment at > 60° latitude, as well as a more rapid alignment at all latitudes. Thus it is recommended that the ship execute at least one "dog-leg" maneuver after transition from coarse to fine alignment as indicated by the output mode word, and that each track angle be maintained for at least 5 minutes (depending on speed, longer for slow steaming). When alignment performance is sufficient to meet navigation requirements (determined primarily by heading uncertainty) the output mode will indicate moving-base fine align complete. GPS PVT or DVL or EM Log or Velocity Log data will continue to be processed as long as the aiding enable command is not cleared in an input message sent to the INS.

3.3.3.3 Heading Initialized Fine Moving-Base Alignment

Heading Initialized Fine Moving-Base Alignment allows the user to manually enter a heading. This automatically triggers the INS to use the entered heading as a coarse initial estimate (expected to be within 10°) and to skip the coarse align submode. The initial heading must be provided in the same message as the initial position. If GPS aided coarse moving base align has already begun and the manual initialized heading mode desired, the align restart command must also be set, then cleared with the valid heading.

3.3.3.4 Extended alignments

All of the above alignments should be extended until the mission requires the navigation portion to commence. In other words, allow the INS to process GPS data until the GPS becomes invalid or unavailable, in preparation for the navigation portion of the mission. It is important that the GPS enable command is set to a zero state (or the GPS disconnected) when the GPS lever arm data is no longer valid.

3.3.3.5 Align Restart

The Align Restart command allows an alignment to be manually aborted. Sending this command while in either an align or navigation mode causes the INS to enter Idle mode, where it will remain until the Restart command is sent again in a zero state AND initialization data is received (either from GPS or manual input).

A fine (but not coarse) Stationary align can be smoothly transitioned to fine moving-base align without restart simply by clearing the stationary align command and enabling GPS or other aiding. A moving-base align can effectively incorporate stationary align intervals via commanded ZUPT (although the actual mode does not change).

The alignment processing can be monitored by observing the ZUPT processed (stationary align or commanded ZUPT) or GPS data processed/rejected output logicals. If neither GPS data processed bit nor the GPS rejected bit is set, then either the enable command was not received or the GPS does not have a four-satellite solution.

3.3.4 Navigation

Aided navigation mode is indicated in the output message when the Fine Alignment is complete and the GPS enable (for MBA) or DVL/EM-Log aiding flag is set. The output mode will indicate aided GPS, Doppler or EM-Log navigation (if fine align is not complete, Doppler aided fine MBA will be indicated when Doppler aiding is enabled). If GPS aiding is enabled during align and the GPS antenna is separate from the vehicle, prior to moving the vehicle for launch (and thus disturbing the GPS antenna lever arm calibration), the GPS aiding enable flag must be disabled. If "Forced Position Fix" aiding is commanded via Special Command, the Kalman will continue to update the estimated position with the provided position data even if the data is determined by the filter to be unreasonable via 3-sigma test.

3.3.4.1 Navigation performance

Navigation performance for missions of duration greater than a few hours is coupled tightly to the reference data, and the ability of the system to utilize this data optimally. Stability of the systematic errors such as Doppler scale factors and water currents (for water track Doppler data) is needed. Therefore it is recommended that the Doppler aiding not be enabled during the shallow portion of the dive (unless the mission is sustained at shallow depths). During this time water currents are wind blown and not representative of nominal currents throughout the mission. In addition, rapid temperature and salinity variations influence the Doppler scale factors via speed-of-sound uncertainty. The depth at which the Doppler should be enabled depends on environmental factors and the mission scenario, so that operator judgment is required. It is expected that typically the enabling should be done when depths of the order of 500m are reached, and that the time to reach this depth should be minimized. If the desired depth has been reached, the Doppler "Autonomous Mode" should be enabled and the DVL will ping in "bottom track" mode and, if unable to reach the bottom, in "water track" mode. If a Special Command Doppler "Water Track Mode" is issued, the DVL should accept this new configuration until a new Special Command is issued to disable this mode. During Doppler "Water Track Mode" only water track data is provided to the Kalman.

Processing of Doppler data can be monitored via the output Doppler processed/rejected logicals. Neither being set indicates either not enabled or 4 beam solution not available from the DVL.

3.3.4.2 Kalman filter estimates

In order to fine tune the Kalman filter estimates of IMU and Doppler states, certain maneuvers during normal missions should be incorporated. A "dog-leg" (>60°) and/or "box-car" with track angle change maintained for at least 10 minutes should be attempted at least once during the early part of bottom track operation, as well as some decelerations and accelerations and some pitch attitude changes, held for a few minutes. Stopping on the bottom and performing a one minute commanded ZUPT followed by one minute of static Doppler bottom track aiding (i.e. clear ZUPT command but remain stationary for another minute) at one or two hour intervals if possible would enhance performance.

3.3.4.3 Pressure depth

The pressure depth is utilized by the INS to damp the vertical channel; that data should be provided whenever the depth reference is accurate to within its nominal specifications. Pressure depth should be provided continuously at 0.5Hz-5Hz rate to ensure stable damped inertial depth; note that depth is a parameter needed to compute sonar Doppler sound speed and directly influences Doppler scale factor. If the depth meter is corrupted by transitory factors (such as certain vehicle dynamics, or environmental factors such as turbulence or wave motion), the data should be set invalid. The inertial tracking of depth can be sustained for periods of a few minutes (somewhat longer if using sonar Doppler). The open loop monitor output logical is set after one minute. The “Operational Data Message” specifies whether to use Pressure Depth or GPS altitude for the vertical channel damping. If “Surface” ship configuration is indicated, the depth reference is set to “Vehicle-INS Offset” (both in the “Configuration Data Message”).

3.3.4.4 Attitude Heading Reference System (AHRS) Operation

The INS can be commanded to provide coarse values of attitude (roll and pitch) and heading in the presence of Velocity Log aiding without the entry of position by setting the AHRS control logical in the Accept Operational Data Message. The INS does not provide valid position data in this mode. When position is entered via the GPS receiver (when the GPS aiding enable flag is set) or the Accept Operational Data Message when either the DOPPLER AIDING ENABLE or the STATIONARY ALIGNMENT COMMAND (Dock side or Land) is set, the INS will initiate a coarse alignment.

3.4 Mechanical Interface

3.4.1 DVL INS Mounting

Figure 7 shows the recommended mechanical mountings for a typical DVL INS installation. Vehicle FORE axis is determined by the location of the DVL transducer heads (Table 3) and the location of the internal inertial sensor +X axis (Figure 5). The bolt/mounting features (used to attach the DVL transducers to the upper structure) provide for heading alignment of the DVL INS. The upper structure cylinder axis is perpendicular to the DVL INS X-Y plane (Figure 5). Software vehicle boresight angles are available (Figure 6 and Section 3.1.2.2.1) to correct the DVL INS roll, pitch and heading output angles. Normal mounting has the four cables exiting AFT (not necessary and can be changed by rotating the top cover if required).

3.4.2 DVL INS Weight and Dimensions

The DVL INS is a cylinder with dimensions of approximately 9” diameter by 19” length, a function of the pressure depth housing utilized, as shown in Figure 7. The weight of the DVL INS is mainly a function of the pressure depth housing utilized.

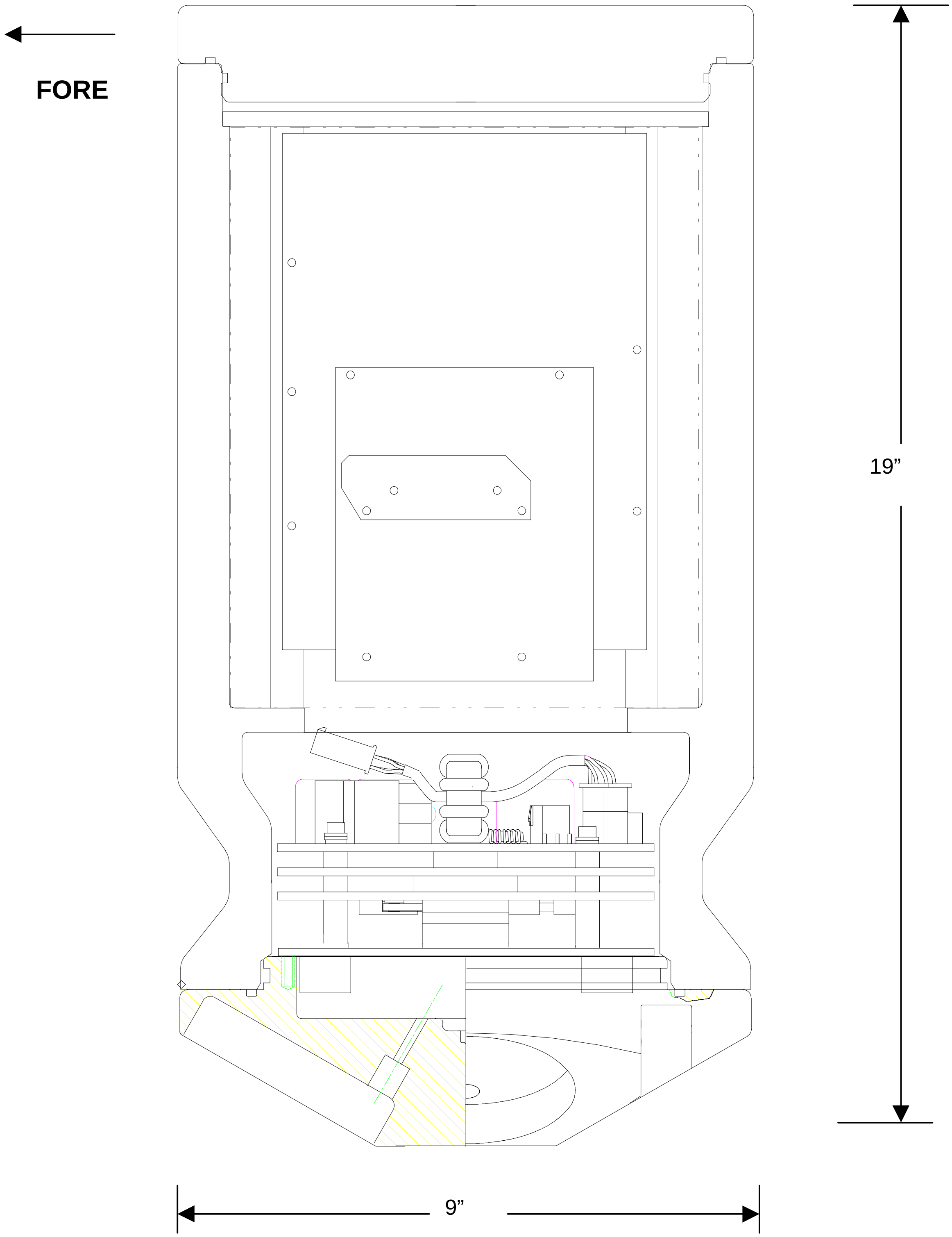
3.4.3 Connector positioning and definition

The physical position of the four (4) electrical connectors on the DVL INS chassis is at the top of the cylinder in Figure 5. The part numbers for these connectors and their mates is provided in Table 1.

Table 1: DVL INS Connector Information

Connector Reference Designator	Connector Part Number (Chassis Connector)	Number of Contacts	Mates With
J1*	LPMBH-7-MP	7	LPMIL-7-FS
J2*	LPMBH-8-MP	8	LPMIL-8-FS
J3*	LPMBH-8-FS	8	LPMIL-8-MP
J4*	LPMBH-2-FS	2	LPMIL-2-MP

* IMPULSE Low Profile Mini Wet Pluggable Series



Dimensions are approximate dependent on pressure depth housing utilized.

Figure 7: DVL INS Mechanical Interface

3.5 Electrical Interface

3.5.1 Connectors
Each external connector reference designation, part number, number of contacts, size, and mating connector is defined in Table 1. The DVL INS signal connector pin functions are in accordance with Table 2.

3.5.1.1 Grounding of the DVL INS
The DVL INS maintains three separate grounds within the chassis. POWER and COMMUNICATION RETURN are available on the J1 connector and should be tied at the power source. COMMUNICATION RETURN and CHASSIS GROUND are tied within the DVL INS. The user is to assure that the devices interfacing with the DVL INS RS-422 communication lines have their signal grounds tied to the COMMUNICATION RETURN on the J1 connector.

Table 2: Connector Signal to Pin Definition

PIN	J1		PIN	J2		PIN	J3
	DVL			INS			DGPS
1	DVL RS-422 OUT A (TO INS [INTERNAL] AND COMPUTER) OR RS-232 IN (FROM INS [EXTERNAL] OR COMPUTER)		1	INS RS-422 OUT HI OR RS-232 OUT (TO DVL)		1	GPS RS-232 PORT B OUT (FROM DGPS)
2	DVL RS-422 OUT B OR RS-232 OUT (TO INS [INTERNAL RS-422 OR RS-232] AND COMPUTER)		2	INS RS-422 OUT HI (TO COMPUTER)		2	INS RS-232 IN
3	DVL/INS POWER +		3	INS RS-422 IN HI (TO COMPUTER)		3	GPS TIME MARK PULSE OUT (FROM DGPS)
4	DVL/INS COMMUNICATION RETURN		4	GPS RS-422 OUT HI (AUXILIARY OUT TO COMPUTER)		4	INS TIME MARK PULSE IN (TO INS)
5	DVL RS-422 IN A (FROM INS [EXTERNAL] OR COMPUTER)		5	INS RS-422 OUT LO (TO DVL)		5	GPS RS-232 PORT A OUT (FROM DGPS)
6	DVL RS-422 IN B (FROM INS [EXTERNAL] OR COMPUTER)		6	INS RS-422 OUT LO (TO COMPUTER)		6	INS RS-232 OUT
7	DVL/INS POWER -		7	INS RS-422 IN LO (FROM COMPUTER)		7	GPS RS-232 PORT A IN (TO DGPS)
			8	GPS RS-422 OUT LO (AUXILIARY OUT TO COMPUTER)		8	INS TIME MARK PULSE RETURN (SIGNAL GROUND)

Note: The J4 connector provides for GPS RF on pin 1 from an antenna to the embedded GPS receiver and +5 VDC power to an antenna preamp. Pin 2 provides the return for voltage and the coax RF shield isolated from chassis.

3.5.2 DVL INS Power Input

The DVL INS turns-on when activated 3.5.2.1 if the steady state power voltage is at any value FROM 20 TO 40 VDC (32 VDC nominal). Loss of power does not damage the DVL INS or affect the computer program or INS calibration data.

The power required for the DVL INS is less than 35 W. Pin assignments for the DVL INS power on connector J1 is in accordance with Table 2. Figure 8 shows the configuration of the power and ground connections between the DVL INS and the user equipment

3.5.2.1 On/Off Control

The DVL INS is activated upon application of system power. This automatically initiates the startup and alignment sequence. The DVL INS deactivates with the removal of primary power. Receipt of a SHUTDOWN command by the INS initiates storage of data. At least 2 seconds prior to deactivation, the bit 1 of D2 of the Accept Operational Data" message (paragraph 4.1.1) is set to effect storage of data into EEPROM. The DVL INS is able to reactivate within 5 seconds after power has been removed.

J1 – DVL I/O CONNECTOR (LPMBH-7-MP)

3	POWER +	TO DVL/INS POWER IN
7	POWER –	TO DVL/INS POWER IN
4	COMMUNICATION RETURN	TO DVL/INS SIGNAL GROUND
1		
2		
5		
6		

Figure 8: DVL INS to External Power Interconnect

3.5.2.2 Mission Computer DVL Connection Interface Definition

The electrical characteristics conform to the EIA standard RS-422. The interface is a full duplex bi-directional (two sets of unidirectional differential lines). Pin assignments for the RS-422 DVL Interface on the DVL INS are in accordance with Table 2 and Figure 9. The message interface is defined in the RDI Workhorse Technical Manual.

The DVL implements an alternate interface that conforms to the EIA standard RS-232 utilizing pins 1 and 2 on the J1 connector. Switches mounted in the DVL and Inertial electronics modules within SEADEVIL control the interface. Either RS-422 or RS-232 operation must be selected on both switches.

Pin assignments for the RS-232 DVL Interface on the DVL INS are in accordance with Table 2 and Figure 9. The message interface is defined in the RDI Workhorse Technical Manual. Pin assignments to the J2 INS I/O connector are in accordance with Table 2 and Figure 8. The INS RS-422 interface electrical characteristics are compatible with the DVL RS-232 interface electrical characteristics. Unless there is a specific requirement to operate the DVL utilizing the RS-232 interface (and the cable lengths are short), it is recommended that the RS-422 interface be utilized. Such a requirement is utilization of the DVL Low Latency Trigger Enable function that utilizes the RS-422 input lines (RD Instrument Application Note FSA-018 [July 2002]).

J1 – DVL I/O CONNECTOR (LPMBH-7-MP)

3		
7		
4	COMMUNICATION RETURN	SIGNAL GROUND
1	RS-422 OUT A	DVL RS-422 OUT A OR RS-232 IN
2	RS-422 OUT B	DVL RS-422 OUT B OR RS-232 OUT
5	RS-422 IN A	DVL RS-422 IN A (FROM INS [J2-1] OR MC)
6	RS-422 IN B	DVL RS-422 IN B (FROM INS [J2- 5] OR MC)

Figure 9: DVL Mission Computer Serial Interface Interconnect

3.5.2.3 Mission Computer INS Connection Interface Definition

The electrical characteristics conform to the EIA standard RS-422. The interface is a full duplex bi-directional (two sets of unidirectional differential lines). Pin assignments for the INS Interface on the DVL INS are in accordance with Table 2 and Figure 10.

J2 – INS I/O CONNECTOR (LPMBH-8-MP)

3 RS-422 IN HI	INS RS-422 IN HI (FROM MC)
7 RS-422 IN LO	INS RS-422 IN LO (FROM MC)
2 RS-422 OUT HI	INS RS-422 OUT HI (TO MC)
6 RS-422 OUT LO	INS RS-422 OUT LO (TO MC)
1 RS-422 OUT HI	INS RS-422 OUT HI BASELINE CONNECT TO DVL RS-422 IN A (OPTION CONNECT TO DVL RS-232 IN) (OPTION CONNECT TO USER COMPUTER)
5 RS-422 OUT LO	INS RS-422 OUT LO BASELINE CONNECT TO DVL RS-422 IN B (OPTION CONNECT TO USER COMPUTER)
4 RS-422 OUT HI	AUXILIARY INS RS-422 OUT HI (USER OPTION)
8 RS-422 OUT LO	AUXILIARY INS RS-422 OUT LO (USER OPTION)

Figure 10: INS Mission Computer Serial Interface Interconnect

3.5.2.4 DVL INS to GPS Connection Definition

The RF antenna signal connection between the DVL INS embedded GPS receiver and an external GPS antenna/preamplifier is via the J4 connector. Figure 11 shows the configuration for the signal connection between the DVL INS embedded GPS receiver or an external GPS receiver and the INS computer.

The configuration for the signal connection between the DVL INS and the embedded DGPS receiver is accomplished at the J3 connector. The user cabling routs the embedded DGPS one Pulse Per Second (1PPS) and the DGPS RS-232 Port B Out to the equivalent INS input signals (jumper J3-1 to J3-2 and J3-3 to J3-4). The embedded DGPS RS-232 Port A Input and Output are available for use on pins J3-5 and J3-7.

The configuration for the signal connection between the DVL INS and an external GPS receiver is accomplished at the J3 connector. The user cabling routs the GPS Time Mark Pulse or 1PPS and the GPS RS-232 output to the equivalent INS input signals (J3-2 and J3-4). For a DoD GPS receiver (PLGR), the INS RS-232 output (J3-6) can be used to initialize communication.

J3 GPS I/O CONNECTOR (LPMBH-8-FS)

1 RS-232 B OUT (GPS)	RS-232 NMEA 183 (TO J3-2 OPTION)
2 RS-232 IN (INS)	RS-232 FROM GPS TO INS (ICD-150 BLOCK 03 OR NMEA-183) (EMBEDDED OR EXTERNAL GPS)
3 GPS 1PPS HI OUT	1PPS FROM EMBEDDED GPS (TO J3-4 OPTION)
4 TIME MARK PULSE IN (INS)	TIME MARK PULSE OR 1PPS FROM GPS (EMBEDDED OR EXTERNAL GPS
8 TIME MARK RETURN	MARK PULSE RETURN (FROM EXTERNAL GPS)
5 RS-232 A OUT (GPS)	RS-232 NMEA (OPTION TO USER)
7 RS-232 A IN (GPS	RS-232 NMEA (OPTION FROM USER)
6 RS-232 OUT (INS)	RS-232 TO DoD GPS (OPTION [PLGR] OR UNUSED)

Figure 11: GPS Receiver Interconnect

3.6 DVL Messages

3.6.1 DVL Configuration Requirements

To perform the operational mission and communicate with the INS, the INS and DVL are pre-set prior to shipment. The INS does not dynamically configure the DVL during operation. The interface protocol must be maintained to 115.2kbaud, odd parity, 1 stop bit in order for the INS to communicate with the DVL. The DVL and INS are pre-set before delivery of the integrated system. Parameters that are used are included in Table 3 with commands as shown.

Table 3: DVL Configuration Parameters

BP1	One Bottom Track Ping/ensemble
CB831	115.2kb, odd parity, 1 stop bit protocol
CF11110	Flow Control: Auto ensemble cycle, Auto ping, Binary data output, Enable serial output.
EZ0000001	Sensor Source - manual speed of sound, depth, heading, pitch, roll (default to 1500m/s,0,0,0,0,35), internal temperature
PD4	Performance data out - output PD4 velocity message
TP00:00.20	Time Between Pings - minimum 200 ms (5 Hz data to INS)
TE00:00:00.00	Time per ensemble – minimum interval set to 0 seconds

Normal configuration - Level operation (limited roll and pitch angles < 45 degrees)
DVL beams 1 and 3 are oriented at 45 degrees either side of the vehicle “fore” direction

EA+13500	Heading Alignment - DVL +X output along INS +X and vehicle fore axis with beam 3 clocked 45° to starboard from fore axis
EX10010	Coordinate Transformation - Ship X, Y, Z frame velocity output, no tilts, 3 beam solution provided (INS does not use 3 beam solution), no bin mapping
CK	Keep parameters as user defaults

Special operation configuration - Inverted operation (DVL pointed up, Roll Boresight Angle (Table 14) of -180° and DVL beams 1 and 3 are oriented at 45 degrees either side of the vehicle “fore” direction

EA+04500	Heading Alignment - DVL +X output along INS +X and vehicle fore axis with beam 3 clocked 45° to port from fore axis
EX10010	Coordinate Transformation - Ship X, Y, Z frame velocity output, no tilts, 3 beam solution provided (INS does not use 3 beam solution), no bin mapping
CK	Keep parameters as user defaults

Special operation configuration - All attitude operation (unlimited roll and pitch angles) –
DVL beam 2 oriented along the vehicle “fore” direction

EX01010	Coordinate Transformation - Instrument X, Y, Z vectors relative to the DVL output, no tilts, 3 beam solution provided (INS does not use 3 beam solution), no bin mapping
CK	Keep parameters as user defaults

3.6.2 DVL velocity output message PD4

During "autonomous" mode, the DVL pings and generates a PD4 output message containing all data associated with DVL velocity for both water track and bottom track data. Refer to Table 4 below and Table D-24 in the RDI Technical Manual for more details of the PD4 message format. Message transmit rate by the DVL is variable, with the maximum rate 50Hz set by the 20ms minimum delay command, and the DVL INS polls for the data at 50Hz.

Table 4: DVL data format

DATA BYTE #	VARIABLE NAME	DESCRIPTION	UNITS	INPUT FORMAT
D1	DVLID	DVL DATA ID	NA	U8
D2	DATSTR	DATA STRUCTURE	NA	U8
D3,D4	NUMBYTE	NUMBER OF DATA BYTES SENT	NA	U16
D5	SYSCONFIG	DEFINES THE DVL HARDWARE/FIRMWARE	NA	U8
D6,D7	XVELBTM	X-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D8,D9	YVELBTM	Y-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D10,D11	ZVELBTM	Z-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D12,D13	EVELBTM	E-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D14,D15	BM1	VERTICAL RANGE TO BOTTOM – BEAM #1	CM	U16
D16,D17	BM2	VERTICAL RANGE TO BOTTOM – BEAM #2	CM	U16
D18,D19	BM3	VERTICAL RANGE TO BOTTOM – BEAM #3	CM	U16
D20,D21	BM4	VERTICAL RANGE TO BOTTOM – BEAM #4	CM	U16
D22	BOTSTAT	STATUS OF BOTTOM REFERENCED CORRELATION AND ECHO AMPLITUDE DATA	NA	U16
D23,D24	XVELREF	X-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D25,D26	YVELREF	Y-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D27,D28	ZVELREF	Z-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D29,D30	EVELREF	E-VELOCITY WRT WATER REFERENCE	MM/S	S16
D31,D32	REFSTRT	REFERENCE LAYER START DISTANCE	DM	S16
D33,D34	REFEND	REFERENCE LAYER END DISTANCE	DM	S16
D35	REFSTAT	REFERENCE LAYER STATUS	NA	U8
D36-D39	TOPING	TIME OF PING	HR/MIN/S 0.01S	U8(4)
D40,D41	BIT	BUILT IN TEST RESULTS	NA	BINARY
D42,D43	SPDSND	SPEED OF SOUND USED BY DVL	M/S	U16
D44,D45	TEMP	TEMPERATURE OF WATER	0.01° C	S16
D46,D47	CHECKSUM	DVL CHECKSUM OF PD4 MESSAGE	NA	U16

From DVL to INS, variable rate, max 5 Hz

3.6.2.1 Test Message:

The PD4 message in its entirety is output on the RS-422 serial interface each time it is received from the DVL as a test message output with ID 21.

3.7 INS Mission Computer Serial Data Interface

The mission computer interface to the INS of the DVL INS system utilizes an RS-422 serial digital port. Navigation output data messages and user control input data messages are transmitted/received by the INS on this interface. The message protocol structure is described in Figure 12. Figure 13 shows the transmission sequence for the bits associated with each byte of information in Figure 12. The protocol utilized is an asynchronous UART. The list of all messages supported is provided in Table 5.

The RS-422 data communication interface consists of two unidirectional data channels (i.e. full duplex bi-directional). One channel is from INS to the host vehicle and the other channel is from the host vehicle to the DVL INS. The data transmission format is serial by bit in accordance with the general requirements of EIA standard RS-232-C asynchronous protocol. Data is transmitted and received in 11 bit packets (Figure 13) consisting of a start bit, 8 bits of data, a parity bit, and a stop bit. The start bit is a logic 0, the data bits are received/transmitted with the lsb first, the parity bit following the msb creates odd parity, and the stop bit is a logic 1. The bus idle state is logic 1.

F	ID	N	D1	D2	---	DN	CH

NOTE: F : MESSAGE START, AA Hex

ID : MESSAGE ID CODE, (0-255)

N : DATA BYTE COUNT (0-255)

D1 ------- DN : DATA, 8 bits X N; 16 bit and 32 bit data are transmitted Least Significant Byte first.

CH: CHECKSUM, 8 bits, each = xor of corresponding bit in all other message bytes including N, ID but excluding F

Messages are classified by TYPE as follows:

OPIN : Operational message input, ID even, < 16
OPOUT : Operational message output, ID odd, < 16
TSTIN : Test message input, ID even, $\geq$ 16
TSTOUT: Test message output, ID odd, > 16

BIT RATE (BAUD) = 115.2kb/s nominal (configurable via an EEPROM constant for rates from 9.6 Kb/s to 2 Mb/s)

Figure 12: RS-422 Message Format

IDLE	START BIT	LSB B0	B1	B2	B3	B4	B5	B6	MSB B7	ODD PARITY	STOP BIT	IDLE

Figure 13: RS-422 Byte Bit Sequence

3.8 INS Messages

Table 5 identifies the INS messages that are Operational input (OPIN) messages or Operational output (OPOUT) messages or Test Output (TSTOUT) messages by Identification (ID) number at the indicated rate. ID 27 indicates TSTOUT messages multiplexed at a 50Hz base rate with a sub ID code (SID) in data bytes 3-4. TSTOUT messages are output by the DVL INS as a result of enabling via message ID 2, byte D7, bit 5 stored in EEPROM. The ID 19 (100 Hz RAW data spooling) message is output by the DVL INS as a result of enabling via message ID 2, byte D7, bit 4 stored in EEPROM. Power cycling is required before a change in these bits, via configuration input message ID 2, is activated.

3.8.1 Mission Computer to INS

Detailed descriptions of messages that transfer data from the mission computer to the INS and data are found in Table 14 and Table 15. These messages are:

1. ACCEPT CONFIGURATION
2. ACCEPT OPERATIONAL
3. ACCEPT VELOCITY LOG DATA

There is one message that requests transfer of data from the INS to the mission computer. A detailed description of this message is found in paragraph 4.1.3. The message is:

1. RETURN CONFIGURATION DATA

3.8.2 INS to Mission Computer

There are eleven messages that transfer data from the INS to the mission computer. Detailed descriptions of these messages are found in paragraph 4.24.2. The messages are:

1. NAVIGATION DATA
2. CONFIGURATION DATA
3. HIGH SPEED IMU DATA
4. DOPPLER PD4
5. GPS PVT DATA A (from DoD GPS RS-422 interface)
6. GPS PVT DATA B from DoD GPS RS-422 interface)
7 GPS GGA (from commercial GPS [NMEA 183] interface)
8 GPS GSA (from commercial GPS [NMEA 183] interface)
8. GPS VTG (from commercial GPS [NMEA 183] interface)
9. INPUT MESSAGE ECHO

In addition INS “Slow Test Messages” and “100 Hz IMU data” may be output to the mission computer. They are not considered standard INS messages but are for Kearfott internal use and may be changed at any time at Kearfott’s discretion. These messages are described in detail in paragraph 5.2.

3.8.3 Navigation Output Data Latency

The processing latency of the data in the output navigation data message is measured from the data sample interrupt (time of validity of the data) to the start of transmission of the navigation data message on the interface bus. This processing latency has a nominal value of 4.6 milliseconds with a total range of 4.1 to 7.0 milliseconds.

The total latency of the navigation data message is the processing latency plus the time of transmission of the message on the interface bus. The time of transmission is dependent on the baud rate and the size of the message. For a baud rate of 115.2 kb/s and a navigation data message of 50 bytes, 11 bits per byte, the transmission time would be 4.8 milliseconds. This would put the total latency in the range from 8.9 to 11.8 milliseconds with a nominal value of 9.4 milliseconds.

Table 5: INS RS-422 Message List

Message ID	SID	Message Name	Data byte count (N)	Rate
Input				
2		Accept Configuration	33	AR
4		Accept Operational	21	AR
6		Return Configuration	0	AR
8		Accept Velocity Log	3	1 Hz
Output				
1		Navigation Data	46	Variable[+]
3		Configuration Data	33	AR
27		Slow Test Messages	64	50 Hz max
27	1	IMU Raw Sums	52	1 Hz
27	2	IMU Compensated Sums	52	1 Hz
27	3	IMU Control Loop 1	60	1 Hz
27	4	IMU Control Loop 2	60	1 Hz
27	5	NAV Calibration	60	1 Hz
27	6	System Status	33	1 Hz
27	7	Kalman States A	52	0.5 Hz
27	8	Kalman States B	52	0.5 Hz
27	16	Kalman States C	60	0.5 Hz
27	9	Kalman Covariance A	52	0.5 Hz
27	10	Kalman Covariance B	52	0.5 Hz
27	18	Kalman Covariance C	60	0.5 Hz
27	17	Observation Status	42	0.5 Hz
27	11	ZUPT Residuals*	52	0.5 Hz
27	12	GPS Velocity Residuals*	52	0.5 Hz
27	13	GPS Position Residuals*	52	0.5 Hz
27	14	DVL Velocity Residuals*	52	0.5 Hz
27	15	Position Fix Residuals*	52	0.5 Hz
19		High Speed IMU Data	30	100 Hz
21		Doppler PD4**	49	Variable As Input[++]
13		GPS PVT Data A***	62	Variable As Input[++]
15		GPS PVT Data B***	62	Variable As Input[++]
7		GPS GGA	Variable As Input	Variable As Input[++]
9		GPS GSA	Variable As Input	Variable As Input[++]
11		GPS VTG	Variable As Input	Variable As Input[++]
ECHO		Message Echo** (message ID's 2, 4, 6, 8)	Variable As Input	50 Hz max

Table 5: INS RS-422 Message List (Continued)

Notes:

+ The data rate is configurable via constant in EEPROM. Inherent DVL INS capability is 50 Hz max.

++ Wraparound of input data (Nominal rates are 5 Hz for Doppler and 1 Hz for GPS data).

* Slow Test Messages (ID 27 SID's 11-15) output only one (or none) SID per 0.5Hz, according to the type of reference being processed by the Kalman filter. Each message is transmitted with a fixed length, 64 bytes, with the unused bytes transmitted as “Spares”.

** Messages 21 and ECHO (uses same ID as input message being echoed) are output at variable rates as/per data received. Echo messages 13 and 15 (GPS PVT) are output only if GPS messages are received via the GPS RS-422 interface. Echo messages 31 - 35 (GPS GGA and GPS VTG) are output only if GPS messages are received via the commercial GPS NMEA RS-422 interface.

. *** PVT - Position/Velocity/Time data message, includes GPS (1Hz) geodetic position and velocity solutions, and associated status and quality indicators.

3.9 GPS Receiver Messages

Data is transferred between the INS and GPS subsystem via a digital (two-state) RS-232 interface. Data is formatted as binary coded digital data (command and messages) and pulse trains (serial data bus clocks). The embedded GPS receiver messages are in accordance with section 3.9.6.

3.9.1 Acceptance of GPS Data by the INS

The INS is mechanized to use GPS data, when available, regardless of operational mode. The INS system position is initialized to the GPS position (unless the operator initializes the position), so that the returned system position should echo that of the GPS. GPS position data is utilized once a minute as an observation to the Kalman filter. In between, GPS velocity data is utilized. The Kalman only incorporates as much of the observation as is required for the optimal solution; thus the system will not slave to the exact GPS position

The only reasons the INS would not use the GPS data are:

GPS aiding flag not set
There is no GPS data and/or Time Mark Pulse or 1 pulse/second
The figure of merit is above 5
The GPS is out of State 5 (no 3-d solution), or
The system velocities and/or position diverge drastically with those of the GPS.

3.9.2 Interface

The data interconnect between the INS and GPS subsystem is via balanced differential voltage circuits in accordance with RS-232. All line drivers comply with the generator electrical characteristics specified in RS-232. The DVL INS is not damaged or malfunction when signal circuits are connected or disconnected with power on or off.

3.9.3 Logic Levels

A binary logic "1" or "set" condition is represented by a positive voltage on the "Hi" line with respect to the "LO" line. A logic "0" or "reset" condition is represented by a positive voltage on the "LO" line with respect to the "Hi" line.

3.9.4 Data Bus Characteristics

All commands and messages are transferred between the GPS subsystem and INS via the data bus.

3.9.5 Data encoding

All serial bus data are encoded in the Non-Return-to-Zero (NRZ) format.

3.9.6 DoD GPS Receiver Characteristics

The DoD GPS GPS system performs an unprompted transmit of the Time Mark Data Message (Table 6) at a 1 (one) Hz rate synchronized to the Time Mark Pulse.

3.9.6.1 Message Characteristics

Messages between the INS and the DoD GPS have the following characteristics:

a. The INS is a passive listener.

b. Messages are constructed on 8 bit bytes.

c. The data fields are constructed from a variable number of characters, from a minimum of zero to a maximum of N. All other fields are of fixed character length.

3.9.6.2 Data Rate

A data rate of 9,600 b/s to 2 Mb/s is supported. The nominal data rate is 9,600 b/s.

3.9.6.3 Time Mark Data Message

Table 6 shows the structure of the DoD GPS Time Mark Message. This data must be synchronized to the 1 Hz (Time Mark Pulse [TMP] or 1PPS [Pulse Per Second]) hardware Pulse coming out of the DoD GPS in order for the INS to accept the data contained in the message. The DoD GPS receiver must be setup to send out the 1 Hz Time Mark Pulse.

3.9.6.4 Buffer Box Status Request

Header only message. DVL INS responds to this command as required to the PLGR receiver at a 1/6 Hz Rate.

3.9.6.5 Connect Command

This message is issued (once at start-up and as required) to instruct the PLGR receiver to continuously transmit the Time Mark Data Message (see Table 6) at a 1 (one) Hz rate synchronous to the Time Mark Pulse.

Table 6: DoD GPS Time Mark Data Message

Item No.	Data Item	Word No.	Data Type	No. Bits	LSB Loc.	LSB Value	Units
1	GPS Time	1-4	Dpfp	64	0	1	s
2	UTC Time	5-8	Dpfp	64	0	1	s
3	Delta T	9	N/A	16	N/A	N/A	always zero
4	Time Mark Counter	10	Uspi	16	0	1	N/A
5	Latitude	11-12	DEC-spfp	32	0	1	radians
5	Longitude	13-14	DEC-spfp	32	0	1	radians
6	ECEF Position X	15-16	DEC-spfp	32	0	1	m
6	ECEF Position Y	17-18	DEC spfp	32	0	1	m
6	ECEF Position Z	19-20	DEC-spfp	32	0	1	m
7	Altitude, MSL	21-22	DEC-spfp	32	0	1	m
8	Altitude, Absolute	23-24	DEC-spfp	32	0	1	m
9	Velocity, East	25-26	DEC-spfp	32	0	1	m/s
9	Velocity, North	27-28	DEC-spfp	32	0	1	m/s
9	Velocity, Up	29-30	DEC-spfp	32	0	1	m/s
10	Acceleration, East	31-32	DEC-spfp	32	0	1	m/s/s
10	Acceleration, North	33-34	DEC-spfp	32	0	1	m/s/s
10	Acceleration, Up	35-36	DEC-spfp	32	0	1	m/s/s
11	Attitude Pitch	37-38	DEC-spfp	32	0	1	radians
11	Attitude, Roll	39-40	DEC-spfp	32	0	1	radians
11	True Heading	41-42	DEC-spfp	32	0	1	radians
12	Magnetic Variation	43-44	DEC-spfp	32	0	1	radians
13	Channel 1 Status A	45	uspi	16	0	1	N/A
13	Channel 1 Status B	46	uspi	16	0	1	N/A
13	Channel 2 Status A	47	uspi	16	0	1	N/A
13	Channel 2 Status B	48	uspi	16	0	1	N/A
13	Channel 3 Status A	49	uspi	16	0	1	N/A
13	Channel 3 Status B	50	uspi	16	0	1	N/A
13	Channel 4 Status A	51	uspi	16	0	1	N/A
13	Channel 4 Status B	52	uspi	16	0	1	N/A
13	Channel 5 Status A	53	uspi	16	0	1	N/A
13	Channel 5 Status B	54	uspi	16	0	1	N/A
14	Figure of Merit	55	uspi	16	0	1	N/A
15	Expected Horz Error	56	uspi	16	0	1	m
15	Expected Vert Error	57	uspi	16	0	1	m
16	Equipment available	58	disc	16	0	1	N/A
17	Equipment Used	59	disc	16	0	1	N/A
18	Time Figure of Merit	60-61	NBCD	16	0	1	N/A

3.9.6.6 Time Mark Message Data Definition
The following are explanations of the data items in Table 6.

3.9.6.6.1 GPS TIME
GPS system time in seconds of week starting at Saturday 2400 hours/Sunday 0000 hours.

3.9.6.6.2 UTC TIME
Universal Time Coordinated (seconds of day).

3.9.6.6.3 DELTA T
Always set to zero.

3.9.6.6.4 TIME MARK COUNTER
This word is structured as follows:
Bits 0-2 contain the counter value, which is between 0 and 5.
Bits 3-15 are spare.

3.9.6.6.5 LATITUDE/LONGITUDE
These words contain the GPS subsystem present position output in latitude/longitude coordinates

3.9.6.6.6 ECEF POSITION X, Y, and Z
These words contain the GPS subsystem present position output in ECEF coordinates.

3.9.6.6.7 ALTITUDE, MSL
These words contain the GPS subsystem present position altitude referenced to MSL.

3.9.6.6.8 ALTITUDE, ABSOLUTE
These words contain the GPS subsystem absolute present position altitude.

3.9.6.6.9 VELOCITY EAST, NORTH, UP
These words contain the GPS subsystem present velocity.

3.9.6.6.10 ACCELERATION EAST, NORTH, UP
These words contain the GPS subsystem present acceleration.

3.9.6.6.11 ATTITUDE PITCH and ROLL; TRUE HEADING
These words contain the GPS subsystem present attitude.

3.9.6.6.12 MAGNETIC VARIATION
These words contain the magnetic variation of the GPS subsystem's present position.

3.9.6.6.13 CHANNEL 1, 2, 3, 4, and 5 STATUS A and B
These words are structured as shown in Table 7 and Table 8.

Table 7: Channel Status A Word

DATA	BIT	DATA TYPE	DEFINITION
Satellite Number	0-4	uspi	Range 0-32
Channel Number	5-7	uspi	
Encryption Type	8	N/A	0=Pcode, 1=Ycode
Channel State	9-11	uspi	Range 1-7
Code Type	12	disc	0=P, 1=C/A
Frequency	13	disc	0=L1, 1=L2
Antenna	14	disc	0=Top, 1=Bottom (never set)
Fault	15	disc	0=No, 1=Yes

Table 8: Channel Status B Word

DATA	BIT	DATA TYPE	DEFINITION
J/S	0-7	uspi	decibels* Hz
C/No	8-15	uspi	decibels* Hz

3.9.6.6.14 FIGURE OF MERIT

This word is structured as shown in Table 9.

Table 9: Figure of Merit Word

DATA	BIT	DATA TYPE	DEFINITION
FOM	0-3	uspi	Range 1-9
ICD-203 Erase Fault	4	disc	1=ICD-203 Erase Fault
FMI	6	N/A	not used
CDU1 or CDU2 Failure	7	disc	not used
AE LRU Failure	8	disc	not used
RPU Failure	9	disc	1=RPU Failure
NAV Data Not Valid	10	disc	1=Nav Data Not Valid
NAV Degraded Due to ICD-203	11	disc	1=Nav Degraded
NAV Data About to go Bad due to ICD-203	12	disc	1=Nav Data About to go Bad
less than 4 measurements incorporated	13	disc	1=<4 measurements incorporated
State 3 Operation	14	disc	1=State 3 Operation
State 5 Operation	16	disc	1=State 5 Operation

3.9.6.6.15 EXPECTED HORIZONTAL and VERTICAL ERRORS

These words are structured as follows:

Bits 0-14 contain the error in meters.
Bit 15 is a spare.

3.9.6.6.16 EQUIPMENT AVAILABLE

Not used.

3.9.6.6.17 EQUIPMENT USED

This word is structured as shown in Table 10.

Table 10: Equipment Used Word

DATA	BIT	DATA TYPE	DEFINITION
Reserved	0-7	disc	N/A
UTC Data Available	8	disc	0=Not Available, 1=UTC Data Available
Mag Var Being Computed	9	disc	0=Supplied, 1= Mag Var Being Computed
MSL Computer	10	disc	0=Supplied, 1=MSL Computed
Spare	11-15	N/A	N/A

3.9.6.6.18 TIME FIGURE OF MERIT

These words are structured as shown in Table 11.

Table 11: Time Figure of Merit

DATA	BIT	DATA TYPE	DEFINITION
Word 60			
Year	0-7	NBCD	
Spare	8-11	N/A	
Time FOM	12-15	un	Valid Range=1-9
Word 61			
Spare	0-3	N/A	
Day of Year	4-15	NBCD	Valid Range-1-366

3.9.7 GPS (NMEA 183) Receiver Characteristics

3.9.7.1 Data Rate

The nominal data rate is 9.6 kb/s. A data rate of 9.6 kb/s to 2 Mb/s may be supported.

3.9.7.2 NMEA-183 Data Messages

Table 12 shows the structure of the NMEA-183 format data messages processed by the DVL INS. This data must be synchronized to the 1 Hz (1PPS - Pulse Per Second) out of the GPS receiver for the INS to accept the data contained in the message. The GPS receiver must be setup to send out this 1PPS Pulse.

Table 12: NMEA 183 Messages to the DVL INS

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: GGA				
UTC	CHAR	HR-MIN-SEC	1	
LATITUDE	CHAR	DEG-MIN	2	
LATITUDE DIRECTION	CHAR	NA	3	N= + , S = -
LONGITUDE	CHAR	DEG-MIN	4	
LONGITUDE DIRECTION	CHAR	NA	5	E = +, W = -
GPS QUALITY 0=INVALID 1=SPS MODE 2=DGPS MODE 3=PPS MODE	CHAR	NA	6	
NUMBER OF SAT'S	CHAR	NA	7	00-12
HDOP	CHAR	NA	8	NOT USED
ALTITUDE (Mean Sea Level)	CHAR	METERS	9	
ALTITUDE UNITS	CHAR	NA	10	NOT USED
GEOID SEPARATION	CHAR	NA	11	NOT USED
GEOID SEPARATION UNITS	CHAR	NA	12	NOT USED
DATA AGE	CHAR	NA	13	NOT USED
STATION ID	CHAR	NA	14	NOT USED

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: GSA				
MANUAL/AUTO MODE	CHAR	NA	1	NOT USED
FIX MODE 2D/3D 1=NO FIX 2=2D FIX 3=3D FIX	CHAR	NA	2	
SATELLITE ID'S	CHAR(12 or 14)	NA	3-14 or 3-16	
PDOP	CHAR	NA	15 or 17	NOT USED
EXPECTED HORIZ. DOP	CHAR	NA	16 or 18	
EXPECTED VERT. DOP	CHAR	NA	17 or 19	

Table 12: NMEA 183 Messages to the DVL INS (Continued)

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: VTG				
TRUE COURSE	CHAR	DEG		
TRUE COURSE UNITS	CHAR	NA	2	NOT USED
MAGNETIC COURSE	CHAR	DEG	3	NOT USED
MAGNETIC COURSE UNITS	CHAR	NA	4	NOT USED
SPEED N	CHAR	KTS	5	
SPEED N UNITS	CHAR	NA	6	NOT USED
SPEED K	CHAR	KM/HR	7	
SPEED K UNITS	CHAR	NA	8	NOT USED

1. NMEA DATA IS IN ASCII CHARACTER FORMAT.
2. THE NMEA MESSAGE IS PRECEDED BY AN ASCII DOLLAR SIGN ($), FOLLOWED BY A 5 ASCII CHARACTER MESSAGE HEADER.
3. NMEA FIELDS ARE SEPARATED BY COMMAS (,).
4. AFTER THE LAST FIELD THERE IS AN ASTERISK (*), FOLLOWED BY A TWO (2) CHARACTER CHECKSUM, FOLLOWED BY AN ASCII CARRIAGE RETURN AND LINE FEED (<CR><LF>).

3.9.7.3 Embedded DGPS receiver Configuration Requirements

To perform the operational mission and communicate with the INS, the INS and embedded DGPS receiver are pre-set prior to shipment. The INS does not dynamically configure the embedded DGPS receiver during operation.

The user must connect the 1PPS signal and the port B DGPS receiver output to the INS RS-232 input (J3 Figure 11). The interface protocol must be maintained at the default value (9.6k baud) in order for the INS to communicate with the embedded DGPS receiver.

The embedded DGPS receiver and INS are pre-set before delivery of the integrated system. The user is able to communicate with the embedded DGPS receiver (see the Thales Navigation DG16 and DG14 OEM Receiver Reference Manual) utilizing port A (Section 3.5.2.4) and modify the receiver configuration.

Parameters that are used for communication with the INS are included in Table 13. Included are parameters to enable the NMEA messages, enable use of "multi bases" for DGPS corrections, and the command for the receiver to retain the parameters after power is cycled. Normal operation is for the DGPS receiver to receive the DGPS correction information in RF format.

Table 13: Embedded DGPS Configuration Parameters

$PASHS,NME,GGA,B,ON	Enable transmission of the NMEA GGA message on Port B
$PASHS,NME,GSA,B,ON	Enable transmission of the NMEA GSA message on Port B
$PASHS,NME,VTG,B,ON	Enable transmission of the NMEA VTG message on Port B
$PASHS,RTC,SLC,WGH	Use multi bases for corrections – Normal operation
$PASHS,SAV,Y	Save user-entered parameters in battery-backed memory
$PASHQ,PAR	Suggested for verification of parameters

3.10 Velocity Log input message

Velocity Log data may also be transmitted utilizing the INS Mission Computer Serial Data Interface (Sections 3.7 and 4.1.4). The format of the message is:

DATA BYTE#	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1, D2	LOGVEL	VELOCITY	0.01 KNOTS	S16
D3	LOGSTAT	VELOCITY LOG STATUS*	NA	U8

* Bit 0: 0 = invalid data
1 = valid data

The data may be utilized in the DVL INS in place of EM Log data on a dedicated data bus capability available in the SEANAV system. Applications where the DVL and GPS aiding data is not available for a significant period of time can utilize this message as velocity aiding information to the inertial system. The capability of providing lever arms to both the DVL and the Velocity Log sensor is not available. It is recommended that DVL lever arm (being of higher quality velocity data) be entered in the DVL INS and the Velocity Log aid be used in conditions of low vehicle dynamics.

4. DATA MESSAGES BETWEEN THE MISSION COMPUTER AND DVL INS

4.1 Data Messages from the Mission Computer to the INS

4.1.1 ACCEPT CONFIGURATION DATA

This command provides the INS the Configuration Data selected by the system user as a function of an installation/vehicle type. Upon receipt of this message, the INS saves the configuration data in EEPROM, which will be utilized at subsequent power-on initializations.

TYPE: OPIN ID: 2

RATE: APERIODIC, POWER CYCLE REQUIRED TO UTILIZE UPDATES

Table 14: Accept Configuration Data Message

DATA BYTE#	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1,D2	VALPHA	ROLL BORESIGHT ANGLE, INS TO VEHICLE (-180° to +180°)	$180°*2^{-15}$	S16
D3,D4	VBETA	PITCH BORESIGHT ANGLE, INS TO VEHICLE (-90° to +90°)	$180°*2^{-15}$	S16
D5,D6	VGAMMA	AZIMUTH BORESIGHT ANGLE, INS TO VEHICLE (-180° to +180°)	$180°*2^{-15}$	S16
D7	DISCRETES		N/A	BINARY
	SURFACE	BIT 7 SURFACE SHIP CONFIGURATION		
	SPARE	BIT 6 RESERVED		
	TSTMSGSEN	BIT 5 SLOW TEST MESSAGE ENABLE		
	TSTMSGFEN	BIT 4 FAST TEST MESSAGE ENABLE		
	DOPCAL	BIT 3 DOPPLER OR EM-LOG CALIBRATION RUN		
	SPARE	BIT 2		
	SPARE	BIT 1		
D8	SATIME	STATIONARY ALIGN TIME (DOCK SIDE)	MIN	U8
D9,D10	VDELX	VEHICLE-INS LONGITUDINAL OFFSET	CM	S16
D11,D12	VDELY	VEHICLE-INS CROSS OFFSET	CM	S16
D13,D14	VDELZ	VEHICLE-INS VERTICAL OFFSET	CM	S16
D15,D16	GPSLX	X-AXIS OFFSET FROM INS TO GPS	CM	S16
D17,D18	GPSLY	Y-AXIS OFFSET FROM INS TO GPS	CM	S16
D19,D20	GPSLZ	Z-AXIS OFFSET FROM INS TO GPS	CM	S16
D21,D22	DOPLX	INS-DOPPLER X-AXIS OFFSET (-1)	CM	S16
D23,D24	DOPLY	INS-DOPPLER Y-AXIS OFFSET (+4)	CM	S16
D25,D26	DOPLZ	INS-DOPPLER Z AXIS OFFSET (-18)	CM	S16
D27,D28	EMLAZIM	AZIMUTH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)	$180°*2^{-15}$	S16
D29,D30	EMLPITCH	PITCH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-90° to +90°)	$180°*2^{-15}$	S16
D31,D32	EMLROLL	ROLL BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)	$180°*2^{-15}$	S16
D33	LSATIME	STATIONARY ALIGN TIME (LAND)	MIN	U8

* Fixed by the Integrated DVL INS mechanical configuration (X = - 1 CM, Y = + 4 CM, Z = - 18 CM).

NOTES:

DVL INS to vehicle boresights (VALPHA, VBETA, and VGAMMA) are measured about the DVL INS case axes (see Figure 6).

The SURFACE discrete causes the INS to drive the depth loop to zero (i.e. reference depth is fixed at zero and input depth is not required for surface ships).

Setting TSTMSGSEN causes the INS to output at 1Hz the full set of multiplexed slow test messages identified by ID 27, listed above, and the GPS PVT messages identified by ID's 13 and 15.

Setting TSTMSGFEN causes the DVL INS to output at 100Hz the single fast test message identified by ID 19 and at max. of 50 Hz identified by ID 21.

The DOPCAL discrete configures the Kalman filter to use large initial covariances for the doppler error states in order to calibrate them. This capability is not required for the DVL INS but is retained for compatability. For systems with DVL that is remote to the INS, this should be performed during integration of a new vehicle, with an aided navigation test run including a boxcar maneuver.

The SATIME defines the fixed dock side stationary align time before aided navigation mode is entered.

The vehicle offset (VDELX, VDELY, VDELZ) defines an external position reference point wrt the SEANAV for manual input and output position. This feature is not currently implemented for this prupose. It is used to determine depth in the Surface Ship configuration.

The origin of the GPS lever arms (GPSLX, GPSLY, and GPSLZ) is the DVL INS (i.e., positive as measured from the DVL INS to the GPS along vehicle axes – see Figure 4.)

EMLAZIM, EMLPITCH, and EMLROLL are vehicle Euler angles with respect to the vehicle's (Velocity Log) coordinate frame. The order of rotations (important for Euler angles) is azimuth followed by pitch followed by roll (which is normally not used [input as "0"]).

The LSATIME defines the fixed land stationary align time before aided navigation mode is entered.

4.1.2 ACCEPT OPERATIONAL DATA

This message directs the INS to accept mode commands and/or geodetic position and/or depth data from the Mission Computer.

TYPE: OPIN ID: 4

RATE: NOMINAL 1 TO 5 HZ FOR PRESSURE DEPTH INPUT, MAX PROCESSING RATE = 100 HZ; OTHER DATA APERIODIC AS REQUIRED

Table 15: Accept Operation Data Message

DATA BYTE #	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1 Bits 7-4 Bits 3-0	VALIDITY CONTROL	INPUT DATA VALIDITY (1 = VALID) AND CONTROL LOGICALS – NOTE 1	NA	BINARY DISCRETE
D2	MODES	MODE CONTROL LOGICALS – NOTE 2	NA	BINARY DISCRETE
D3-D6	INIT LAT	INPUT LATITUDE (-90° to +90°)	$180° * 2^{-31}$	S32
D7-D10	INIT LON	INPUT LONGITUDE (-180° to +180°)	$180° * 2^{-31}$	S32
D11-D14	IDEPTH	INPUT PRESSURE DEPTH (NEGATIVE DENOTES ALTITUDE DATA)	0.01M	S32
D15,D16	INITHDG	INPUT HEADING (-180° to +180°)	$180° * 2^{-15}$	S16
D17,D18	SALINITY	INPUT WATER SALINITY	0.01 PPT	U16
D19,D20	CEPOS	INPUT POSITION QUALITY*	0.01m CEP	U16
D21	FORCOMM	SPECIAL COMMANDS**	NA	BINARY DISCRETE
		BIT # Definition		
		0 Forced Position Fix***		
		1-2 **** DVL Water Track and/or Bottom Track Mode Command		
	LANDFLAG	3 Land/Dock Side Align Switch (1=Land)		

Note1 : D1 definition

VALIDITY	INPUT DATA VALIDITY LOGICALS (1 = VALID)
	BIT # DEFINITION
VPOS	7 LAT/LON VALID
VDPTH	6 PRESSURE DEPTH VALID
VHDG	5 HEADING VALID
VSALIN	4 SALINITY VALID
	3, 2 SPARES
	CONTROL LOGICALS
AHRS	1 ALIGN WITHOUT POSITION (ATTITUDE HEADING REFERENCE SYSTEM) THE INS DETERMINES ATTITUDE AND HEADING BUT DOES NOT PROVIDE VALID POSITION – RECEIPT OF POSITON (BIT 7 LAT/LON VALID OR GPS) INITATES COARSE ALIGNMENT MODE OPERATION
VERTDAMP	0 GPS/PRESSURE DEPTH DAMPING OF VERTICAL CHANNEL (1=GPS, 0=PRESSURE DEPTH)

Note 2 : D2 definition

MODES	MODE CONTROL LOGICALS	
	BIT #	DEFINITION
STALIGNC	7	STATIONARY ALIGNMENT COMMAND
RESTART	6	ALIGNMENT RESTART COMMAND
ZUPENAB	5	ZUPT ENABLE FLAG***
ZUPCOM	4	COMMAND ZUPT
GPSENAB	3	GPS AIDING ENABLE FLAG***
DOPENAB	2	DOPPLER AIDING ENABLE FLAG***
SHTDNCOM	1	SHUTDOWN COMMAND
DOPPING	0	DOPPLER PING COMMAND****

NOTES:

In STATIONARY ALIGNMENT, only zero velocity updates are used (although position is accepted to initialize the alignment).

In a moving align and aided navigation all of the above listed references can be accepted if enabled.

Setting ALIGNMENT RESTART causes the INS to abort the current Align/NAV mode operation and re-enter IDLE mode, allowing an alignment to restart upon availability of initialization data (either manual or GPS).

Setting ZUPENAB false precludes the INS from performing an automatic ZUPT.

Setting ZUPTCOM forces a zero reference velocity to be processed (i.e. vehicle resting on bottom); ZUPENAB is required to be set true.

Setting GPSENAB is required for the INS to perform a GPS aided moving-base alignment.

Setting DOPENAB is required to perform DVL or EM Log or Velocity aided navigation.

Setting SHTDNCOM causes the INS to store in EEPROM the current Kalman filter estimates of INS to DVL calibrated parameters, and then to power down.

Setting DOPPING causes the INS to initialize the DVL to initiate PINGing. Resetting causes the INS to stop the DVL from PINGing.

INPUT LATITUDE and LONGITUDE is used for initialization (when GPS position is not available) or in manual position update (valid must be set "1" in message)

INPUT PRESSURE DEPTH is used (valid must be set "1" in message) for underwater applications. GPS altitude or "Surface Ship" (Configuration Message forces depth to zero) can be used in place of pressure Depth. See Note 1 above (VERTDAMP).

INPUT HEADING is optional and is used only at initialization (valid must be set "1" in message) allowing the INS to enter "fine align" sub-mode directly (i.e. coarse align not performed). This data is not required.

If INPUT POSITION QUALITY (CEPOS, CEP, 50 %) is 0.0 will default (valid must be set "1') to the value defined by EEPROM variable RPOSF (Variance).

**These commands are configured to force the acceptance (i.e. over-ride the programmed rejection) of these inputs. Bit settings have the following meaning with regard to special commands:
0 = no , 1 = yes (enable special command)

*** This Forced Position Fix command over rides the Kalman Filter observation rejection logic and forces processing of VALID (D1 Note 1 Bit 7) INPUT LAT and INPUT LON as observations to the Kalman filter. This may be used when the INS Kalman filter is rejecting data that the mission computer determines to be valid.

**** This DVL water and/or bottom-track two-bit mode command (FORCOMM, bits 1-2) is defined as follows:
- 00: Water-mass layer pings disabled. Bottom track pings only (bottom-track mode).
- 01: A water-mass layer ping is transmitted following each bottom-track ping (water-track/bottom-track mode).
- 10: A water-mass layer ping is send after every bottom-track ping that did not find the bottom (Autonomous mode).
- 11: Disables bottom-track ping and enables the water-track ping (water-track mode).

4.1.3 RETURN CONFIGURATION DATA

This command (no data, i.e. N = 0) requests configuration data currently used by the INS. The INS response to this request is a single transmission of a CONFIGURATION DATA message of Table 18.

TYPE: OPIN ID: 6

RATE: APERIODIC AS REQUIRED

4.1.4 ACCEPT VELOCITY LOG DATA

This message sends Velocity Log data to the DVL INS system via the primary serial interface.

TYPE: OPIN

ID: 8

RATE: NOMINAL 1 Hz

Velocity Log Data Format

DATA BYTE#	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1, D2	LOGVEL	VELOCITY	0.01 KNOTS	S16
D3	LOGSTAT	VELOCITY LOG STATUS*	NA	U8

* Bit 0: 0 = invalid data
1 = valid data

4.2 Data Messages from INS to the Mission Computer

4.2.1 Message: NAVIGATION DATA

TYPE: OPOUT ID: 1

Table 16: Navigation Data Message

DATA BYTE #	DATA MNEMONIC	DESCRIPTION	UNITS	OUTPUT FORMAT
D1,D2	CYCLES	50HZ FREE RUNNING CYCLE COUNTER	NA	U16
D3	MODE	SYSTEM MODE	NA	CODED HEXIDECIMAL
D4	MONITOR	NAVIGATION MONITOR	NA	BINARY DISCRETES
D5-D8	LAT	SYSTEM LATITUDE (-90° to +90°)	$180°*2^{-31}$	
D9-D12	LON	SYSTEM LONGITUDE (-180° to +180°)	$180°*2^{-31}$	
D13-D16	DEPTH	SYSTEM (INERTIAL) DEPTH (NEGATIVE DENOTES ALTITUDE) (MSL)	0.1M	S32
D17,D18	BHEIGHT	HEIGHT ABOVE BOTTOM (FROM DVL) (D4 BIT 0 INDICATES VALID DATA	0.01M	U16
D19,D20	ROLL	VEHICLE ROLL ANGLE (-180° to +180°)	$180°*2^{-15}$	S16
D21,D22	PITCH	VEHICLE PITCH ANGLE (-90° to +90°)	$180°*2^{-15}$	S16
D23,D24	HEADING	VEHICLE TRUE HEADING (0° to +360°)	$180°*2^{-15}$	U16
D25,D26	VN * or VBODYx	NORTH VELOCITY (OR VEHICLE X) (-32 M/S TO +32 M/S – LSB)	2^{-10}M/S	S16
D27,D28	VE * or VBODYy	EAST VELOCITY (OR VEHICLE Y) (-32 M/S TO +32 M/S – LSB)	2^{-10}M/S	S16
D29,D30	VDOWN * or VBODYz	DOWN VELOCITY (OR VEHICLE Z) (-32 M/S TO +32 M/S – LSB)	2^{-10}M/S	S16
D31,D32	ACCELX	VEHICLE X ACCELERATION (-32M/S^2 to 32M/S^2-LSB)	2^{-10}M/S^2	S16
D33,D34	ACCELY	VEHICLE Y ACCELERATION (-32M/S^2 to 32M/S^2-LSB)	2^{-10}M/S^2	S16
D35,D36	ACCELZ	VEHICLE Z ACCELERATION (-32M/S^2 to 32M/S^2-LSB)	2^{-10}M/S^2	S16
D37,D38	PRATE	VEHICLE X AXIS ANGULAR RATE (-4 R/S TO +4 R/S – LSB)	2^{-13} RADIANS/S	S16
D39,D40	QRATE	VEHICLE Y AXIS ANGULAR RATE (-4 R/S TO +4 R/S – LSB)	2^{-13} RADIANS/S	S16
D41,D42	RRATE	VEHICLE Z AXIS ANGULAR RATE (-4 R/S TO +4 R/S – LSB)	2^{-13} RADIANS/S	S16
D43-D46	UTC TIME	MESSAGE VALID TIME IN GPS UTC UNITS	2^{-14} SEC	U32

* NOTE: Coordinate frame is selected via EEPROM parameter.

Note: D3 - MODE – SYSTEM MODE - CODED HEXIDECIMAL definition

D3	MODE	SYSTEM MODE	NA	CODED HEXIDECIMAL
	00H =	IDLE		
	01H =	COARSE STATIONARY ALIGN		
	02H =	FINE STATIONARY ALIGN - NOT COMPLETE		
	03H =	FINE STATIONARY ALIGN - COMPLETE		
	04H =	COARSE GPS ALIGN		
	05H =	FINE GPS ALIGN - NOT COMPLETE		
	06H =	FINE GPS ALIGN - COMPLETE		
	07H =	DOPPLER ALIGN - NOT COMPLETE		
	08H =	DOPPLER ALIGN - COMPLETE		
	09H =	AIDED NAVIGATION		
	0AH =	NO/GO (SYSTEM FAILURE)		

Note: D4 –MONITOR – NAVIGATION MONITOR - BINARY DISCRETES definition

D4	MONITOR	NAVIGATION MONITOR	NA	BINARY DISCRETES
		BIT # DEFINITION		
		7 DEPTH LOOP OPEN > 1 MINUTE		
		6 GPS DATA PROCESSED		
		5 GPS DATA REJECTED		
		4 DOPPLER DATA PROCESSED		
		3 DOPPLER DATA REJECTED		
		2 ZUPT PROCESSED		
		1 RESERVED SPARE		
		0 VALID DVL HEIGHT		

Table 17: Definition of INS Output Data

+ DEPTH = BELOW MEAN SEA LEVEL

+ BHEIGHT = HEIGHT ABOVE SEA BOTTOM

+ ROLL = PORT SIDE UP

+ PITCH = BOW UP

+ HEADING = CLOCKWISE ROTATION

The following velocities are selected via a parameter in EEPROM:

+ VN or VBODYX = NORTHERLY or VELOCITY IN THE DIRECTION OF THE VEHICLE X-AXIS

+ VE or VBODY = EASTERLY or VELOCITY IN THE DIRECTION OF THE VEHICLE Y-AXIS

+ VDOWN or VBODYZ = DOWN or VELOCITY IN THE DIRECTION OF THE VEHICLE Z-AXIS

+ ACCELX = ACCELERATION IN THE DIRECTION OF THE BOW (VEHICLE X-AXIS)

+ ACCELY = ACCELERATION IN THE DIRECTION OF THE PORT SIDE (VEHICLE Y-AXIS)

+ ACCELZ = ACCELERATION IN THE DIRECTION OF UP (VEHICLE Z-AXIS)

+ PRATE = POSITIVE ANGULAR RATE ABOUT VEHICLE X-AXIS

+ QRATE = POSITIVE ANGULAR RATE ABOUT VEHICLE Y-AXIS

+ RRATE = POSITIVE ANGULAR RATE ABOUT VEHICLE Z-AXIS

4.2.2 Message: CONFIGURATION DATA

This message outputs the current configuration data stored in EEPROM in response to a RETURN CONFIGURATION DATA command.

TYPE: OPOUT ID: 3

Table 18: Configuration Data Message

DATA BYTE #	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1,D2	VALPHA	ROLL BORESIGHT ANGLE, DVL INS TO VEHICLE (-180° to +180°)	$180°*2^{-15}$	S16
D3,D4	VBETA	PITCH BORESIGHT ANGLE, DVL INS TO VEHICLE (-90° to +90°)	$180°*2^{-15}$	S16
D5,D6	VGAMMA	AZIMUTH BORESIGHT ANGLE, DVL INS TO VEHICLE (-180° to +180°)	$180°*2^{-15}$	S16
D7	DISCRETES		N/A	BINARY
	SURFACE	BIT 7 SURFACE SHIP CONFIGURATION		
	SPARE	BIT 6 RESERVED		
	TSTMSGSEN	BIT 5 SLOW TEST MESSAGE ENABLE		
	TSTMSGFEN	BIT 4 FAST TEST MESSAGE ENABLE		
	DOPCAL	BIT 3 DOPPLER OR EM-LOG CALIBRATION RUN		
	SPARE	BIT 2		
	SPARE	BIT 1		
D8	SATIME	STATIONARY ALIGN TIME (DOCK SIDE)	MIN	U16
D9,D10	VDELX	VEHICLE-INS LONGITUDINAL OFFSET	CM	S16
D11,D12	VDELY	VEHICLE-INS CROSS OFFSET	CM	S16
D13,D14	VDELZ	VEHICLE-INS VERTICAL OFFSET	CM	S16
D15,D16	GPSLX	X-AXIS OFFSET FROM INS TO GPS	CM	S16
D17,D18	GPSLY	Y-AXIS OFFSET FROM INS TO GPS	CM	S16
D19,D20	GPSLZ	Z-AXIS OFFSET FROM INS TO GPS	CM	S16
D21,D22	DOPLX	INS-DOPPLER X-AXIS OFFSET*	CM	S16
D23,D24	DOPLY	INS-DOPPLER Y-AXIS OFFSET*	CM	S16
D25,D26	DOPLZ	INS-DOPPLER Z AXIS OFFSET*	CM	S16
D27,D28	EMLAZIM	AZIMUTH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)	$180° *2^{-15}$	S16
D29,D30	EMLPITCH	PITCH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-90° TO +90°)	$180° *2^{-15}$	S16
D31,D32	EMLROLL	ROLL BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)	$180° *2^{-15}$	S16
D33	LSATIME	STATIONARY ALIGN TIME (LAND)	MIN	U8

* Fixed by the Integrated DVL INS mechanical configuration.

4.2.3 Message: DoD GPS PVT Data A

TYPE: TSTOUT ID: 13

Table 19: DoD GPS PVT Data A Message

DATA BYTE	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1-D8	GPS TIME	GPS TIME PVT DATA VALID	SEC	DECDFP
D9-D16	UTC TIME	UTC TIME PVT DATA VALID	SEC	DECDFP
D17,D18	SPARE	RESERVED FOR DELTA TIME		
D19,D20	SPARE	RESERVED FOR TIME MARK COUNTER		
D21-D24	GPSLAT	GPS WGS-84 LATITUDE	RADIANS	DECFP
D25-D28	GPSLON	GPS WGS-84 LONGITUDE	RADIANS	DECFP
D29-D32	ECEFX	GPS ECEF X POSITION	METERS	DECFP
D33-D36	ECEFY	GPS ECEF Y POSITION	METERS	DECFP
D37-D40	ECEFZ	GPS ECEF Z POSITION	METERS	DECFP
D41-D44	GPSALTMSL	GPS WGS-84 ALTITUDE - MEAN SEA LEVEL (HEIGHT ABOVE ELLIPSOID)	METERS	DECFP
D45-D48	GPSALTABS	GPS WGS-84 ALTITUDE – ABSOLUTE (HEIGHT ABOVE ELLIPSOID)	METERS	DECFP
D49-D52	GPSVE	GPS VELOCITY EAST	M/S	DECFP
D53-D56	GPSVN	GPS VELOCITY NORTH	M/S	DECFP
D57-D60	GPSVUP	GPS VELOCITY UP	M/S	DECFP
D61-D62	TMTIME	GPS TIME MARK TIME	20MS	U16

4.2.4 Message: DoD GPS PVT Data B

TYPE: TSTOUT ID: 15

Table 20: DoD GPS PVT Data B Message

DATA BYTE #	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1-D4	SPARE	RESERVED FOR ACCELERATION EAST	M/S	DECFP
D5-D8	SPARE	RESERVED FOR ACCELERATION NORTH		
D9-D12	SPARE	RESERVED FOR ACCELERATION UP		
D13-D16	SPARE	RESERVED FOR PITCH ATTITUDE	RADIANS	
D17-D20	SPARE	RESERVED FOR ROLL ATTITUDE	RADIANS	
D21-D24	SPARE	RESERVED FOR TRUE HEADING	RADIANS	
D25-D28	SPARE	RESERVED FOR MAGNETIC VARIATION	RADIANS	
D29,D30	CHISTATA	CHANNEL 1 STATUS A (SEE NOTE 1)	NA	BINARY DISCRETES
D31,D32	CHISTATB	CHANNEL 1 STATUS B (SEE NOTE 2)	NA	BINARY DISCRETES
D33,D34	CH2STATA	CHANNEL 2 STATUS A (SEE NOTE 1)	NA	BINARY DISCRETES
D35,D36	CH2STATB	CHANNEL 2 STATUS B (SEE NOTE 2)	NA	BINARY DISCRETES
D37,D38	CH3STATA	CHANNEL 3 STATUS A (SEE NOTE 1)	NA	BINARY DISCRETES
D39,D40	CH3STATB	CHANNEL 3 STATUS B (SEE NOTE 2)	NA	BINARY DISCRETES
D41,D42	CH4STATA	CHANNEL 4 STATUS A (SEE NOTE 1)	NA	BINARY DISCRETES
D43,D44	CH4STATB	CHANNEL 4 STATUS B (SEE NOTE 2)	NA	BINARY DISCRETES
D45,D46	CH5STATA	CHANNEL 5 STATUS A (SEE NOTE 1)	NA	BINARY DISCRETES
D47,D48	CH5STATB	CHANNEL 5 STATUS B (SEE NOTE 2)	NA	BINARY DISCRETES
D49,D50	FOMWORD	FIGURE OF MERIT WORD (SEE NOTE 3)	NA	BINARY DISCRETES
D51,D52	EHPE	GPS EXPECTED HORIZONTAL POSITION ERROR	METERS	U16
D53,D54	EVPE	GPS EXPECTED VERTICAL POSITION ERROR	METERS	U16
D55,D56	NWRNGPS	WARNING MESSAGE NUMBER (SEE NOTE 4)	NA	U16
D57,D58	EQUIPU	EQUIPMENT USED	NA	BINARY DISCRETES
D59-D62	TFOMWORD	GPS TIME FIGURE OF MERIT WORD	NA	BINARY DISCRETES

Note 1:

Table 21: Channel Status A Data

BIT	DATA	DATA TYPE	DEFINITION
0-4	SATELLITE NUMBER	U4	RANGE 0-31 (0=#32)
5-7	TRACKING CHANNEL NUMBER	U3	RANGE 1-5
8	SPARE		
9-11	TRACKING STATE	U3	RANGE 1-7
12	CODE TYPE	DISCRETE	0=P/Y, 1=C/A
13	SPARE RESERVED FOR L1/L2 DISCRETE		
14	SPARE RESERVED FOR ANTENNA SELECT		
15	FAULT	LOG	0-NO, 1=YES

Note 2:

Table 22: Channel Status B Data

BIT	DATA	DATA TYPE	DEFINITION
0-7	J/S	U8	DECIBELS
8-15	C/No	U8	DECIBELS

Note 3:

Table 23: Figure of Merit Data

BIT	DATA	DATA TYPE	DEFINITION
0-3	FOM	UN	RANGE 1-9
4	ICD-203 ERASE FAULT	DISC	1 = ICD-203 ERASE FAULT
5	ICD-203 REQ'TS NOT MET	DISC	1 = ICD-203 REQ'TS NOT MET
6	FMI	N/A	NOT USED
7	CDU1 OR CDU2 FAILURE	DISC	NOT USED
8	AE LRU FAILURE	DISC	NOT USED
9	RPU FAILURE	DISC	1 = RPU FAILURE
10	NAV DATA NOT VALID	DISC	1 = NAV DATA NOT VALID
11	NAV DEGRADED DUE TO ICD-203	DISC	1 = NAV DEGRADED
12	NAV DATA ABOUT TO BAD DUE TO ICD-203	DISC	1 = NAV DATA ABOUT TO GO BAD
13	< 4 MEAS. INCORPORATED	DISC	1 = < 4 MEAS. INCORPORATED
14	STATE 3 OPERATION	DISC	1 = STATE 3 OBSERVATION
15	STATE 5 OPERATION	DISC	1 = STATE 5 OBSERVATION

Note 4:

Warning ID	Warning Message - First 16 Char	Warning Message – Second 16 Char
1	Invalid key	entered
2	Bad key	detected
3	All keys	zeroized
4	Zeroize failed	
5	Spare Message	
6	Spare Message	
7	No key for	tomorrow
8	Check GUV issue	number
9	Insufficient	Y-code SVs
10	Possible	spoofers
11	Low memory	battery
12	Low primary	battery
13	External antenna	lost
14	External antenna	fault
15	External power	lost
16	Non rechargeable	battery
17	Emergency	zeroize passed
18	Emergency	zeroize failed
19	Failures found	see fail log
20	No Failures	detected
21	Datum Mismatch	Wpnnn and WPFnnn
22	The Receiver has	cleared Memory
23-32	Spare message	

4.2.5 Message: NMEA 183 GGA Data

TYPE: TSTOUT ID: 7

Table 24: NMEA 183 GGA Message

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: GGA				
UTC	CHAR	HR-MIN-SEC	1	
LATITUDE	CHAR	DEG-MIN	2	
LATITUDE DIRECTION	CHAR	NA	3	N= + , S= -
LONGITUDE	CHAR	DEG-MIN	4	
LONGITUDE DIRECTION	CHAR	NA	5	E= + , W= -
GPS QUALITY 0=INVALID 1=SPS MODE 2=DGPS MODE 3=PPS MODE	CHAR	NA	6	
NUMBER OF SAT'S	CHAR	NA	7	00-12
HDOP	CHAR	NA	8	NOT USED
ALTITUDE (Mean Sea Level)	CHAR	METERS	9	
ALTITUDE UNITS	CHAR	NA	10	NOT USED
GEOID SEPARATION	CHAR	NA	11	NOT USED
GEOID SEPARATION UNITS	CHAR	NA	12	NOT USED
DATA AGE	CHAR	NA	13	NOT USED
STATION ID	CHAR	NA	14	NOT USED

NOTE:

1. NMEA DATA IS IN ASCII CHARACTER FORMAT.
2. THE NMEA MESSAGE IS PRECEDED BY AN ASCII DOLLAR SIGN ($), FOLLOWED BY A 5 ASCII CHARACTER MESSAGE HEADER.
3. NMEA FIELDS ARE SEPARATED BY COMMAS (,).
4. AFTER THE LAST FIELD THERE IS AN ASTERISK (*), FOLLOWED BY A TWO (2) CHARACTER CHECKSUM, FOLLOWED BY AN ASCII CARRIAGE RETURN AND LINE FEED (<CR><LF>).

4.2.6 Message: NMEA 183 GSA Data

TYPE: TSTOUT ID: 9

Table 25: NMEA 183 GSA Message

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: GSA				
MANUAL/AUTO MODE	CHAR	NA	1	NOT USED
FIX MODE 2D/3D 1=NO FIX 2=2D FIX 3=3D FIX	CHAR	NA	2	
SATELLITE ID'S	CHAR(12 or 14)	NA	3-14 or 3-16	
PDOP	CHAR	NA	15 or 17	NOT USED
EXPECTED HORIZ. DOP	CHAR	NA	16 or 18	
EXPECTED VERT. DOP	CHAR	NA	17 or 19	

4.2.7 Message: NMEA 183 VGT Data

TYPE: TSTOUT ID: 11

Table 26: NMEA 183 VGT Message

NAME	DATA TYPE	UNITS	FIELD	NOTE
Message Header: VTG				
TRUE COURSE	CHAR	DEG		
TRUE COURSE UNITS	CHAR	NA	2	NOT USED
MAGNETIC COURSE	CHAR	DEG	3	NOT USED
MAGNETIC COURSE UNITS	CHAR	NA	4	NOT USED
SPEED N	CHAR	KTS	5	
SPEED N UNITS	CHAR	NA	6	NOT USED
SPEED K	CHAR	KM/HR	7	
SPEED K UNITS	CHAR	NA	8	NOT USED

NOTE:

1. NMEA DATA IS IN ASCII CHARACTER FORMAT.
2. THE NMEA MESSAGE IS PRECEDED BY AN ASCII DOLLAR SIGN ($), FOLLOWED BY A 5 ASCII CHARACTER MESSAGE HEADER.
3. NMEA FIELDS ARE SEPARATED BY COMMAS (,).
4. AFTER THE LAST FIELD THERE IS AN ASTERISK (*), FOLLOWED BY A TWO (2) CHARACTER CHECKSUM, FOLLOWED BY AN ASCII CARRIAGE RETURN AND LINE FEED(<CR><LF>).

4.2.8 Message: DOPPLER PD4 DATA

TYPE: TSTOUT ID: 21

Table 27: Doppler PD4 data

DATA BYTES	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1,D2	KTNAV	TIME OF DOPPLER PD4 MESSAGE	20 MS	U16
D3	DVLID	DVL DATA ID	NA	U8
D4	DATSTR	DATA STRUCTURE	NA	U8
D5,D6	NUMBYTE	NUMBER OF DATA BYTES SENT	NA	U16
D7	SYSCONFIG	DEFINES THE DVL HARDWARE/FIRMWARE	NA	U8
D8,D9	XVELBTM	X-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D10,D11	YVELBTM	Y-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D12,D13	ZVELBTM	Z-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D14,D15	EVELBTM	E-VELOCITY IN RELATION TO BOTTOM	MM/S	S16
D16,D17	BM1	VERTICAL RANGE TO BOTTOM – BEAM #1	CM	U16
D18,D19	BM2	VERTICAL RANGE TO BOTTOM – BEAM #2	CM	U16
D20,D21	BM3	VERTICAL RANGE TO BOTTOM – BEAM #3	CM	U16
D22,D23	BM4	VERTICAL RANGE TO BOTTOM – BEAM #4	CM	U16
D24	BOTSTAT	STATUS OF BOTTOM REFERENCED CORRELATION AND ECHO AMPLITUDE DATA	NA	U16
D25,D26	XVELREF	X-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D27,D28	YVELREF	Y-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D29,D30	ZVELREF	Z-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D31,D32	EVELREF	E-VELOCITY WRT WATER REFERENCE LAYER	MM/S	S16
D33,D34	REFSTRT	REFERENCE LAYER START DISTANCE	DM	S16
D35,D36	REFEND	REFERENCE LAYER END DISTANCE	DM	S16
D37	REFSTAT	REFERENCE LAYER STATUS	NA	U8
D38-D41	TOPING	TIME OF PING – HR/MIN/SEC/0.01 S		U8 (4)
D42,D43	BIT	BUILT IN TEST RESULTS	NA	BINARY
D44,D45	SPDSND	SPEED OF SOUND USED BY DVL	M/S	U16
D46,D47	TEMP	TEMPERATURE OF WATER	0.1 C	S16
D48,D49	CHECKSUM	DVL CHECKSUM OF PD4 MESSAGE	NA	U16

4.2.9 Message: RAWDAT – 100 Hz IMU DATA

TYPE: TSTOUT ID: 19

Table 28: 100 Hz IMU data

DATA BYTES	DATA MNEMONIC	DESCRIPTION	UNITS	INPUT FORMAT
D1,D2	KTNAV	TIME OF RAWDAT MESSAGE DATA VALIDITY	100 HZ	U16
D3,D4		(SPARE)		
D5,D8	PHX	COMPENSATED 100 HZ BODY X ROTATION	RADIANS	C31 FP
D9,D12	PHY	COMPENSATED 100 HZ BODY Y ROTATION	RADIANS	C31 FP
D13,D16	PHZ	COMPENSATED 100 HZ BODY Z ROTATION	RADIANS	C31 FP
D17,D20	VBX	COMPENSATED 100 HZ BODY X Δ VELOCITY	FEET/SEC.	C31 FP
D21,D24	VBY	COMPENSATED 100 HZ BODY Y Δ VELOCITY	FEET/SEC.	C31 FP
D25,D28	VBZ	COMPENSATED 100 HZ BODY Z Δ VELOCITY	FEET/SEC.	C31 FP
D29,D30	GPSTM	SYSTEM TIME OF GPS TIME MARK	100 HZ	U16

Note: C31 FP is C31 Floating-Point format.

5. INS TEST MESSAGE INTERFACE

5.1 Test Message Summary

This section defines the Kearfott test message content for the INS on the mission computer interface. Table 29 summarizes the messages transmitted by DVL INS when “Slow Test Messages” are enabled.

Table 29: Test Message Summary

TYPE: TSTOUT ID: 27

Message length - 64 Bytes (All Sub ID messages are transmitted 64 bytes in length)

Sub ID (SID)	Message Name	Data Byte Count (N)	Frequency (Hz)
1	IMU RAW Data	52	1
2	IMU Compensated Data	52	1
3	IMU Control 1	60	1
4	IMU Control 2	60	1
5	NAV Calibration Data	60	1
6	System Status	33	1
7	Kalman Accumulated state vector A	64	0.5
8	Kalman Accumulated state vector B	52	0.5
16	Kalman Accumulated state vector C	60	0.5
9	Kalman Covariance A	64	0.5
10	Kalman Covariance B	52	0.5
18	Kalman Covariance C	60	0.5
17	Observation Status	36	0.5
11	ZUPT Residuals	52	0.5
12	GPS Velocity Residual	52	0.5
13	GPS Position Residual	52	0.5
14	DVL or EM-LOG Velocity Residuals	52	0.5
15	Position Fix Residuals	52	0.5

Notes:

These messages are for Kearfott internal use and may be changed at any time at Kearfott’s discretion.

The first data word is the Time of the Message, output format U16, units 20 msec.

The second data word is the Message Identifier, output format U16, units are NA.

All other data words, unless specified, are C31 floating point

Spare words are set to zero

5.1.1 C31 Floating Point Format

The floating-point format consists of three fields: an exponent field (e), a single-bit sign field (s), and a fraction field (f). The exponent field is a two's complement number. The sign field and fraction field may be considered one unit and referred to as the mantissa field (man). The two's complement fraction is combined with the sign bit and the implied most significant bit to create the mantissa. The mantissa represents a normalized two's complement number. A normalized representation implies a most significant nonsign bit, thus providing additional precision. The value of a floating-point number x as a function of the fields e, s, and f is given as

$x = 01.f \times 2^e$	If s=0, or if the leading 0 is the sign bit and the 1 is the implied most significant nonsign bit
$x = 10.f \times 2^e$	If s=1, or if the leading 1 is the sign bit and the 0 is the implied most significant nonsign bit
$x = 0$	If e= most negative two's complement value of the exponent field (-128), s = 0, and f = 0

e	s	f
B31 – B24	B23	B22 – B0
		← (mantissa) →

The Double Precision floating point format consists of two 32 bit words. The first is identical to the floating point format above. The other contains an 8 bit extension of the mantissa and 24 “zero” bits.

5.2 Test Message Details

5.2.1 IMU RAW Data

TYPE: TSTOUT SID: 1

Table 30: IMU Raw Data message

DATA BYTE #	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	1
D5-D8	BSNGSUM(1)	Red Gyro Pulses (pulse/sec)
D9-D12	BSNGSUM(2)	White Gyro Pulses (pulse/sec)
D13-D16	BSNGSUM(3)	Blue Gyro Pulses (pulse/sec)
D17-D20	BSACSUM(1)	A Accelerometer Pulses (pulse/sec))
D21-D24	BSACSUM(2)	B Accelerometer Pulses (pulse/sec))
D25-D28	BSACSUM(3)	C Accelerometer Pulses (pulse/sec))
D29-D32	BSCONG(1)	X Conning Correction (radians/sec)
D33-D36	BSCONG(2)	Y Conning Correction (radians/sec)
D37-D40	BSCONG(3)	Z Conning Correction (radians/sec)
D41-D44	ACBIAS(1)	X Accelerometer Bias (ft/sec**2)
D45-D48	ACBIAS(2)	Y Accelerometer Bias (ft/sec**2)
D49-D52	ACBIAS(3)	Z Accelerometer Bias (ft/sec**2)

5.2.2 IMU Compensated Data

TYPE: TSTOUT SID: 2

Table 31: IMU Compensated data message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	2
D5-D8	BCTN(1)	X Gyro Bias (radians/sec)
D9-D12	BCTN(2)	Y Gyro Bias (radians/sec)
D13-D16	BCTN(3)	Z Gyro Bias radians/sec)
D17-D20	CFDNA	Commanded Dither Noise (fraction of 1)
D21-D24	BSMCOSD	Dither in Phase (radians)
D25-D28	BSMSIND	Dither Quadrature (radians)
D29-D32	DVCOMPNVB(1)	X Delta Velocity (ft/sec**2)
D33-D36	DVCOMPNVB(2)	Y Delta Velocity (ft/sec**2)
D37-D40	DVCOMPNVB(3)	Z Delta Velocity (ft/sec**2)
D41-D44	BSDTHETNV(1)	X Delta Angle (radians/sec)
D45-D48	BSDTHETNV(2)	Y Delta Angle (radians/sec)
D49-D52	BSDTHETNV(3)	Z Delta Angle (radians/sec)

5.2.3 IMU Control Loop 1

TYPE: TSTOUT SID: 3

Table 32: IMU Control Loop 1 message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message(20 msec)
D3,D4	IDENT	3
D5-D8	PLCLCROS	L PLC Mirror Drive (fraction of 1)
D9-D12	PLCMCROS	M PLC Mirror Drive (fraction of 1)
D13-D16	PLCNCROS	N PLC Mirror Drive (fraction of 1)
D17-D20	PLCCROSSR	Red PLC Integrator (fraction of 1)
D21-D24	PLCCROSSW	White PLC Integrator (fraction of 1)
D25-D28	PLCCROSSB	Blue PLC Integrator (fraction of 1)
D29-D32	RDFRNGIN	Red Fringe Intensity (fraction of 1)
D33-D36	WHFRNGIN	White Fringe Intensity (fraction of 1)
D37-D40	BLFRNGIN	Blue Fringe Intensity (fraction of 1)
D41-D44	MDHPNUMR	Red Number of Mode Hops Counts (integer)
D45-D48	MDHPNUMW	White Number of Mode Hops Counts (integer)
D49-D52	MDHPNUMB	Blue Number of Mode Hops Counts (integer)
D53-D56	MAXAMP	Max Dither Amplitude (radians/sec)
D57-D60	SNAPAMP	Dither Amp Snapshot (radians/sec)

5.2.4 IMU Control Loop 2

TYPE: TSTOUT SID: 4

Table 33: IMU Control Loop 2 message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1-D2	KTNAV	Time of Message (20 msec)
D3-D4	IDENT	4
D5-D8	TDFREQ	Filtered Dither Frequency (Hz)
D9-D12	MAXCOM	Max Dither Command (fraction of 1)
D13-D16	SNAPCOM	Dither Command Snapshot (fraction of 1)
D17-D20	DGAIN	Software Dither Gain (fraction of 1)
D21-D24	TGYRO	Gyro Temperature (deg F)
D25-D28	TACCEL(1)	X Accelerometer Temperature (deg F)
D29-D32	TACCEL(2)	Y Accelerometer Temperature (deg F)
D33-D36	TACCEL(3)	Z Accelerometer Temperature (deg F)
D37-D40	BSCULSUM(1)	X Sculling Correction (ft/sec**2)
D41-D44	BSCULSUM(2)	Y Sculling Correction (ft/sec**2)
D45-D48	BSCULSUM(3)	Z Sculling Correction (ft/sec**2)
D49-D52	DVSIZEFB(1)	X Buffered Size Effect (ft/sec**2)
D53-D56	DVSIZEFB(2)	Y Buffered Size Effect (ft/sec**2)
D57-D60	DVSIZEFB(3)	Z Buffered Size Effect (ft/sec**2)

5.2.5 NAV Calibration Data

TYPE: TSTOUT SID: 5

Table 34: NAV Calibration data message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	5
D5-D8	LLVEL(1)	X Level Velocity (ft/sec)
D9-D12	LLVEL(2)	Y Level Velocity (ft/sec)
D13-D16	LLVEL(3)	Z Level Velocity (ft/sec)
D17-D20	ALPHA	Wander Angle (radians)
D21-D24	ROLL	Roll Angle (radians)
D25-D28	PITCH	Pitch Angle (radians)
D29-D32	TH	True Heading Angle (radians)
D33-D40	LAT (λ)	Latitude (radians) Note 1
D41-D48	LON (ϕ)	Longitude (radians) Note 1
D49-D52	H	Altitude (ft)
D53-D57		Align Quality (radians)
D57-D60		Horizontal Position Quality (ft)

Note 1 – C31 double precision floating-point format

5.2.6 System Status

TYPE: TSTOUT SID: 6

Table 35: System Status message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	6
D5-D8	VERSION	OFP Version (Binary)
D9-D12		OFP Checksum (Binary)
D13,D14		BIT Summary (Binary) Note 1
D15,D16		IMU BIT Status (Binary) Note 2
D17,D18		IMU Temperature BIT (Binary) Note 3
D19-D22		IMU BIT Cumulative Status (Binary) Note 4
D23-D26		IMU Auxiliary Info Word (Binary)
D27,D28		Processor Status (Binary) Note 5
D29,D30		Task Error Word (Binary) Note 6
D31,D32		Parallel EEPROM Errors (Binary) Note 7
D33		Serial I/O Status (Binary) Note 8

Note 1

BIT	
0-3	Current BIT State
4	Startup Fail
6	Periodic BIT Fail
7	Critical Fail
8	Processor Good
9	Control Good
10	Task Good
12	IMU Good
13	Power Good

Note 2

BIT	
0-6	BIT Index Note 9
7	Degraded BIT
8	Startup/Periodic BIT Fail (0/1)
9	Startup/Periodic BIT Programs (0/1)
10	Factory IMU/Lab Discrete
11	Critical Fail
12	Spare
13	Spare
14	IMU Bad Data
15	Spare

Note 3

BIT	
0	Gyro saturation fail
1	A Accelerometer temperature saturation fail
2	B Accelerometer temperature saturation fail
3	C Accelerometer temperature saturation fail
4	Gyro Temperature reasonableness fail
5	A Accelerometer temperature reasonableness fail
6	B Accelerometer temperature reasonableness fail
7	C Accelerometer temperature reasonableness fail
8	Gyro over temperature
9	Gyro under temperature
10	Accelerometer over temperature
11	Accelerometer under temperature
15	all temperatures fail

Note 4

BIT			BIT	
0	Exec Integrity BIT		16	Gyro Reasonableness – R axis BIT
1	CPU Integrity BIT		17	Gyro Reasonableness – W axis BIT
2	RAM Pattern BIT		18	Gyro Reasonableness – B axis BIT
3	RAM Checksum BIT		19	Accel Reasonableness – X axis BIT
4	EEPROM Checksum /Pattern BIT		20	Accel Reasonableness – Y axis BIT
5	VFC CAL BIT		21	Accel Reasonableness – Z axis BIT
6	A/D Circuitry BIT		22	Watchdog Timer Test BIT
7	Accel Pendulum Offset BIT		23	Some Temperature Sensor BIT
8	All Temperature Fail BIT		24	Dither Loop Not Optimal BIT
9	Dither Loop BIT		25	Serial Link from C31 BIT
10	Laser Current BIT		26	Gyro Data Exceeded Output BIT
11	PLC Red BIT		27	(Spare)
12	PLC White BIT		28	ASIC Wraparound BIT
13	PLC Blue BIT		29	Accel Data Exceeded Output BIT
14	Dither frequency BIT		30	EEPROM Interface BIT
15	Dither amplitude BIT		31	(Spare)

Note 5

BIT	
0	ROM Checksum Fail

Note 6

BIT	
0	Kalman Observation Overload
1	Kalman Filter Overload
3	Low Rate Overload
5	NAV Overload
7	Control NAV Error
8	Kalman Observation Error
9	Kalman Filter Error
11	Low Rate Error
13	NAV Error

Note 7

BIT	
0	Spare
1	NAV Parameter Pattern Fail
2	Configuration Pattern Fail
3	Shutdown Pattern Fail
5	Default Parameter Loaded
6	Default Configuration Loaded
7	Default Shutdown Loaded
9	NAV Parameter Checksum Fail
10	Configuration Checksum Fail
11	Shutdown Checksum Fail

Note 8

BIT	
0	Not Ready to Ping
1	DVL Checksum Fail
3	No Time Mark Pulse

Note 9

	IMU BIT INDEX DICTIONARY			
0	NO FAILURES			
1	RAM FAIL IN STARTUP		45	EEPROM INTERFACE
2	EEPROM FAIL IN STARTUP (IMUCP IMAGE)		46	PLC LOOP JITTER RED
3	DITHER LOOP FAIL (AMPLITUDE) IN STARTUP		47	PLC LOOP JITTER WHITE
4	DITHER LOOP FAIL (DRIVE) IN STARTUP		48	PLC LOOP JITTER BLUE
5	(SPARE)		49	ALL TEMPERATURE REASONABLENESS
6	(SPARE)		50	SOME TEMPERATURE REASONABLENESS / DEGRADED
7	DITHER FRQ FAIL (MAX) IN STARTUP		51	DITHER LOOP FAIL (AMPL) IN PERIODIC
8	DITHER FRQ FAIL (MIN) IN STARTUP		52	DITHER LOOP FAIL(DRIVE) IN PERIODIC
9	DITHER AMPL FAIL (MAX) IN STARTUP		53	OVER TEMPERATURE INDICATION
10	DITHER AMPL FAIL (MIN) IN STARTUP		54	(SPARE)
11	DITHER OFF		55	R GYRO SATURATION
12	PLC OFF		56	W GYRO SATURATION
13	(SPARE)		57	B GYRO SATURATION
14	EXEC FAIL (TIME OVERFLOW) IN PERIODIC		58	R GYRO CONSISTENCY
15	(SPARE)		59	W GYRO CONSISTENCY
16	CPU INTEGRITY FAIL		60	B GYRO CONSISTENCY
17	ADC NOT READY FAIL		61	R GYRO OUT OF LIMITS
18	RAM FAIL		62	W GYRO OUT OF LIMITS
19	WATCH DOG TIMER TEST FAIL		63	B GYRO OUT OF LIMITS
20	EEPROM FAIL IN STARTUP (ACP IMAGE)		64	X AXIS VFC BIAS CALIBRATION FAIL
21	A/D FAIL (REFERENCE)		65	Y AXIS VFC BIAS CALIBRATION FAIL
22	A/D FAIL (OFFSET)		66	Z AXIS VFC BIAS CALIBRATION FAIL
23	(SPARE)		67	ALTERNATE AXIS VFC BIAS CAL FAIL
24	DITHER FREQ FAIL (MAX) IN PERIODIC		68	X AXIS VFC SCALE FACTOR CAL FAIL
25	DITHER FREQ FAIL (MIN) IN PERIODIC		69	Y AXIS VFC SCALE FACTOR CAL FAIL
26	DITHER AMPL FAIL (MAX) IN PERIODIC		70	Z AXIS VFC SCALE FACTOR CAL FAIL
27	DITHER AMPL FAIL (MIN) IN PERIODIC		71	ALTER AXIS VFC SCALE FACTOR CAL FAIL
28	(SPARE)		72	X AXIS ACCELEROMETER PENDULUM
29	ACCEL PENDULUM OFFSET FAIL IN STARTUP		73	Y AXIS ACCELEROMETER PENDULUM
30	X ACCELEROMETER SATURATION		74	Z AXIS ACCELEROMETER PENDULUM
31	Y ACCELEROMETER SATURATION		75	(SPARE)
32	Z ACCELEROMETER SATURATION		76	ERRATIC CLOCK STARTUP (TIMEOUT)
33	X ACCELEROMETER CONSISTENCY		73	Y AXIS ACCELEROMETER PENDULUM
34	Y ACCELEROMETER CONSISTENCY		74	Z AXIS ACCELEROMETER PENDULUM
35	Z ACCELEROMETER CONSISTENCY		75	(SPARE)
36	X ACCELEROMETER OUT OF LIMITS		76	ERRATIC CLOCK STARTUP (TIMEOUT)
37	Y ACCELEROMETER OUT OF LIMITS		77	COMMANDED FREQ DITHER FAIL
38	Z ACCELEROMETER OUT OF LIMITS		78	LASER INTENSITY SATURATION RED
39	LASER CURRENT FAIL (HVPS-GYRO BALLAST)		79	LASER INTENSITY SATURATION WHITE
40	LASER CURRENT FAIL (RED AXIS)		80	LASER INTENSITY SATURATION BLUE
41	LASER CURRENT FAIL (WHITE AXIS)		81	ACCEL EXTREME SATURATION FAIL X
42	LASER CURRENT FAIL (BLUE AXIS)		82	ACCEL EXTREME SATURATION FAIL Y
43	PLC LOOP FAIL (DRIVE VOLTAGE)		83	ACCEL EXTREME SATURATION FAIL Z
44	ASIC WRAPAROUND FAIL		84-127	(SPARES)

5.2.7 Kalman Accumulated state vector A

TYPE: TSTOUT SID: 7

Table 36: Kalman Accumulated state vector A message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3-D4	IDENT	7
D5-D8	XKBUF(DRX)	X Position Error State (ft)
D9-D12	XKBUF(DRY)	Y Position Error State (ft)
D13-D16	XKBUF(EVX)	X Velocity (Error State ft/sec)
D17-D20	XKBUF(EVY)	Y Velocity (ft/sec)
D21-D24	XKBUF(THX)	X Tilt Error State (radians)
D25-D28	XKBUF(THY)	Y Tilt Error State (radians)
D29-D32	XKBUF(PSIZ)	Heading Error State (radians)
D33-D36	XKBUF(EH)	Altitude Error State (ft)
D37-D40	XKBUF(EVZ)	Z Velocity Error State (ft/sec)
D41-D44	XKBUF(EASFX)	X Accelerometer Scale Factor Correction (fraction of 1)
D45-D48	XKBUF(EASFY)	Y Accelerometer Scale Factor Correction (fraction of 1)
D49-D52	XKBUF(EASFZ)	Z Accelerometer Scale Factor Correction (fraction of 1)
D53-D56	XKBUF(EBXWU)	X Accel. Bias Warm-up Error State (ft/sec**2)
D57-D60	XKBUF(EBYWU)	Y Accel. Bias Warm-up Error State (ft/sec**2)
D61-D64	XKBUF(EBZWU)	Z Accel. Bias Warm-up Error State (ft/sec**2)

5.2.8 Kalman Covariance A

TYPE: TSTOUT SID: 9

Table 37: Kalman Covariance A message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	9
D5-D8	PBUF(DRX)	X Position σ (ft)
D9-D12	PBUF(DRY)	Y Position σ (ft)
D13-D16	PBUF(EVX)	X Velocity σ (ft/sec)
D17-D20	PBUF(EVY)	Y Velocity σ (ft/sec)
D21-D24	PBUF(THX)	X Tilt σ (radians)
D25-D28	PBUF(THY)	Y Tilt σ (radians)
D29-D32	PBUF(PSIZ)	Heading σ (radians)
D33-D36	PBUF(EH)	Altitude σ (ft)
D37-D40	PBUF(EVZ)	Z Velocity σ (ft/sec)
D41-D44	PBUF(EASFX)	X Accelerometer Scale Factor σ (fraction of 1)
D45-D48	PBUF(EASFY)	Y Accelerometer Scale Factor σ (fraction of 1)
D49-D52	PBUF(EASFZ)	Z Accelerometer Scale Factor σ (fraction of 1)
D53-D56	PBUF((EBXWU)	X Accel. Bias Warm-up σ (ft/sec**2)
D57-D60	PBUF(EBYWU)	Y Accel. Bias Warm-up σ (ft/sec**2)
D60-D64	PBUF(EBZWU)	Z Accel. Bias Warm-up σ (ft/sec**2)

Note: The output position quality can be estimated by computing the following parameters:
CEP(50%) = 0.589*(PBUF(DRX) + PBUF(DRY))
CEP(95%) = 2.08*CEP(50%)

5.2.9 Kalman Accumulated state vector B

TYPE: TSTOUT SID: 8

Table 38: Kalman Accumulated state vector B message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	8
D5-D8	XKBUF(EBX)	X Accelerometer Bias Error State (ft/sec**2)
D9-D12	XKBUF(EBY)	Y Accelerometer Bias Error State (ft/sec**2)
D13-D16	XKBUF(EBZ)	Z Accelerometer Bias Error State (ft/sec**2)
D17-D20	XKBUF(EDX)	X Gyro Bias Error State (radians/sec)
D21-D24	XKBUF(EDY)	Y Gyro Bias Error State (radians/sec)
D25-D28	XKBUF(EDZ)	Z Gyro Bias Error State (radians/sec)
D29-D32	XKBUF(SINA)	Sine (heading misalignment) (N/A)
D33-D36	XKBUF(OMCOSA)	1-Cosine (heading misalignment) (N/A)
D37-D40	XKBUF(EEMB)	Velocity Log Bias Error (ft/s)
D41-D44	XKBUF(EEMSF)	Velocity Log Scale Factor Error(fraction of 1)
D45-D48	XKBUF(EEMA)	Velocity Log Azimuth Boresight error (radians)
D49-D52	XKBUF(EEMP)	Velocity Log Pitch Boresight error (radians)
D53-D56	XKBUF(DSLAT)	Error of sine of latitude (unitless)

5.2.10 Kalman Covariance B

TYPE: TSTOUT SID: 10

Table 39: Kalman Covariance B message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3-D4	IDENT	10
D5-D8	PBUF(EBX)	X Accelerometer Bias σ (ft/sec**2)
D9-D12	PBUF(EBY)	Y Accelerometer Bias σ (ft/sec**2)
D13-D16	PBUF(EBZ)	Z Accelerometer Bias σ (ft/sec**2)
D17-D20	PBUF(EDX)	X Gyro Bias σ (radians/sec)
D21-D24	PBUF(EDY)	Y Gyro Bias σ (radians/sec)
D25-D28	PBUF(EDZ)	Z Gyro Bias σ (radians/sec)
D29-D32	PBUF(SINA)	Sin(heading misalignment) σ (N/A)
D33-D36	PBUF(OMCOSA)	1-Cos(heading misalignment) σ (N/A)
D37-D40	PBUF(EEMB)	Velocity Log Bias Error σ (ft/s)
D41-D44	PBUF(EEMSF)	Velocity Log Scale Factor Error σ (fraction of 1)
D45-D48	PBUF(EEMA)	Velocity Log Azimuth Boresight error σ (radians)
D49-D52	PBUF(EEMP)	Velocity Log Pitch Boresight error σ (radians)
D53-D56	PBUF(DSLAT)	Error of sine of latitude σ (unitless)

5.2.11 Kalman Accumulated state vector C

TYPE: TSTOUT SID: 17

Table 40: Kalman Accumulated state vector C message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	17
D5-D8	XKBUF(EDOPXY)	Y into X Doppler Cross Coupling (fraction of 1)
D9-D12	XKBUF(EDOPXZ)	Z into X Doppler Cross Coupling (fraction of 1)
D13-D16	XKBUF(EDOPYX)	X into Y Doppler Cross Coupling (fraction of 1)
D17-D20	XKBUF(EDOPYZ)	Z into Y Doppler Cross Coupling (fraction of 1)
D21-D24	XKBUF(EDOPZX)	X into Z Doppler Cross Coupling (fraction of 1)
D25-D28	XKBUF(EDOPZY)	Y into Z Doppler Cross Coupling (fraction of 1)
D29-D32	XKBUF(EWCURX)	X Water Current Error(ft/s)
D33-D36	XKBUF(EWCURY)	Y Water Current Error (ft/s)
D37-D40	XKBUF(EDOPBX)	X Doppler Bias Error (ft/s)
D41-D44	XKBUF(EDOPBY)	Y Doppler Bias Error (ft/s)
D45-D48	XKBUF(EDOPBZ)	Z Doppler Bias Error (ft/s)
D49-D52	XKBUF(EDOPSFX)	X Doppler Scale Factor Error (fraction of 1)
D53-D56	XKBUF(EDOPSFY)	Y Doppler Scale Factor Error (fraction of 1)
D57-D60	XKBUF(EDOPSFZ)	Z Doppler Scale Factor Error (fraction of 1)

5.2.12 Kalman Covariance C

TYPE: TSTOUT SID: 18

Table 41: Kalman Covariance C message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	18
D5-D8	PBUF(EDOPXY)	Y into X Doppler Cross Coupling σ (fraction of 1)
D9-D12	PBUF(EDOPXZ)	Z into X Doppler Cross Coupling σ (fraction of 1)
D13-D16	PBUF(EDOPYX)	X into Y Doppler Cross Coupling σ (fraction of 1)
D17-D20	PBUF(EDOPYZ)	Z into Y Doppler Cross Coupling σ (fraction of 1)
D21-D24	PBUF(ZX)	X into Z Doppler Cross Coupling σ (fraction of 1)
D25-D28	PBUF(ZY)	Y into Z Doppler Cross Coupling σ (fraction of 1)
D29-D32	PBUF(EWCURX)	X Water Current σ (ft/s)
D33-D36	PBUF(EWCURY)	Y Water Current σ (ft/s)
D37-D40	PBUF(EDOPBX)	X Doppler Bias σ (ft/s)
D41-D44	PBUF(EDOPBY)	Y Doppler Bias σ (ft/s)
D45-D48	PBUF(EDOPBZ)	Z Doppler Bias σ (ft/s)
D49-D52	PBUF(EDOPSFX)	X Doppler Scale Factor σ (fraction of 1)
D53-D56	PBUF(EDOPSFY)	Y Doppler Scale Factor σ (fraction of 1)
D57-D60	PBUF(EDOPSFZ)	Z Doppler Scale Factor σ (fraction of 1)

5.2.13 Position Fix Residual

TYPE: TSTOUT SID: 15

Table 42: Position Fix Residual message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	15
D5,D6	KOBREJX	Observation X Reject, 1=Rejected (U16)
D7,D8		Spare
D9,D12	RAW_RESX	Raw X Component Residual (ft)
D13,D16	COR_RESX	Corrected X Component Residual (ft)
D17-D20	NOISEX	Observation X Noise Model (ft)
D21,D22	KOBREJY	Observation Y Reject, 1=Rejected (U16)
D23,D24		Spare
D25-D28	RAW_RESY	Raw Y Component Residual (ft)
D29-D32	COR_RESY	Corrected Y Component Residual (ft)
D33-D36	NOISEY	Observation Y Noise Model (ft)
D37,D38	KOBREJZ	Observation Z Reject, 1=Rejected (U16)
D39,D40		Spare
D41-D44	RAW_RESZ	Raw Z Component Residual (ft)
D45-D48	COR_RESZ	Corrected Z Component Residual (ft)
D49-D52	NOISEZ	Observation Z Noise Model (ft)

5.2.14 ZUPT Residual

TYPE: TSTOUT SID: 11

Table 43: ZUPT Residual message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	11
D5,D6	KOBREJX	Observation X Reject, 1=Rejected (U16)
D7,D8		Spare
D9,D12	RAW_RESX	Raw X Component Residual (ft)
D13,D16	COR_RESX	Corrected X Component Residual (ft)
D17-D20	NOISEX	Observation X Noise Model (ft)
D21,D22	KOBREJY	Observation Y Reject, 1=Rejected (U16)
D23,D24		Spare
D25-D28	RAW_RESY	Raw Y Component Residual (ft)
D29-D32	COR_RESY	Corrected Y Component Residual (ft)
D33-D36	NOISEY	Observation Y Noise Model (ft)
D37,D38	KOBREJZ	Observation Z Reject, 1=Rejected (U16)
D39,D40		Spare
D41-D44	RAW_RESZ	Raw Z Component Residual (ft)
D45-D48	COR_RESZ	Corrected Z Component Residual (ft)
D49-D52	NOISEZ	Observation Z Noise Model (ft)

5.2.15 GPS Position Residual

TYPE: TSTOUT SID: 13

Table 44: GPS Position Residual message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	13
D5,D6	KOBREJX	Observation X Reject, 1=Rejected (U16)
D7,D8		Spare
D9,D12	RAW_RESX	Raw X Component Residual (ft)
D13,D16	COR_RESX	Corrected X Component Residual (ft)
D17-D20	NOISEX	Observation X Noise Model (ft)
D21,D22	KOBREJY	Observation Y Reject, 1=Rejected (U16)
D23,D24		Spare
D25-D28	RAW_RESY	Raw Y Component Residual (ft)
D29-D32	COR_RESY	Corrected Y Component Residual (ft)
D33-D36	NOISEY	Observation Y Noise Model (ft)
D37,D38	KOBREJZ	Observation Z Reject, 1=Rejected (U16)
D39,D40		Spare
D41-D44	RAW_RESZ	Raw Z Component Residual (ft)
D45-D48	COR_RESZ	Corrected Z Component Residual (ft)
D49-D52	NOISEZ	Observation Z Noise Model (ft)

5.2.16 GPS Velocity Residual

TYPE: TSTOUT SID: 12

Table 45: GPS Velocity Residual message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	12
D5,D6	KOBREJX	Observation X Reject, 1=Rejected (U16)
D7,D8		Spare
D9,D12	RAW_RESX	Raw X Component Residual (ft/s)
D13,D16	COR_RESX	Corrected X Component Residual (ft/s)
D17-D20	NOISEX	Observation X Noise Model (ft/s)
D21,D22	KOBREJY	Observation y Reject, 1=Rejected (U16)
D23,D24		Spare
D25-D28	RAW_RESY	Raw Y Component Residual (ft/s)
D29-D32	COR_RESY	Corrected Y Component Residual (ft/s)
D33-D36	NOISEY	Observation Y Noise Model (ft/s)
D37,D38	KOBREJZ	Observation Z Reject, 1=Rejected (U16)
D39,D40		Spare
D41-D44	RAW_RESZ	Raw Z Component Residual (ft/s)
D45-D48	COR_RESZ	Corrected Z Component Residual (ft/s)
D49-D52	NOISEZ	Observation Z Noise Model (ft/s)

5.2.17 DVL Velocity Residual

TYPE: TSTOUT

SID: 14

Table 46: DVL Velocity Residual

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	14
D5,D6	KOBREJX	Observation X Reject, 1=Rejected (U16)
D7,D8		Spare
D9,D12	RAW_RESX	Raw X Component Residual (ft/s)
D13,D16	COR_RESX	Corrected X Component Residual (ft/s)
D17-D20	NOISEX	Observation X Noise Model (ft/s)
D21,D22	KOBREJY	Observation y Reject, 1=Rejected (U16)
D23,D24		Spare
D25-D28	RAW_RESY	Raw Y Component Residual (ft/s)
D29-D32	COR_RESY	Corrected Y Component Residual (ft/s)
D33-D36	NOISEY	Observation Y Noise Model (ft/s)
D37,D38	KOBREJZ	Observation Z Reject, 1=Rejected (U16)
D39,D40		Spare
D41-D44	RAW_RESZ	Raw Z Component Residual (ft/s)
D45-D48	COR_RESZ	Corrected Z Component Residual (ft/s)
D49-D52	NOISEZ	Observation Z Noise Model (ft/s)

5.2.18 Observation Status

TYPE: TSTOUT

SID: 17

Table 47: Observation Status message

DATA BYTES	VARIABLE NAME	DESCRIPTION
D1,D2	KTNAV	Time of Message (20 msec)
D3,D4	IDENT	17
D5,D6	DISCR	Packed Logicals – see below
D7,D8	SOUNDSPD	Computed Speed of Sound (2^{-4}m/s)
D9,D10	DOPTEMP	Doppler Water Temperature (2^{-8}deg c)
D11,D12	SALINITY	Water Salinity (2^{-6}parts per thousand)
D13,D14	IDEPTH	Pressure Depth (ft)
D15,D16	IDY(1)	Kalman Observation Type
D17,D18	VNF	Low - Pass Filter NAV Velocity (ft/sec)
D19,D20	ACCF	Low – Pass Filter NAV Acceleration (ft/sec^2)
D21,D22	(SPARES)	
D23,D24		Observation Latency (10 ms)
D25,D26	NDOP	Number Doppler Samples/Observation (NA)
D27,D30	EH	Pressure Depth Loop Error (ft)
D31,D42	VBODY	Body Frame Inertial Velocity (ft/s)

Discrete word Definition

Bit #	VARIABLE	Description
0	KOBREJ	Kalman Observation Rejection
1	DOBREJ	Motion ZUPT Rejection*
2	MOTION	Motion Detected Flag
3	VDOP	Valid Doppler Used by Kalman
4	VPOS	Valid Position Fix used by Kalman
5		SPARE
6		SPARE
7		SPARE
8	ZUP REJ	ZUPT Observation Reject
9	FORCED ZUP	Manual ZUPT Enabled/Processed
10		Pressure Depth Loop Closed