



**Kearfott**

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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)**  
**(SEADeViL)**

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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<br>9 Aug 1991 | GPS User Equipment Control Document For Instrumentation<br>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,<br>Electrical Characteristics of Balanced Voltage Digital Interface<br>Circuits |
| RS-232-D Jan 1987 | Standard Interface between Data Terminal Equipment and Data<br>Communication Equipment employing Serial Binary Data<br>Interchange       |
| IEC 1010-1 Part 1 | International Engineering Consortium Standard<br>General Requirements                                                                    |

#### NON-KEARFOTT DOCUMENTS

|                                                     |                                                                                                                      |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Navigator Technical Manual<br>October 1997          | RD Instruments Workhorse Navigator<br>Doppler Velocity Log<br>Acoustic Doppler Current Profilers<br>Technical Manual |
| NMEA 0183<br>Version 2.20<br>January 1, 1997        | Standard For Interfacing Marine Electronic Devices                                                                   |
| Thales Navigation<br>630851 Rev. A<br>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.

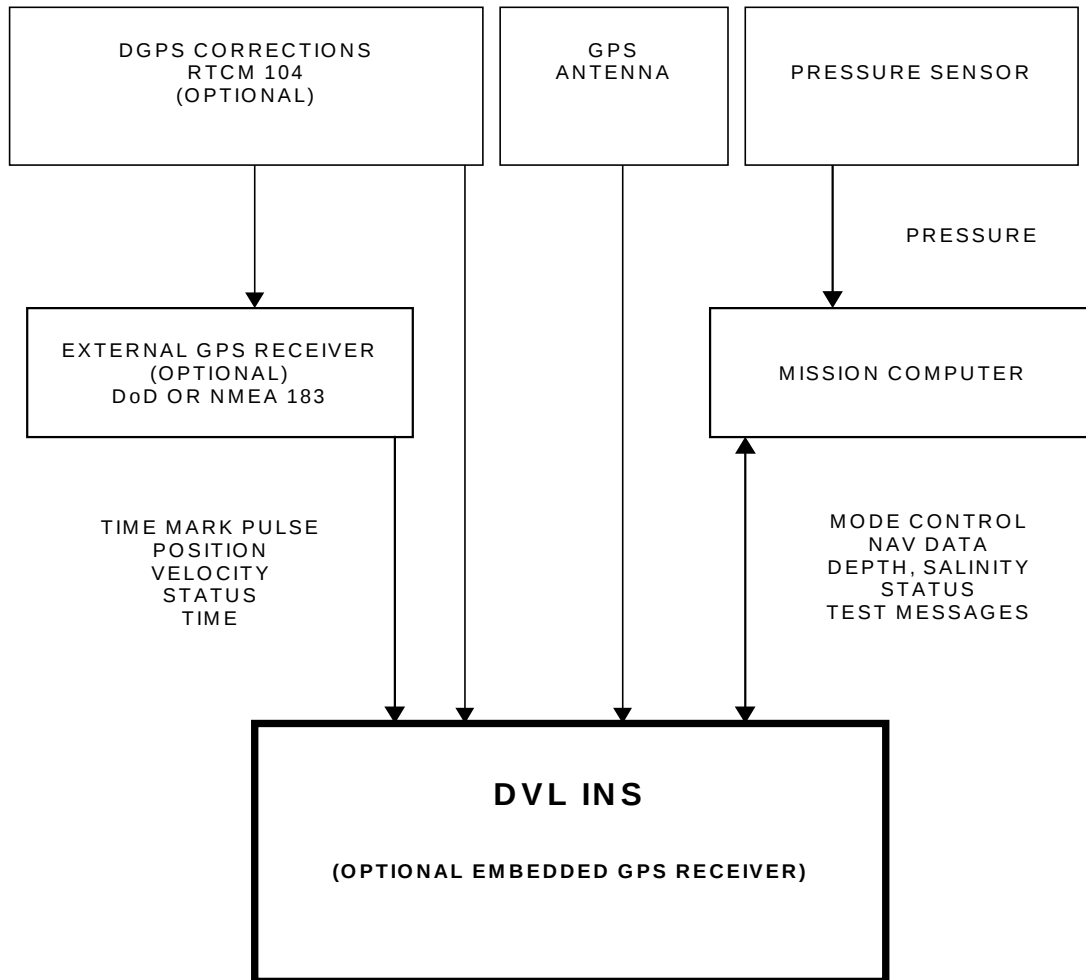


Figure 1: Typical DVL INS Operational Block Diagram

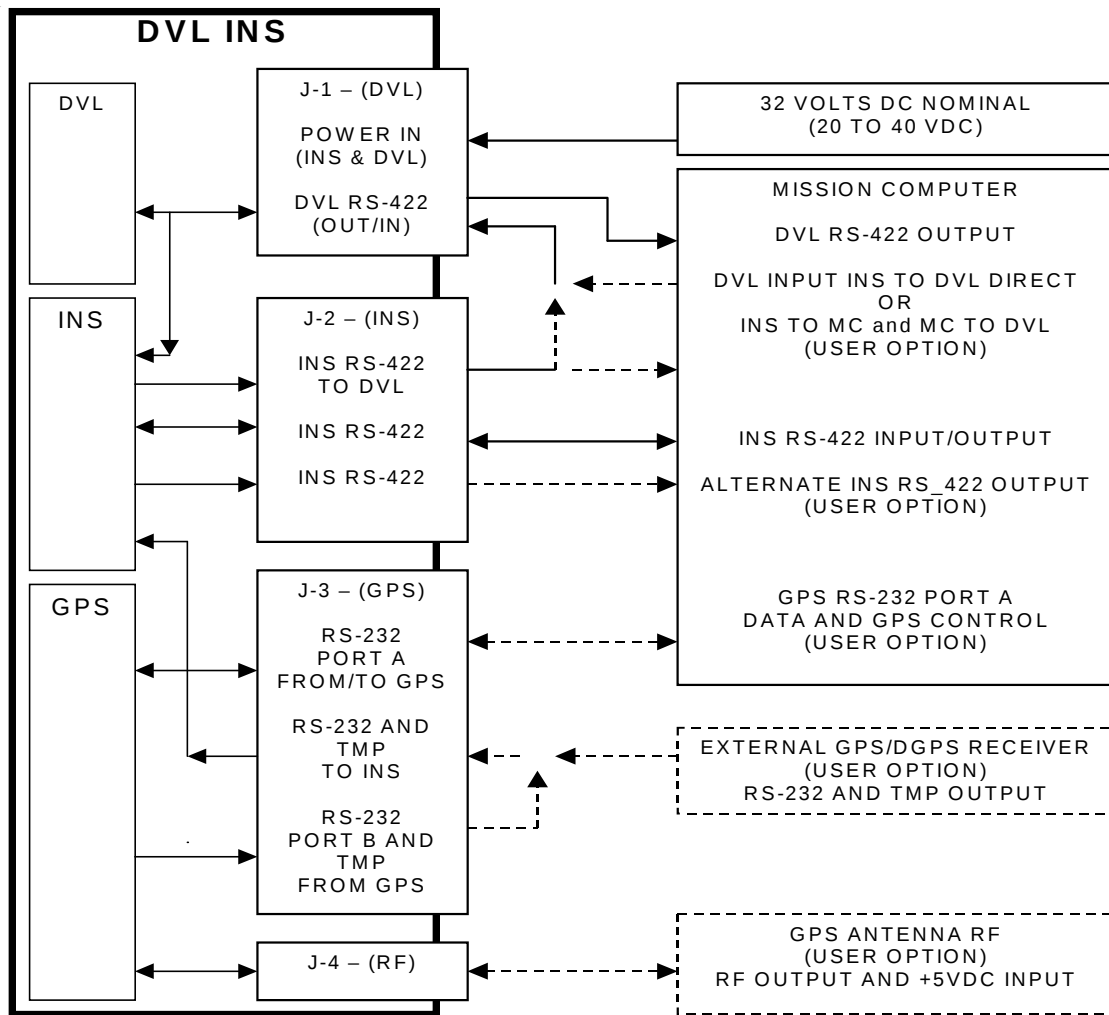


Figure 2: DVL INS Application

### 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

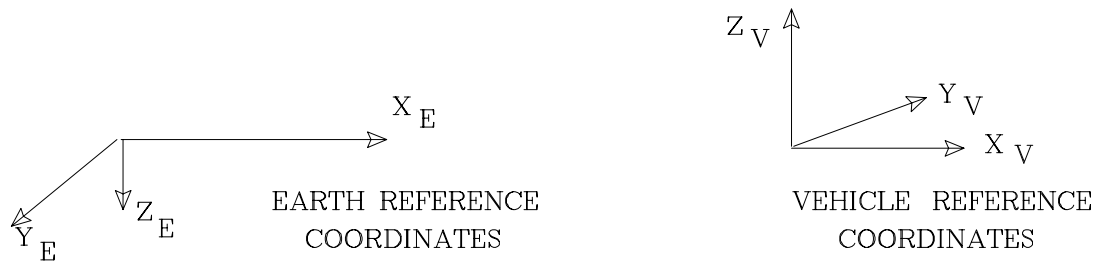
The GPS antenna lever arms, defined in the vehicle frame, are measured from the location of the inertial sensors in the SEANAV to the antenna. The accuracy required of the GPS antenna lever arms is < 25 cm. If these vary from mission to mission, they should be reset accordingly.

##### 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.



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

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

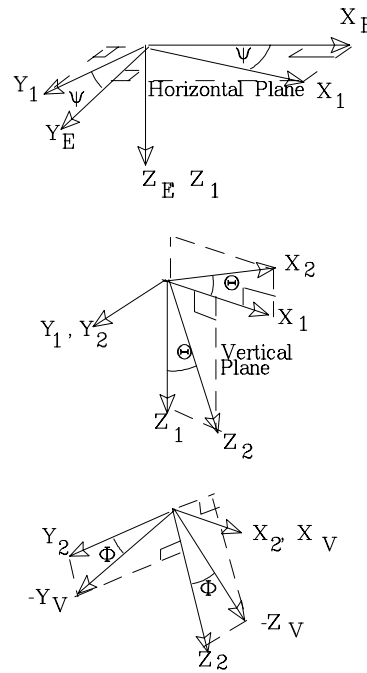
$$\Theta = \begin{bmatrix} \cos \Theta & 0 & -\sin \Theta \\ 0 & 1 & 0 \\ \sin \Theta & 0 & \cos \Theta \end{bmatrix}$$

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

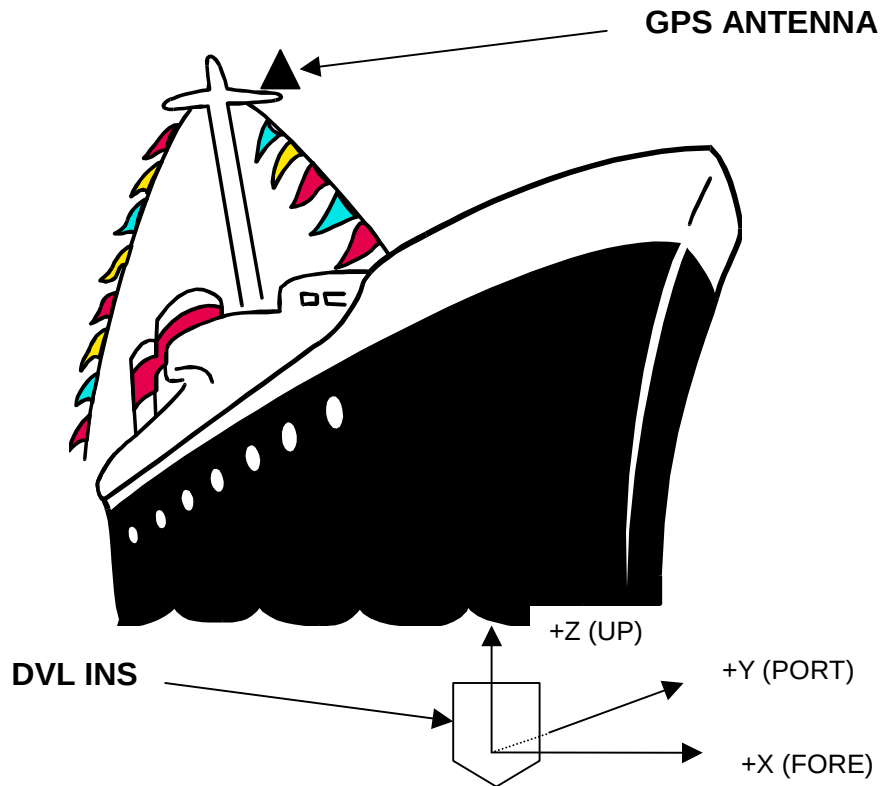
$\Psi$  = AZIMUTH

$\Theta$  = PITCH

$\Phi$  = 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

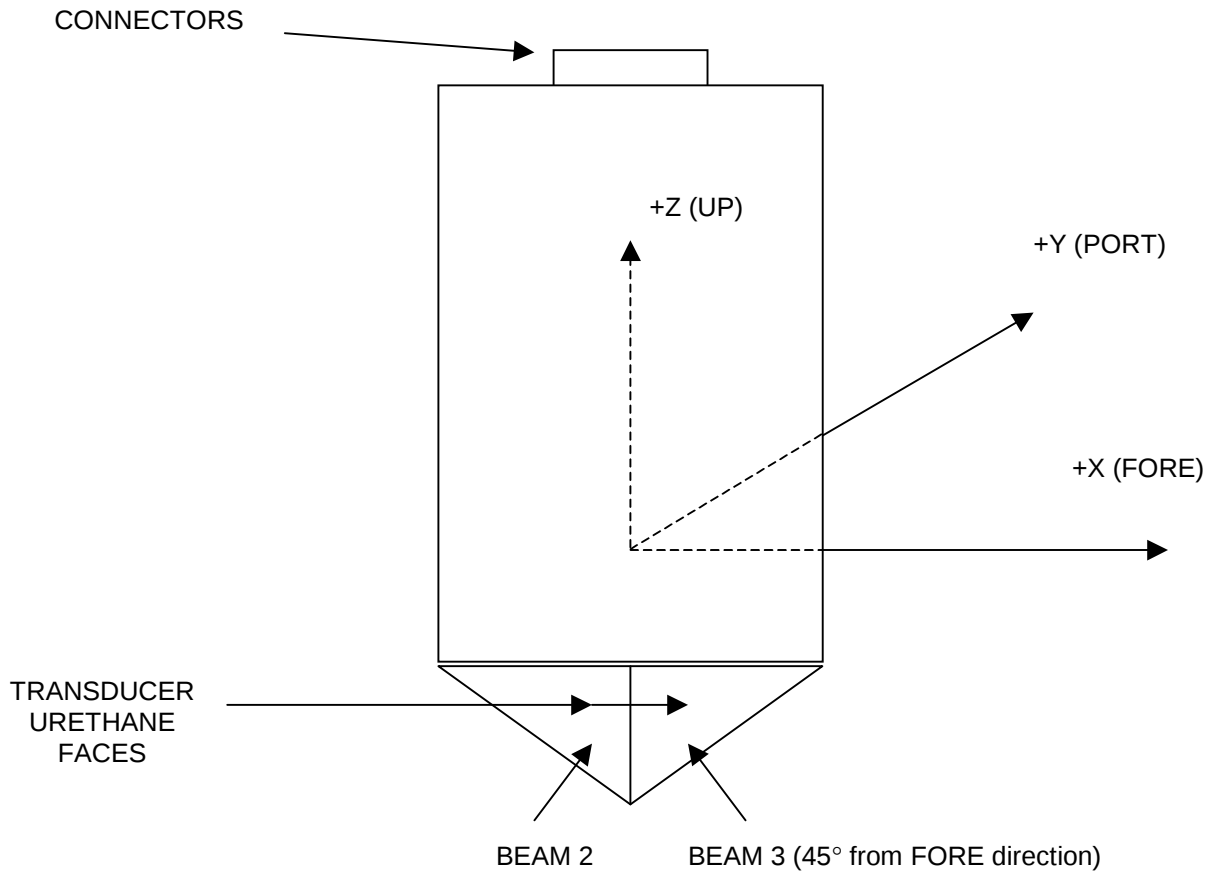
GPS ANTENNA AFT OF DVL INS      X is Negative

GPS ANTENNA PORT OF DVL INS      Y is Positive

GPS ANTENNA ABOVE DVL INS      Z is Positive

Note: Accuracy required  $\approx 25$  cm.

**Figure 4: GPS Antenna Lever Arm Offsets**

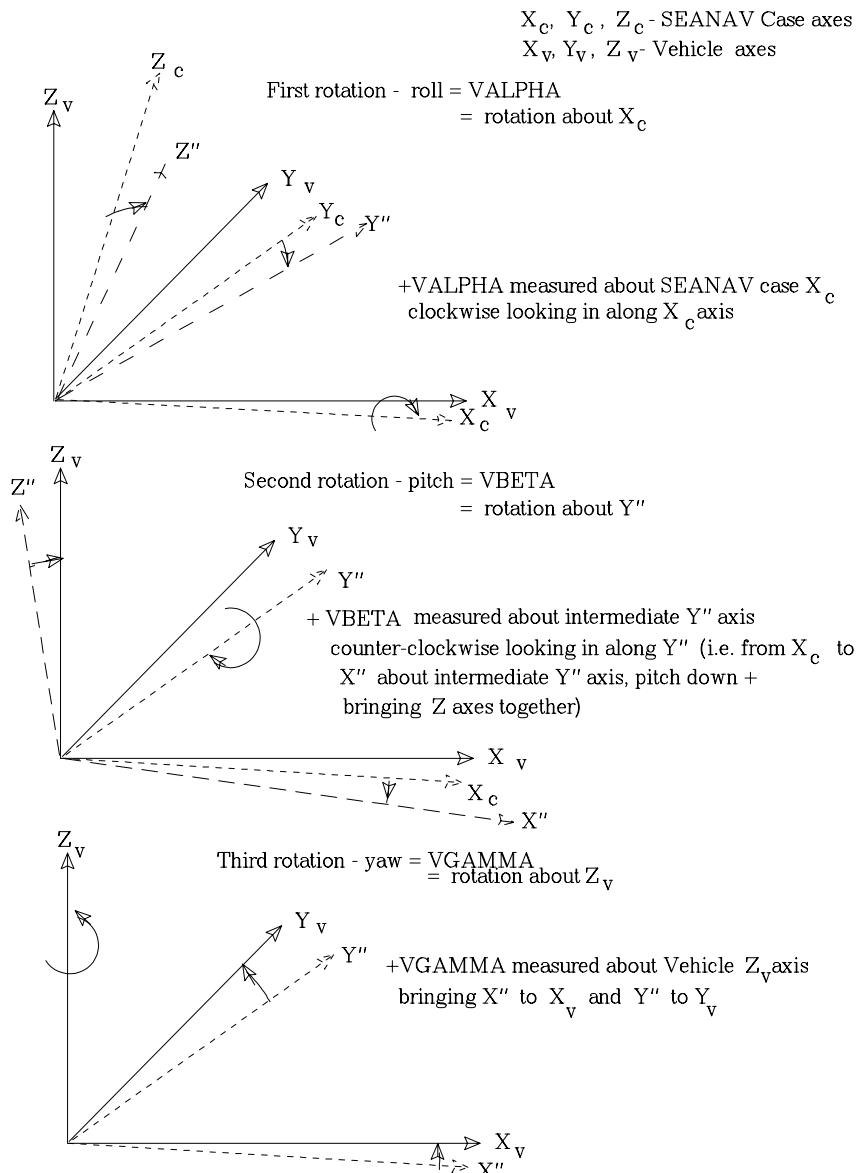


Note: Normal configuration diagram - Viewed from starboard facing port – fore to right.  
DVL beams 1 and 3 are oriented at 45 degrees either side of the vehicle “fore” direction

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  $> 60^\circ$ , 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  $\sigma$  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  $> 60^\circ$  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  $10^\circ$ ) 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.

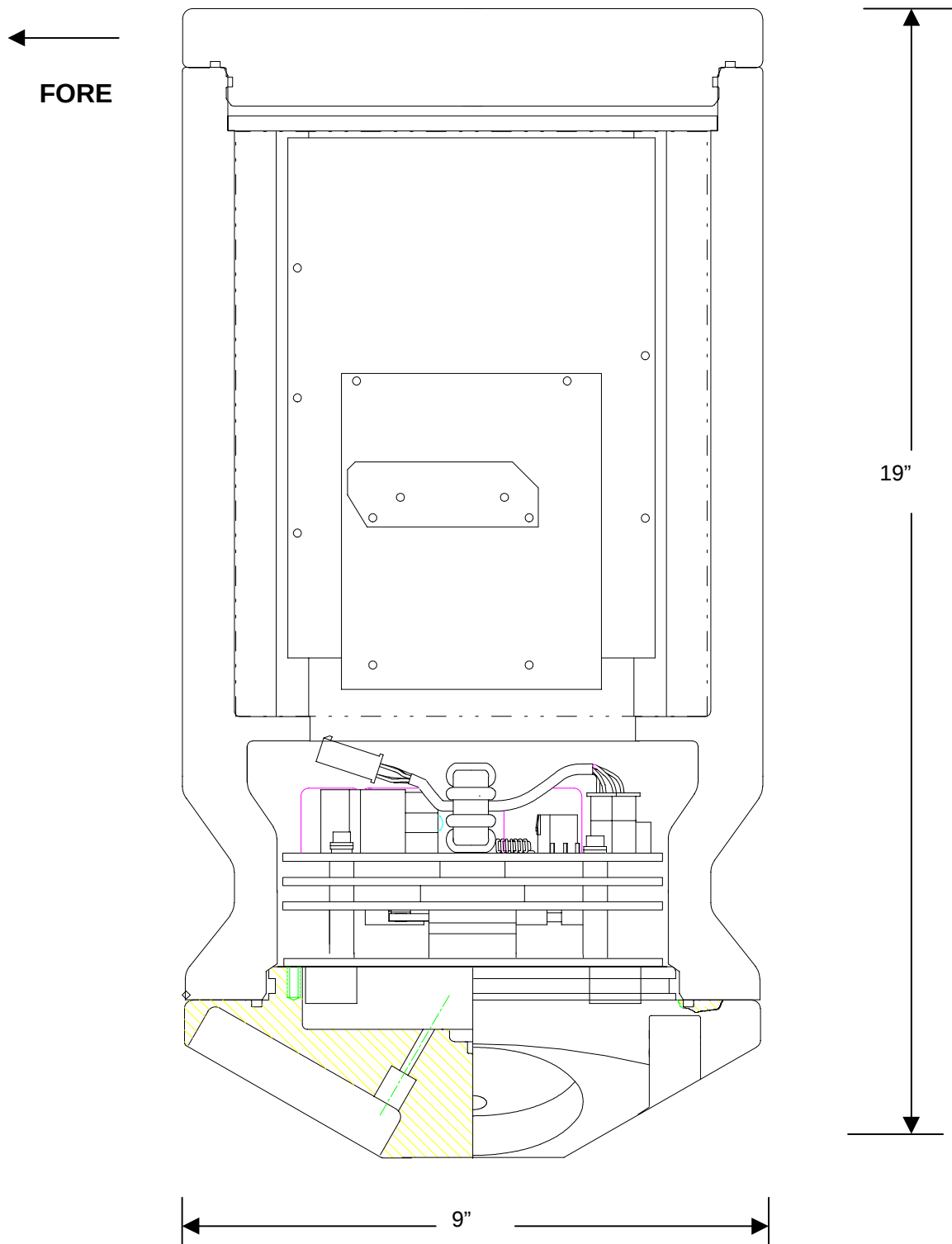
#### 3.4.3 Connector positioning and definition

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<br>RS-422 OUT A<br>(TO INS [INTERNAL]<br>AND COMPUTER)<br>OR RS-232 IN (FROM INS<br>[EXTERNAL] OR<br>COMPUTER) |  | 1   | INS<br>RS-422 OUT HI<br>OR RS-232 OUT<br>(TO DVL)      |  | 1   | GPS<br>RS-232 PORT B OUT<br>(FROM DGPS)             |
| 2   | DVL<br>RS-422 OUT B<br>OR RS-232 OUT<br>(TO INS [INTERNAL RS-<br>422 OR RS-232] AND<br>COMPUTER)                   |  | 2   | INS<br>RS-422 OUT HI<br>(TO COMPUTER)                  |  | 2   | INS<br>RS-232 IN                                    |
| 3   | DVL/INS<br>POWER +                                                                                                 |  | 3   | INS<br>RS-422 IN HI<br>(TO COMPUTER)                   |  | 3   | GPS<br>TIME MARK PULSE<br>OUT (FROM DGPS)           |
| 4   | DVL/INS<br>COMMUNICATION<br>RETURN                                                                                 |  | 4   | GPS<br>RS-422 OUT HI<br>(AUXILIARY OUT TO<br>COMPUTER) |  | 4   | INS<br>TIME MARK PULSE<br>IN (TO INS)               |
| 5   | DVL<br>RS-422 IN A<br>(FROM INS [EXTERNAL]<br>OR COMPUTER)                                                         |  | 5   | INS<br>RS-422 OUT LO (TO<br>DVL)                       |  | 5   | GPS<br>RS-232 PORT A OUT<br>(FROM DGPS)             |
| 6   | DVL<br>RS-422 IN B<br>(FROM INS [EXTERNAL]<br>OR COMPUTER)                                                         |  | 6   | INS<br>RS-422 OUT LO<br>(TO COMPUTER)                  |  | 6   | INS<br>RS-232 OUT                                   |
| 7   | DVL/INS<br>POWER -                                                                                                 |  | 7   | INS<br>RS-422 IN LO<br>(FROM COMPUTER)                 |  | 7   | GPS<br>RS-232 PORT A IN<br>(TO DGPS)                |
|     |                                                                                                                    |  | 8   | GPS<br>RS-422 OUT LO<br>(AUXILIARY OUT TO<br>COMPUTER) |  | 8   | INS<br>TIME MARK PULSE<br>RETURN<br>(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<br>(FROM INS [J2-1] OR MC)  |
| 6 | RS-422 IN B          | DVL RS-422 IN B<br>(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<br>BASELINE CONNECT TO DVL RS-422 IN A<br>(OPTION CONNECT TO DVL RS-232 IN)<br>(OPTION CONNECT TO USER COMPUTER) |
| 5 RS-422 OUT LO | INS RS-422 OUT LO<br>BASELINE CONNECT TO DVL RS-422 IN B<br>(OPTION CONNECT TO USER COMPUTER)                                      |
| 4 RS-422 OUT HI | AUXILIARY INS RS-422 OUT HI<br>(USER OPTION)                                                                                       |
| 8 RS-422 OUT LO | AUXILIARY INS RS-422 OUT LO<br>(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 routes 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 routes 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<br>(TO J3-2 OPTION)                                                    |
| 2 RS-232 IN (INS)             | RS-232 FROM GPS TO INS<br>(ICD-150 BLOCK 03 OR NMEA-183)<br>(EMBEDDED OR EXTERNAL GPS) |
| 3 GPS 1PPS HI OUT             | 1PPS FROM EMBEDDED GPS<br>(TO J3-4 OPTION)                                             |
| 4 TIME MARK PULSE IN<br>(INS) | TIME MARK PULSE OR 1PPS FROM GPS<br>(EMBEDDED OR EXTERNAL GPS)                         |
| 8 TIME MARK RETURN            | MARK PULSE RETURN<br>(FROM EXTERNAL GPS)                                               |
| 5 RS-232 A OUT (GPS)          | RS-232 NMEA<br>(OPTION TO USER)                                                        |
| 7 RS-232 A IN (GPS)           | RS-232 NMEA<br>(OPTION FROM USER)                                                      |
| 6 RS-232 OUT (INS)            | RS-232 TO DoD GPS<br>(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<br>BYTE # | VARIABLE<br>NAME | DESCRIPTION                                                        | UNITS             | INPUT<br>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<br>CORRELATION AND ECHO AMPLITUDE DATA | NA                | U16             |
| D23,D24        | XVELREF          | X-VELOCITY WRT WATER REFERENCE<br>LAYER                            | MM/S              | S16             |
| D25,D26        | YVELREF          | Y-VELOCITY WRT WATER REFERENCE<br>LAYER                            | MM/S              | S16             |
| D27,D28        | ZVELREF          | Z-VELOCITY WRT WATER REFERENCE<br>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<br>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, ≥ 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<br>BIT | LSB<br>B0 | B1 | B2 | B3 | B4 | B5 | B6 | MSB<br>B7 | ODD<br>PARITY | STOP<br>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 <sup>+</sup>           |
| 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 <sup>++</sup> |
| 13         |     | GPS PVT Data A***                           | 62                  | Variable As Input <sup>++</sup> |
| 15         |     | GPS PVT Data B***                           | 62                  | Variable As Input <sup>++</sup> |
| 7          |     | GPS GGA                                     | Variable As Input   | Variable As Input <sup>++</sup> |
| 9          |     | GPS GSA                                     | Variable As Input   | Variable As Input <sup>++</sup> |
| 11         |     | GPS VTG                                     | Variable As Input   | Variable As Input <sup>++</sup> |
| ECHO       |     | Message Echo**<br>(message ID's 2, 4, 6, 8) | Variable As Input   | 50 Hz max                       |

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

Notes:

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

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

<sup>\*</sup> 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".

<sup>\*\*</sup> 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.

<sup>\*\*\*</sup> 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 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<br>(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         |
|----------------------------------------------------------------------|-----------|------------|-------|--------------|
| <u>Message Header: GGA</u>                                           |           |            |       |              |
| 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<br>0=INVALID      1=SPS MODE<br>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     |
|----------------------------------------------------|----------------|-------|--------------|----------|
| <u>Message Header: GSA</u>                         |                |       |              |          |
| MANUAL/AUTO MODE                                   | CHAR           | NA    | 1            | NOT USED |
| FIX MODE 2D/3D<br>1=NO FIX<br>2=2D FIX<br>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<br>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 <sup>-15</sup> | S16          |
| D3,D4      | VBETA         | PITCH BORESIGHT ANGLE, INS TO VEHICLE (-90° to +90°)                     | 180°*2 <sup>-15</sup> | S16          |
| D5,D6      | VGAMMA        | AZIMUTH BORESIGHT ANGLE, INS TO VEHICLE (-180° to +180°)                 | 180°*2 <sup>-15</sup> | 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 <sup>-15</sup> | S16          |
| D29,D30    | EMLPITCH      | PITCH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-90° to +90°)     | 180°*2 <sup>-15</sup> | S16          |
| D31,D32    | EMLROLL       | ROLL BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)    | 180°*2 <sup>-15</sup> | 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<br>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 <sup>-31</sup> | S32             |
| D7-D10                  | INIT LON         | INPUT LONGITUDE (-180° to +180°)                              | 180°*2 <sup>-31</sup> | S32             |
| D11-D14                 | IDEPH            | INPUT PRESSURE DEPTH (NEGATIVE DENOTES ALTITUDE DATA)         | 0.01M                 | S32             |
| D15,D16                 | INITHDG          | INPUT HEADING (-180° to +180°)                                | 180°*2 <sup>-15</sup> | 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<br>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<br>HEXIDECIMAL |
| D4          | MONITOR             | NAVIGATION MONITOR                                                         | NA                           | BINARY<br>DISCRETES  |
| D5-D8       | LAT                 | SYSTEM LATITUDE<br>(-90° to +90°)                                          | $180^{\circ} \times 2^{-31}$ |                      |
| D9-D12      | LON                 | SYSTEM LONGITUDE<br>(-180° to +180°)                                       | $180^{\circ} \times 2^{-31}$ |                      |
| D13-D16     | DEPTH               | SYSTEM (INERTIAL) DEPTH<br>(NEGATIVE DENOTES ALTITUDE) (MSL)               | 0.1M                         | S32                  |
| D17,D18     | BHEIGHT             | HEIGHT ABOVE BOTTOM (FROM DVL)<br>(D4 BIT 0 INDICATES VALID DATA)          | 0.01M                        | U16                  |
| D19,D20     | ROLL                | VEHICLE ROLL ANGLE<br>(-180° to +180°)                                     | $180^{\circ} \times 2^{-15}$ | S16                  |
| D21,D22     | PITCH               | VEHICLE PITCH ANGLE<br>(-90° to +90°)                                      | $180^{\circ} \times 2^{-15}$ | S16                  |
| D23,D24     | HEADING             | VEHICLE TRUE HEADING<br>(0° to +360°)                                      | $180^{\circ} \times 2^{-15}$ | U16                  |
| D25,D26     | VN* or<br>VBODYx    | NORTH VELOCITY (OR VEHICLE X)<br>(-32 M/S TO +32 M/S – LSB)                | $2^{-10} \text{M/S}$         | S16                  |
| D27,D28     | VE* or<br>VBODYy    | EAST VELOCITY (OR VEHICLE Y)<br>(-32 M/S TO +32 M/S – LSB)                 | $2^{-10} \text{M/S}$         | S16                  |
| D29,D30     | VDOWN* or<br>VBODYz | DOWN VELOCITY (OR VEHICLE Z)<br>(-32 M/S TO +32 M/S – LSB)                 | $2^{-10} \text{M/S}$         | S16                  |
| D31,D32     | ACCELX              | VEHICLE X ACCELERATION<br>(-32M/S <sup>2</sup> to 32M/S <sup>2</sup> -LSB) | $2^{-10} \text{M/S}^2$       | S16                  |
| D33,D34     | ACCELY              | VEHICLE Y ACCELERATION<br>(-32M/S <sup>2</sup> to 32M/S <sup>2</sup> -LSB) | $2^{-10} \text{M/S}^2$       | S16                  |
| D35,D36     | ACCELZ              | VEHICLE Z ACCELERATION<br>(-32M/S <sup>2</sup> to 32M/S <sup>2</sup> -LSB) | $2^{-10} \text{M/S}^2$       | S16                  |
| D37,D38     | PRATE               | VEHICLE X AXIS ANGULAR RATE<br>(-4 R/S TO +4 R/S – LSB)                    | $2^{-13}$<br>RADIANS/S       | S16                  |
| D39,D40     | QRATE               | VEHICLE Y AXIS ANGULAR RATE<br>(-4 R/S TO +4 R/S – LSB)                    | $2^{-13}$<br>RADIANS/S       | S16                  |
| D41,D42     | RRATE               | VEHICLE Z AXIS ANGULAR RATE<br>(-4 R/S TO +4 R/S – LSB)                    | $2^{-13}$<br>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<br>HEXIDECIMAL |
|----|-------|-----------------------------------------|----|----------------------|
|    | 00H = | IDLE                                    |    |                      |
|    | 01H = | COARSE STATIONARY ALIGN                 |    |                      |
|    | 02H = | FINE STATIONARY ALIGN - NOT<br>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<br>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 VBODYy = 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°)                | $180^{\circ} \cdot 2^{-15}$ | S16          |
| D3,D4       | VBETA         | PITCH BORESIGHT ANGLE, DVL INS TO VEHICLE (-90° to +90°)                 | $180^{\circ} \cdot 2^{-15}$ | S16          |
| D5,D6       | VGAMMA        | AZIMUTH BORESIGHT ANGLE, DVL INS TO VEHICLE (-180° to +180°)             | $180^{\circ} \cdot 2^{-15}$ | 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°) | $180^{\circ} \cdot 2^{-15}$ | S16          |
| D29,D30     | EMLPITCH      | PITCH BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-90° TO +90°)     | $180^{\circ} \cdot 2^{-15}$ | S16          |
| D31,D32     | EMLROLL       | ROLL BORESIGHT ANGLE, SHIP'S VELOCITY LOG TO VEHICLE (-180° TO +180°)    | $180^{\circ} \cdot 2^{-15}$ | 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<br>BYTE | DATA<br>MNEMONIC | DESCRIPTION                                                      | UNITS   | INPUT<br>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<br>LEVEL (HEIGHT ABOVE ELLIPSOID) | METERS  | DECFP           |
| D45-D48      | GPSALTABS        | GPS WGS-84 ALTITUDE – ABSOLUTE<br>(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<br>BYTE # | DATA<br>MNEMONIC | DESCRIPTION                               | UNITS   | INPUT<br>FORMAT     |
|----------------|------------------|-------------------------------------------|---------|---------------------|
| D1-D4          | SPARE            | RESERVED FOR ACCELERATION EAST            | M/S     | DECFP               |
| D5-D8          | SPARE            | RESERVED FOR ACCELERATION<br>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<br>(SEE NOTE 1)        | NA      | BINARY<br>DISCRETES |
| D31,D32        | CHISTATB         | CHANNEL 1 STATUS B<br>(SEE NOTE 2)        | NA      | BINARY<br>DISCRETES |
| D33,D34        | CH2STATA         | CHANNEL 2 STATUS A<br>(SEE NOTE 1)        | NA      | BINARY<br>DISCRETES |
| D35,D36        | CH2STATB         | CHANNEL 2 STATUS B<br>(SEE NOTE 2)        | NA      | BINARY<br>DISCRETES |
| D37,D38        | CH3STATA         | CHANNEL 3 STATUS A<br>(SEE NOTE 1)        | NA      | BINARY<br>DISCRETES |
| D39,D40        | CH3STATB         | CHANNEL 3 STATUS B<br>(SEE NOTE 2)        | NA      | BINARY<br>DISCRETES |
| D41,D42        | CH4STATA         | CHANNEL 4 STATUS A<br>(SEE NOTE 1)        | NA      | BINARY<br>DISCRETES |
| D43,D44        | CH4STATB         | CHANNEL 4 STATUS B<br>(SEE NOTE 2)        | NA      | BINARY<br>DISCRETES |
| D45,D46        | CH5STATA         | CHANNEL 5 STATUS A<br>(SEE NOTE 1)        | NA      | BINARY<br>DISCRETES |
| D47,D48        | CH5STATB         | CHANNEL 5 STATUS B<br>(SEE NOTE 2)        | NA      | BINARY<br>DISCRETES |
| D49,D50        | FOMWORD          | FIGURE OF MERIT WORD<br>(SEE NOTE 3)      | NA      | BINARY<br>DISCRETES |
| D51,D52        | EHPE             | GPS EXPECTED HORIZONTAL POSITION<br>ERROR | METERS  | U16                 |
| D53,D54        | EVPE             | GPS EXPECTED VERTICAL POSITION<br>ERROR   | METERS  | U16                 |
| D55,D56        | NWRNGPS          | WARNING MESSAGE NUMBER<br>(SEE NOTE 4)    | NA      | U16                 |
| D57,D58        | EQUIPU           | EQUIPMENT USED                            | NA      | BINARY<br>DISCRETES |
| D59-D62        | TFOMWORD         | GPS TIME FIGURE OF MERIT WORD             | NA      | BINARY<br>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<br>0=INVALID<br>1=SPS MODE<br>2=DGPS MODE<br>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<br>1=NO FIX<br>2=2D FIX<br>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<br>BYTES | DATA<br>MNEMONIC | DESCRIPTION                                                        | UNITS | INPUT<br>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<br>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 $\Delta$ VELOCITY | FEET/SEC. | C31 FP       |
| D21,D24    | VBY           | COMPENSATED 100 HZ BODY Y $\Delta$ VELOCITY | FEET/SEC. | C31 FP       |
| D25,D28    | VBZ           | COMPENSATED 100 HZ BODY Z $\Delta$ 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

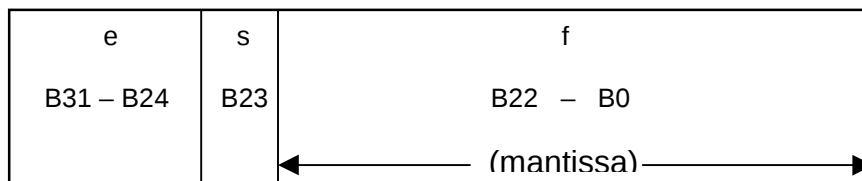
### 5.1.1 C31 Floating Point Format

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  
                  $f = 0$



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 ( $\lambda$ ) | Latitude (radians) Note 1        |
| D41-D48    | LON ( $\phi$ )    | 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 $\sigma$ (ft)                              |
| D9-D12     | PBUF(DRY)     | Y Position $\sigma$ (ft)                              |
| D13-D16    | PBUF(EVX)     | X Velocity $\sigma$ (ft/sec)                          |
| D17-D20    | PBUF(EVY)     | Y Velocity $\sigma$ (ft/sec)                          |
| D21-D24    | PBUF(THX)     | X Tilt $\sigma$ (radians)                             |
| D25-D28    | PBUF(THY)     | Y Tilt $\sigma$ (radians)                             |
| D29-D32    | PBUF(PSIZ)    | Heading $\sigma$ (radians)                            |
| D33-D36    | PBUF(EH)      | Altitude $\sigma$ (ft)                                |
| D37-D40    | PBUF(EVZ)     | Z Velocity $\sigma$ (ft/sec)                          |
| D41-D44    | PBUF(EASFX)   | X Accelerometer Scale Factor $\sigma$ (fraction of 1) |
| D45-D48    | PBUF(EASFY)   | Y Accelerometer Scale Factor $\sigma$ (fraction of 1) |
| D49-D52    | PBUF(EASFZ)   | Z Accelerometer Scale Factor $\sigma$ (fraction of 1) |
| D53-D56    | PBUF((EBXWU)  | X Accel. Bias Warm-up $\sigma$ (ft/sec**2)            |
| D57-D60    | PBUF(EBYWU)   | Y Accel. Bias Warm-up $\sigma$ (ft/sec**2)            |
| D60-D64    | PBUF(EBZWU)   | Z Accel. Bias Warm-up $\sigma$ (ft/sec**2)            |

Note: The output position quality can be estimated by computing the following parameters:

$$\text{CEP}(50\%) = 0.589 * (\text{PBUF}(\text{DRX}) + \text{PBUF}(\text{DRY}))$$

$$\text{CEP}(95\%) = 2.08 * \text{CEP}(50\%)$$

## 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 $\sigma$ (ft/sec**2)                |
| D9-D12     | PBUF(EBY)     | Y Accelerometer Bias $\sigma$ (ft/sec**2)                |
| D13-D16    | PBUF(EBZ)     | Z Accelerometer Bias $\sigma$ (ft/sec**2)                |
| D17-D20    | PBUF(EDX)     | X Gyro Bias $\sigma$ (radians/sec)                       |
| D21-D24    | PBUF(EDY)     | Y Gyro Bias $\sigma$ (radians/sec)                       |
| D25-D28    | PBUF(EDZ)     | Z Gyro Bias $\sigma$ (radians/sec)                       |
| D29-D32    | PBUF(SINA)    | Sin(heading misalignment) $\sigma$ (N/A)                 |
| D33-D36    | PBUF(OMCOSA)  | 1-Cos(heading misalignment) $\sigma$ (N/A)               |
| D37-D40    | PBUF(EEMB)    | Velocity Log Bias Error $\sigma$ (ft/s)                  |
| D41-D44    | PBUF(EEMSF)   | Velocity Log Scale Factor Error $\sigma$ (fraction of 1) |
| D45-D48    | PBUF(EEMA)    | Velocity Log Azimuth Boresight error $\sigma$ (radians)  |
| D49-D52    | PBUF(EEMP)    | Velocity Log Pitch Boresight error $\sigma$ (radians)    |
| D53-D56    | PBUF(DSLAT)   | Error of sine of latitude $\sigma$ (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 $\sigma$ (fraction of 1) |
| D9-D12     | PBUF(EDOPXZ)  | Z into X Doppler Cross Coupling $\sigma$ (fraction of 1) |
| D13-D16    | PBUF(EDOPYX)  | X into Y Doppler Cross Coupling $\sigma$ (fraction of 1) |
| D17-D20    | PBUF(EDOPYZ)  | Z into Y Doppler Cross Coupling $\sigma$ (fraction of 1) |
| D21-D24    | PBUF(ZX)      | X into Z Doppler Cross Coupling $\sigma$ (fraction of 1) |
| D25-D28    | PBUF(ZY)      | Y into Z Doppler Cross Coupling $\sigma$ (fraction of 1) |
| D29-D32    | PBUF(EWCURX)  | X Water Current $\sigma$ (ft/s)                          |
| D33-D36    | PBUF(EWCURY)  | Y Water Current $\sigma$ (ft/s)                          |
| D37-D40    | PBUF(EDOPBX)  | X Doppler Bias $\sigma$ (ft/s)                           |
| D41-D44    | PBUF(EDOPBY)  | Y Doppler Bias $\sigma$ (ft/s)                           |
| D45-D48    | PBUF(EDOPBZ)  | Z Doppler Bias $\sigma$ (ft/s)                           |
| D49-D52    | PBUF(EDOPSFX) | X Doppler Scale Factor $\sigma$ (fraction of 1)          |
| D53-D56    | PBUF(EDOPSFY) | Y Doppler Scale Factor $\sigma$ (fraction of 1)          |
| D57-D60    | PBUF(EDOPSFZ) | Z Doppler Scale Factor $\sigma$ (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    | IDPTH         | 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 <sup>2</sup> ) |
| 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        |