Application Note

INS + DVL calibration

iXblue

Revision History

Edition	Date	Comments
A	11/2018	Creation
B	05/2019	Appendix D & chapter 6 updated
C	05/2019	Update GPS to GNSS screen captures
D	11/2019	Chapters 4 & 6.3 & 6.4 & 7.2 updated
E	12/2019	Chapter 6.3 updated
F	03/2020	Web-based graphical user interface updates, news criteria, new control commands
G	11/2020	Chapter 7.2.2 updated
H	10/2022	Chapters 3, 6, 7, 8 and Appendix D updated

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1 Object

This document is an addendum to the INS user manuals.
This document points out the calibration procedure for an INS associated to a RDI Workhorse DVL and NORTEK DVL. This procedure applies to a detached DVL or to a “DVL ready”[1] system.

This document describes the method to calibrate the misalignment between the INS and the DVL and speed scale factor residual error of the DVL. It applies to Phins Surface, Marins, Phins Subsea, Rovins, Rovins Nano and Phins Compact Series products.

All the mechanical drawings are provided on the product flash drive.

Do not hesitate to contact iXblue technical support for further information: support@ixblue.com

[1] INS unit mechanically coupled to DVL.

2 Reference documents

- RDI Documentation
  - > Navigator Technical Manual_Nov06 (P/N 957-6172-00, November 2006)
  - > Navigator ADCP/DVL user guide P/N 957-6173-00 (September 2002)
  - > Application Note FSA018 (November 2004) Pioneer DVL Guide_Aug21
  - > Tasman DVL Guide_Jan22
- Nortek Documentation
  - > N3015-005 Quick Guide DVL (2022)
  - > N3015-006 DVL Operations (2022)
  - > N3015-008 Nortek DVL Integrators Guide (2022)

3 Firmware restrictions

This specification and procedure for RDI Workhorse DVL is only applicable starting from the following INS firmware version:

Designation	Version
Interface Board Firmware	FrmWCINT_INS_6_41
DSP Board Firmware	FrmWDSP4_INS_5_60
Web MMI	Web_xxxxxx_5.10-1.92.1

This specification and procedure for RDI Pioneer, Tasman & Nortek DVL is only applicable starting from the following INS firmware version (Pack 12.1.10):

Designation	Version
Interface Board Firmware	FrmWCINT_INS_6_55_3_1_1
DSP Board Firmware	FrmWDSP4_INS_6_43_5_1
Web MMI	Web_MMI_5.76.4-1.125.58.1

4 Required Tools for INS/DVL Calibration

All the DVL and product drawings are available on the product flash drive.

The following equipment are required:

- INS test cable to power and configure the system.
- CTD or SVP probe to enter sound velocity into INS.
- CTD or SVP to INS cable
- DVL interface plate
- DVL to INS cable
- RDI or Nortek DVL test cable to set DVL parameters directly
- INS power supply
- DVL power supply
- Hercules setup to communicate with INS repeater interface through:
  - > Serial interface:
    - Baud rate: 57600 bauds
    - Parity: Odd
    - Stop bits: 2
  - > Ethernet interface: TCP/IP port 8110.

Use a separate power supply for INS and DVL. Refer to the Product Technical Description to get details on the power supply definition.
Do not use INS power supply to power both systems.

5 Navigation performance specification

The navigation performance commercial specification is defined as:

- 0.05 % DT CEP50 for Phins Subsea & Phins Compact C7
- 0.10 % DT CEP50 for Phins Surface, Marins, Rovins and Phins Compact C5
- 0.20 % DT CEP50 for Rovins Nano & Phins Compact C3
- CEP50: Circular Error Probability of 50 %

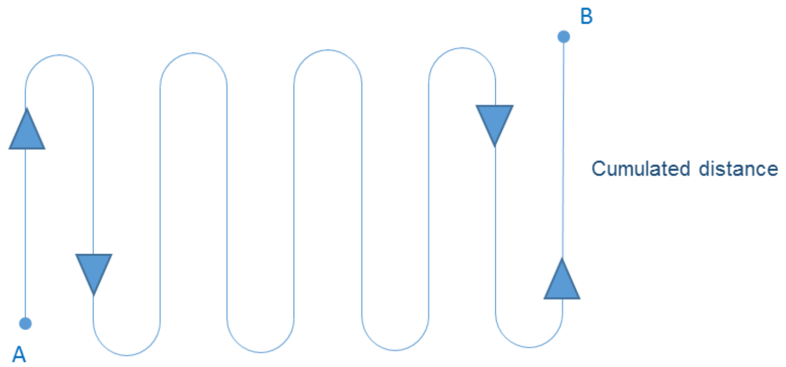
  This means that if you perform 100 verification lines more than 50 of them should have a position drift below 0.1% of distance travelled. This of course is not practical, so we need to convert this value into an operational value. Making the assumption that position errors are Gaussian random errors, then CEP50 error converts into Distance Root Mean Square (DRMS) error as follow:

  > 1DRMS_Error = 0.85 of CEP50, it is the distance root mean square error, in this case there is a 66% probability to have a position drift within this value.

  > 2DRMS_Error = 1.70 of CEP50, it is the distance root mean square error, in this case there is a 95% probability to have a position drift within this value.

  > 3DRMS_Error = 2.55 of CEP50, it is the distance root mean square error (is commonly considered as the maximum error), in this case there is a 99% probability to have a position drift within this value.

- The distance travelled (DT) is the cumulated distance from the beginning of the navigation when the calibration process begins. This is depicted below:



- The Position drift (error) is the horizontal position error between the reference (RTK GNSS) and the INS+DVL coupling result.

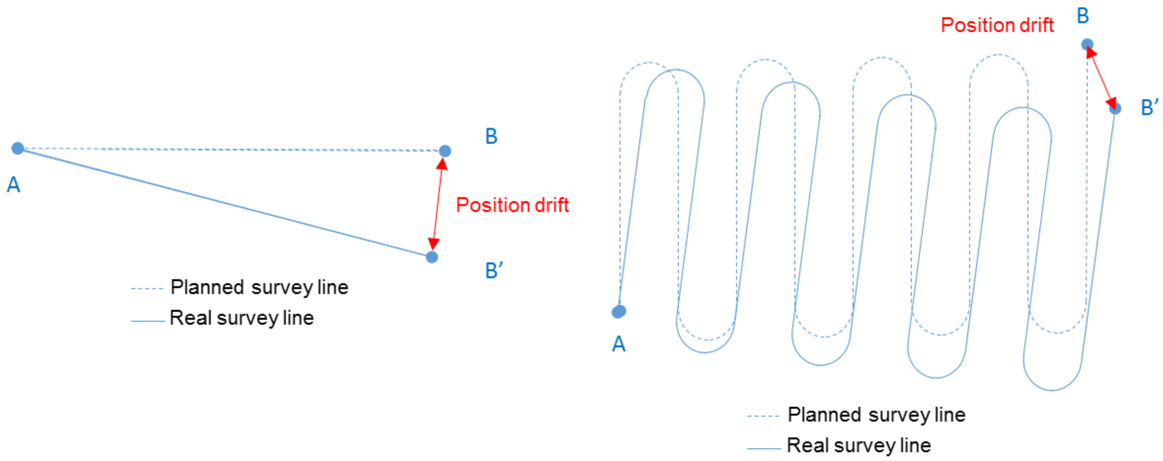


Figure 1 - DVL calibration misalignment Error or INS heading error

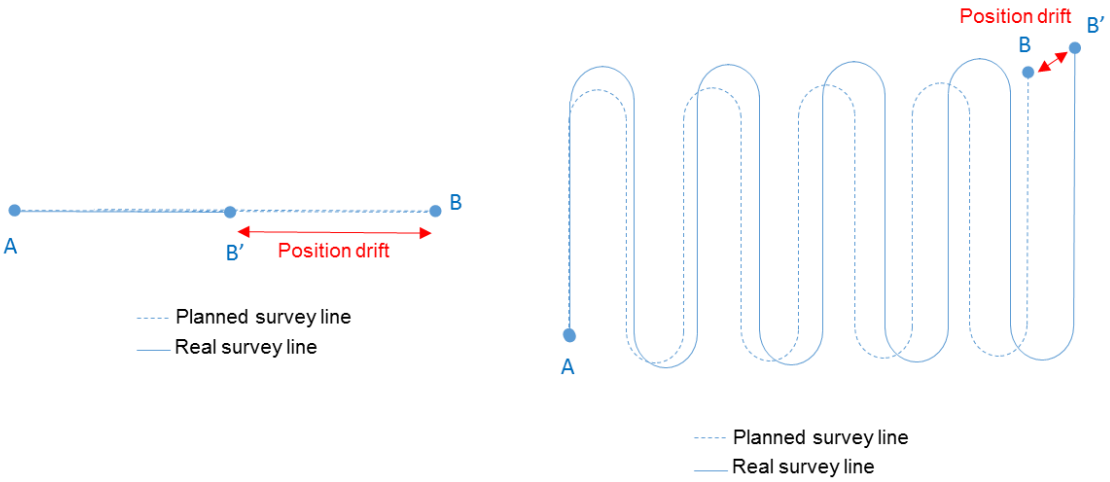


Figure 2 - Sound velocity error or DVL speed scale factor error

6 Performance pre-requisites

We recommend the following configuration to obtain the best performances:

- Use an SVP probe with a sound velocity accuracy better than ±0.1 m/s.
- Use preferably the serial interface to minimize the latency effect and avoid Ethernet / serial converters that will bring uncontrolled latency.
- The calibration process will **only** use the bottom track velocity.
- To optimize the performance (scale factor estimation), the calibration shall be performed at mid-range of the DVL.
- The range to bottom variation (distance between the DVL and the bottom) during the calibration process shall be limited at 15 m max.
- When the calibration process start, the INS will apply a predetermine DVL SD function to the following conditions:

Protocols	DVL SD
NORTEK DF21/22	2.5 cm/s
PD0 & Phased Array	2.5 cm/s
PD0 & Piston	5.0 cm/s
Others	≥ 5.0 cm/s

- If for any reason (quality integration, latency, lever arm accuracy etc..) the INS starts to reject the DVL during a too long time (more than 10 % of time), the “Advanced parameters” can be enabled (web-based graphical user interface or through control command) to override this value with an appropriate value (refer to the Product Installation & Setup Guide to get more details on this mechanism).
- The calibration feature is a metrology process which estimates the DVL scale factor error and mechanical misalignments (heading & pitch):
  - For SURFACE application, we strongly encourage the use of RTK GNSS, which will offer the best result with a minimum of calibration time. If RTK is not an option, use at least a Differential GNSS (or SBAS) to keep a reasonable ratio between quality result and calibration time. On Surface, if a Depth sensor is not available, the “Altitude mode” can be set to GPS.
  - For SUBSEA application, a USBL positioning sensors can be used, but the calibration process accuracy will be affected by the bias celerity and environmental noise. On Subsea, the Depth sensor **is required**, the “Altitude mode” must be set to Depth.

7 DVL Configuration

7.1 Hardware Configuration

To meet iXblue performance specifications, you must send sound velocity data to one of the INS inputs to get an accurate DVL speed scale factor compensation (refer to the Appendix E Influence of Temperature, Salinity and Depth on Sound Velocity).

7.2 Direct Configuration of the DVL

You can configure the DVL by connecting the DVL test cable to a PC.
It is recommended to use Hercules setup software which can be downloaded following this link: https://www.hw-group.com/software/hercules-setup-utility
Then double-click on the setup file and install the software.

It is convenient to use **Hercules setup 3.2.8** to send a break or an auto-detect to the DVL. Alternatively for INS generation III you can configure DVL through the INS Web-based interface using the DVL sensor control window (recommended). This avoids disconnecting the DVL cable especially on "DVL Ready" systems, product + DVL.
Refer to Appendix A and Appendix B.

7.3 RDI Workhorse DVL Setting

This is the best recommended configuration. It applies for all cases: setup with an SVP or CTD (compulsory to meet full INS+DVL position specification) or setup without SVP or CTD. It also deals with the case where DVL has a pressure probe option (EZ command).

Here are the settings that need to be changed from default factory values (refer to RDI, Navigator Technical Manual_Nov06, P/N 957-6172-00, November 2006) for default factory values. Settings in black are permanent. Settings in **red** should be updated prior to operation.

Command	Description
@	Break command
CR1	To load the default factory setting.
PD6	To select PD6 output protocol.
EX01010	EX01xxx: Instrument coordinates. X, Y, Z vectors relative to the ADCP. Heading/Pitch/Roll not applied. EXxxx1x Allows 3-beam solutions if one beam is below the correlation threshold set by default WC setting.
EZ1000001	DVL calculates speed of sound using manually entered salinity, DVL internal temperature sensor and manually entered depth unless depth option is available EZ should be set to **EZ1100001** to use internal depth sensor. **EZxx000xx** means that we do not use DVL internal heading and tilt sensors. The INS will correct speed measurement using the SVP or CTD speed by applying a scale factor correction: (EC value/ SVP value). Although we could use a fixed EC=1500 m/s value it can useful, for quality control or trouble shooting, to compare consistency of DVL calculated sound velocity to SVP sound velocity.

EZ*cdhprst*

Field		Value = 0	Value = 1	Value = 2	Value = 3
c	Speed of Sound	Manual #EC	Calculate using ED, ES and ET	N/A	Use SVSS Sensor
d	Depth	Manual #ED	Depth Sensor	N/A	N/A
h	Heading	Manual #EH	Internal Transducer Sensor	N/A	User NMEA HDT
p	Pitch (tilt1)	Manual #EP	Internal Transducer Sensor	N/A	N/A
r	Roll (tilt2)	Manual #ER	Internal Transducer Sensor	N/A	N/A
s	Salinity	Manual #ES	N/A	N/A	N/A
t	Temperature	Manual #ET	Internal transducer sensor	N/A	N/A

Command	Description
ES35	Manual salinity is set to default salinity 35. If you want an accurate estimation of DVL sound velocity when no external SVP sensor is available of for quality control, you must set salinity with an accuracy better than << ± 1°/°°, before starting calibration or operation.
ED00000	Manual depth is set to default value 0. If you want an accurate estimation of DVL sound velocity in the situation where no external SVP sensor is available or for quality control, you must set depth with an accuracy better than of ± 100 m, before calibration or operation.
TE00:00:00:20	To set ping recurrence to 200 ms (5 Hz).
BK0	Bottom track only.
CB811[2]	115200, None, 1 stop bit (this high speed is to limit latency of data due to length of ASCII PD6 protocol).
CK	To save settings. Send a break and verify that the settings were saved with the **PD?**, **EX?**, **EZ?**, **ES?**, **ED?**, **TE?**, **BK?**, **CB?** commands.
CS	To start pinging.

[2] If the baud rate was set to another value, in order to change it you must perform the following sequence if you are using the broadcast feature: send the CBnnn change the baud rate in INS settings, then CK command to save this setting and then CS command.

7.4 RDI Pioneer & Tasman DVL Setting

This is the best recommended configuration.
It applies for all cases: setup with an SVP or CTD (compulsory to meet full INS+DVL position specification) or setup without SVP or CTD. It also deals with the case where DVL has a pressure probe option.

Here are the settings that need to be changed from default factory values (refer to RDI, Pioneer & Tasman guide) for default factory values.
Settings in black are permanent. Settings in **red** should be updated prior to operation.

Command	Description
@	Break command
CR1	To load the default factory setting.
PD0	To select PD0 output protocol (available also for WHN DVL).
EX01010	EX01xxx: Instrument coordinates. X, Y, Z vectors relative to the DVL. Heading/Pitch/Roll not applied. EXxxx1x: Allows 3-beam solutions if one beam is below the correlation threshold set by default WC setting.
EZ00000010	EZ set to EZ00000010 apply the speed of sound fixed by EC value. EZ set to EZ11000010 apply the internal speed of sound computation based on salinity manually entered, internal temperature sensor and internal depth sensor (if option is available). EZ set to Ezxx000xxx means that we do not use DVL internal heading and tilt sensors. The INS will correct speed measurement using the SVP or CTD in applying a scale factor correction: EC value/ SVP. The internal Speed of Sound computation is useful to control the external SV integrity. If for any reason it starts to send inconsistent information, the INS will use instead the last valid speed of sound measurement.

EZ*cdhprstu*

Field		Value = 0	Value = 1
c	Speed of Sound	Manual #EC	Calculates using available depth, salinity and temperature
d	Depth	Manual #ED	Internal Keller pressure sensor
h	Heading	Manual #EH	Internal AHRS
p	Pitch (tilt1)	Manual #EP	Internal AHRS
r	Roll (tilt2)	Manual #ER	Not used (Roll source specified by Pitch field)
s	Salinity	Manual #ES	Not Allowed
t	Temperature	Manual #ET	Internal transducer sensor
u	Up/Down Orientation	Manual #EU	Not Allowed

Command (*)	Description
@	Break command
#EE0000000	Switch off Vertical Corrections (only for Phased array DVL)
ES35	Manual salinity is set to default salinity 35. If you want an accurate estimation of DVL sound velocity when no external SVP sensor is available of for quality control, you must set salinity with an accuracy better than << +/- 1°/°°,before starting calibration or operation.
ED00000	Manual depth is set to default value 0. If you want an accurate estimation of DVL sound velocity in the situation where no external SVP sensor is available or for quality control, you must set depth with an accuracy of +/- 0.5 m, before calibration or operation.
#BJ 100 101 000	Command to enable the Bottom Track High Resolution Velocity Format & Navigation Parameters Data Format (only for Phased array DVL). This command will enable additional information into the PD0 protocol to improve the navigation quality.
TE00:00:00:20	To set ping recurrence to 200 ms (5 Hz).
BK0	Bottom track only.
CB811[3]	Serial: • Baud rate: 115200 bauds • Parity: None • Stop bits: 1
CK	To save settings.
CS	To start pinging.

(*) To retrieve the current DVL parameter the « ? » character can be used. For example: PD?, ES?, ED?

[3] If the baud rate has been set to another value, in order to change it you must perform the following sequence if you are using the broadcast feature: send the CBnnn change the baud rate in INS settings, then CK command to save this setting and then CS command.

7.5 NORTEK DVL Setting

This is the best recommended configuration that can be setup through the INS web MMI (see Appendix A) or by using the Nortek MMI (in this case, refer to the N3015-006 DVL Operations document).

It applies for all cases: setup with an SVP or CTD (compulsory to meet full INS+DVL position specification) or setup without SVP or CTD. It also deals with the case where DVL has a pressure probe option.

Here are the settings that need to be changed from default factory values (refer to Nortek notice: N3015-008 Nortek DVL Integrators Guide) for iXblue values.

Settings in black are permanent. Settings in **red** should be updated prior to operation (except

"DVL-ready" system, it has been already configured by iXblue).

Command (*)	**Description**
K1W%!Q	Stop ping
MC	Switch on Command mode
SETBT,DF=21	Protocol Binary Nortek protocol selected for Bottom track data
SETBT,RANGE=75.00 SETBT,RANGE=180.00	Range max of the DVL @75m (1 MHz version) Range max of the DVL @180m (500 kHz version)
SETCURPROF,CY="XYZ"	Ship frame
SETCURPROF,CH=0	All beams are used
When used in salt water: **SETDVL,SA=35.0** **When used in fresh water:** **SETDVL,SA=0.0**	When the DVL in salt water set the salinity to 35 ppm When the DVL in fresh water set the salinity to 0 ppm
SETDVL,SV=1500	Speed of sound fix to 1500 m/s
SETDVL,SR=3	Sample rate at 3 Hz (not configured by default)
SETINST,BR=115200	Serial baud rate: 115200 bauds
SAVE,CONFIG	Save the current parameters
START	Switch on « continuous measurement » mode

(*) All « SET » command can be modified into « GET » command to retrieve the current DVL parameter.

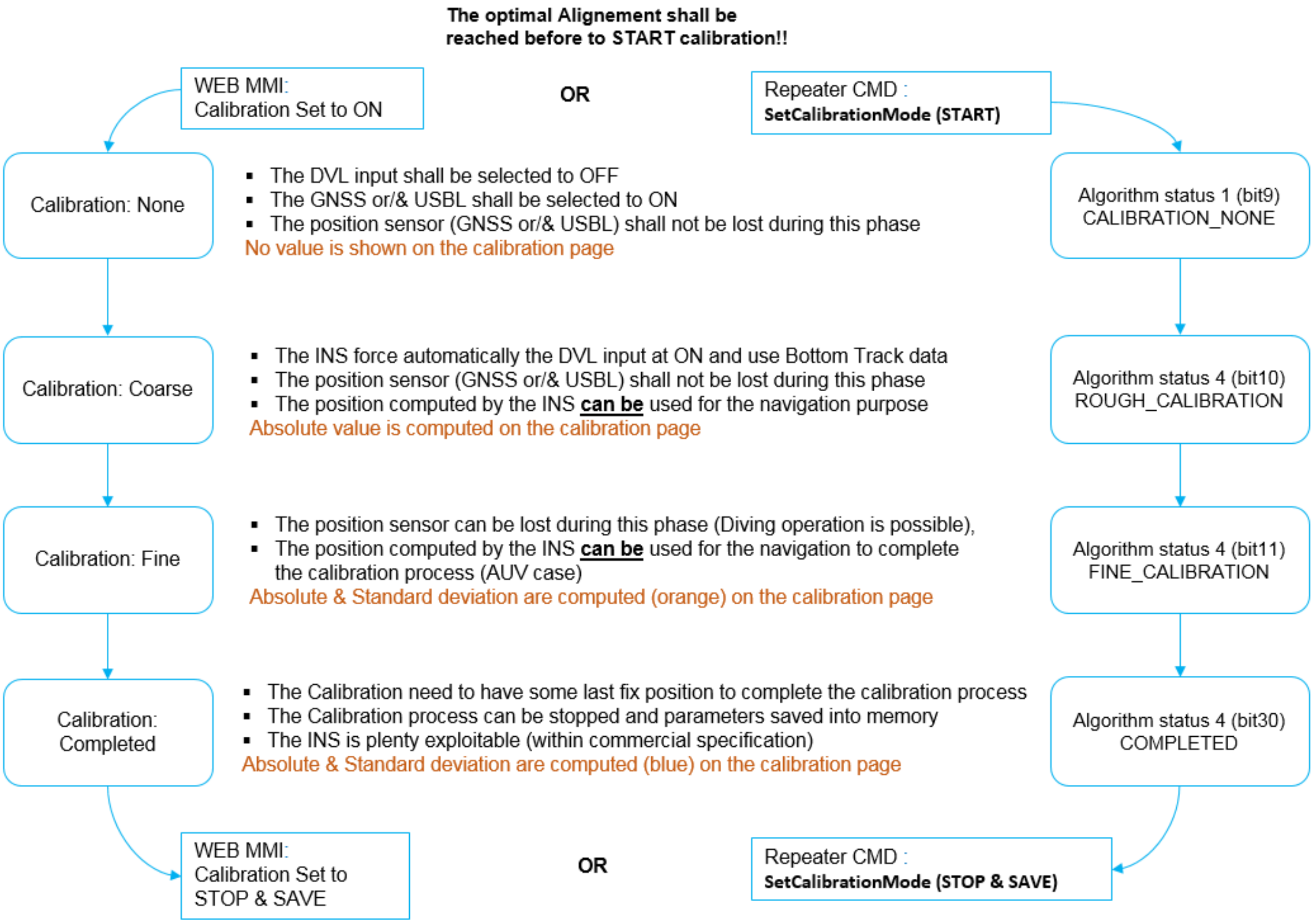
For example: « SETBT,RANGE=75 » can be modified to « GETBT,RANGE ».

8 Calibration Procedure

Calibration can be performed:

- with GNSS at the surface (highly recommended) or using USBL positioning system if the calibration cannot be done at the surface ;
- with surface GNSS, followed by a dive and a final surfacing with GNSS to complete the calibration.

8.1 DVL Calibration Algorithm Workflow



Refer to the Product Interface Library to get information on the algorithm status.

8.2 Calibrating DVL1

8.2.1 SYSTEM CONFIGURATION

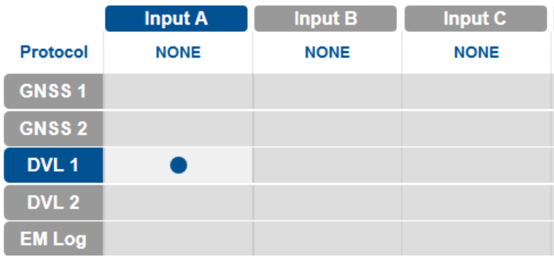
Step **Action**

1. Configure **DVL1** input.

DVL type	Protocol	Baud rate	Parity	Stop bit	DVL type
Nortek	Nortek DF21 22	115200 bauds	None	1	Standard
RDI Workhorse	RDI PD6	115200 bauds	None	1	Standard
RDI Pioneer RDI Tasman	RDI PD0	115200 bauds	None	1	Phased Array

To get the specified performance, use specified protocol.

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **INPUTS** option:



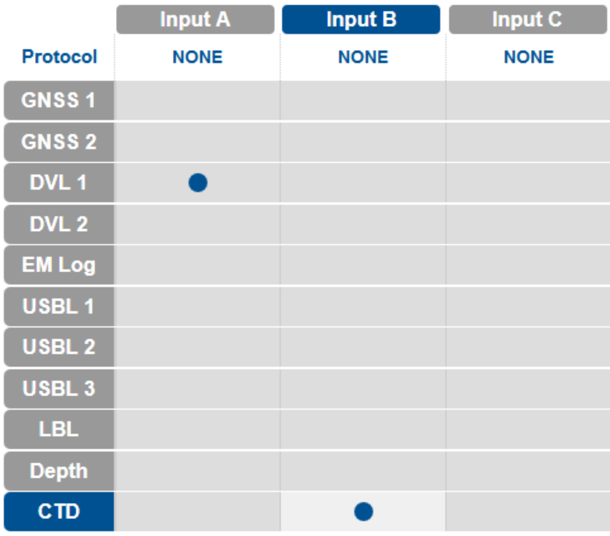
- Select **DVL1** on the chosen port.
- Then set **INPUT X** (X= A, B,...G) SETTINGS.
- Then enter **DVL lever arms** with an accuracy of 5 cm in the DVL1 SETTINGS Lever Arms parameters. Refer to Appendix C for lever arm values of INS "DVL ready" systems.
- For a coupled INS+DVL system, enter **DVL misalignment**: -45°
- In the **DVL** input, tick the **DVL coupled to system** box. If this ticked box is ticked, the DVL calibration values will be updated if user misalignment is modified.

- Enter the appropriate **DVL type** "Standard" (Piston) or "Phased Array"

- Save the setting by clicking on the **OK** button.
- You can check data is received with "DVL reception" status displayed on the main CONTROL page (only with DVL in the water and has bottom lock).

Step	Action
2.	Configure **SVP** input of 1 Hz:

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **INPUTS** option.

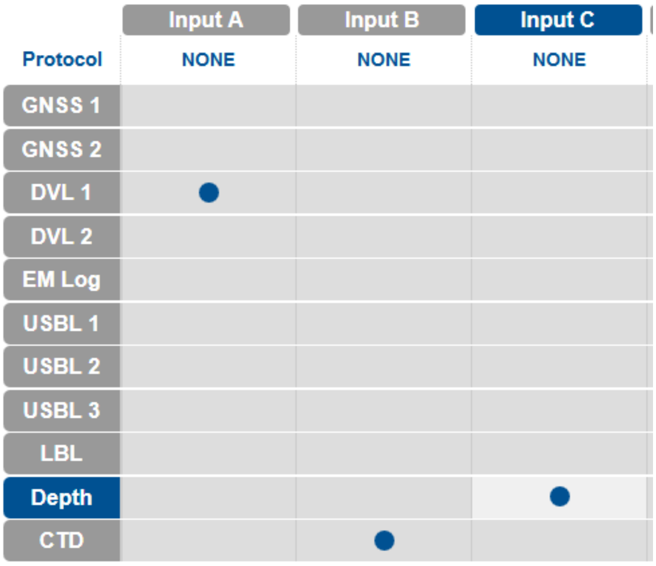


- Select **CTD** on the chosen port.
- Then set **INPUT X (X= A,B,...G) SETTINGS** according to SVP output settings.

You can check data validity by observing the data telegram flow in the **EXTERNAL SENSOR DATA** window and data on the **navigation data** page.

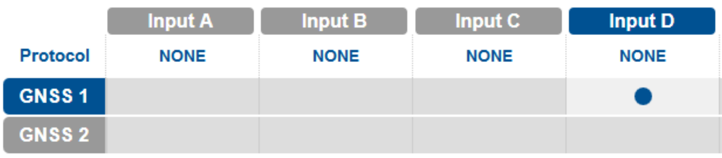
Step	Action
3.	Configure **Depth** input rate of 1 Hz (Max: 5 Hz)

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **INPUTS** option.
- Select **Depth** on the chosen port.
- Then set **INPUT X (X= A,B,...G) SETTINGS** according to Depth output settings.



Step	Action
4.	Configure **GNSS** (resp. USBL) input at 1 Hz (resp. max acoustic recurrence using any time stamped protocol) with “GNSS” protocol (USBL protocol).

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **INPUTS** option.



- Select **GNSS** (resp. USBL) on the chosen port.
- Enter **GNSS** (resp. USBL) **lever arms** with accuracy equal or better than 10% of GNSS (resp. USBL) accuracy (i.e. 30 cm for DGNSS with 3 m accuracy, 2 cm for RTK GNSS with 5 cm accuracy).

Step **Action**

5. Configure **Time**[4] input

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **INPUTS** option.
- Select **UTC** on the chosen port.
- Select **GPS** protocol on the same port as described above.
- Under **UTC SETTINGS** select the input pulse and the protocol (usually PPS rising + Time).

Note: if GNSS is rejected during acceleration of turns it could be that the PPS pulse protocol is not configured correctly (PPS Falling + Time instead of PPS rising + time). Check it in the GNSS user manual.

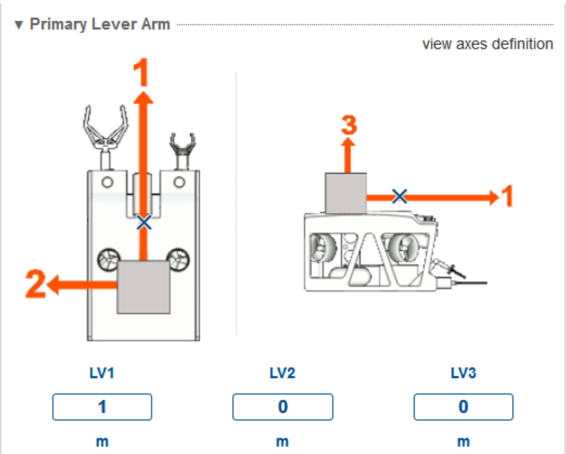
6. Configure Altitude mode

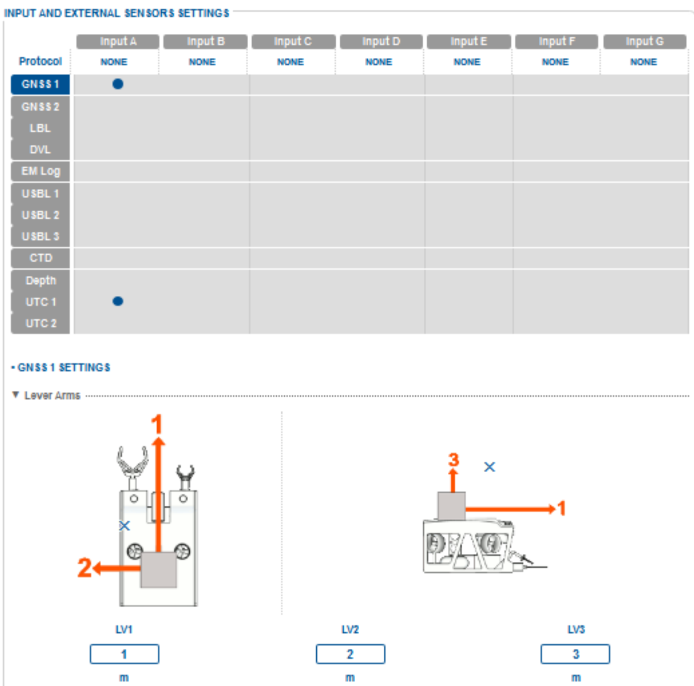
- From the INS Web-Based Graphical User Interface, click on **SETUP** menu then select **NAVIGATION PARAMETERS** option.
- Set **Altitude Mode** to **GPS** for Surface calibration with using RTK or SBAS GPS or **DEPTH** for Subsea calibration.

[4] The use of ZDA and PPS time is **highly** recommended to guarantee a metrology calibration and a precise calibration check.

Step	Action
7.	**Set primary lever arms**:

- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **MECHANICAL PARAMETERS** option.
- Set Primary Lever arms.
- Primary lever arms must be set with values identical to GNSS (resp. USBL transponder) lever arms. This will enable position of INS+DVL and GNSS (resp. USBL transponder) to be defined at the same location during the verification phase to verify the INS + DVL position drift on the data if necessary.
- To see the GNSS (USBL) lever arm: click on **INSTALLATION** menu then select **INPUTS** option. Click on GNSS (USBL) sensor then set the values.





Step	Action
8.	Prepare data logging:

- Output “POSTPROCESSING” data is configured on an Ethernet port (highly recommended) or Serial port otherwise. This is only for quality control or debug if necessary after calibration.
- From the INS Web-Based Graphical User Interface, click on **INSTALLATION** menu then select **OUTPUTS** option.
- Set “**POSTPROCESSING**” protocol at 100 Hz on a chosen output port (preferably in Ethernet / TPC Server).

8.2.2 CALIBRATION

Two virtual points A and B are referenced to navigate between. Traveled distance must be at least 1,000 times and preferably 10,000 times the position sensor accuracy to minimize the impact of its noise on the INS+DVL calibration parameters calculation. The minimum line length for calibration regardless of the positioning sensor accuracy is 1km, to ensure there has been enough data for a good evaluation of the calibration parameters.

Position sensor reference	Typical Error	Required cumulated calibration distance	Error due to position sensor in % of travelled distance
GNSS Natural	3 m	3 – 30 km	0.01%
GNSS Differential	50 cm	1km – 5 km	0.01%
GNSS RTK	10 cm	1 km	0.01%

This minimum distance is depended to the system tested, in this example we take the Phins Subsea commercial specification as reference (0.05%). The Rovins Nano or Phins Compact C3 will demand less distance to meet the calibration result quality.

Note: From table above, it can be seen that RTK is highly recommended in practice to minimize calibration distances. Augmented Differential GNSS can be an option but natural GNSS is not practical and should be avoided. The use of a low DVL standard deviation (SD) will help to minimums the calibration distance, but you need to be careful that the lower SD does not cause DVL rejections.

There is no constraint on the specific calibration pattern to follow, but once optimal alignment has been completed, perform the calibration using a figure of eight pattern followed by a straight line between A & B (ideally with 1 line each direction, A to B then B to A) will give the best ratio between the minimum distance travelled requirement and quality of the final result.

Step	Action
1.	**Setup preparation**

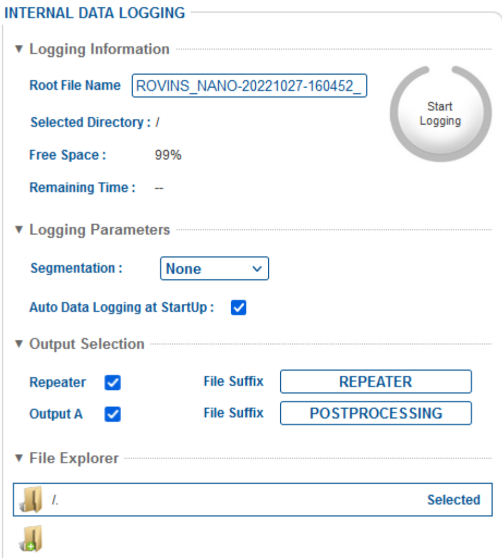
Check that GNSS (resp. USBL) sensor is enabled on the CONTROL page in the detailed status area of the INS Web-Based Graphical User Interface and that it is correctly accepted by the INS (i.e. the message ‘GNSS valid’ must appear in the detailed status area).

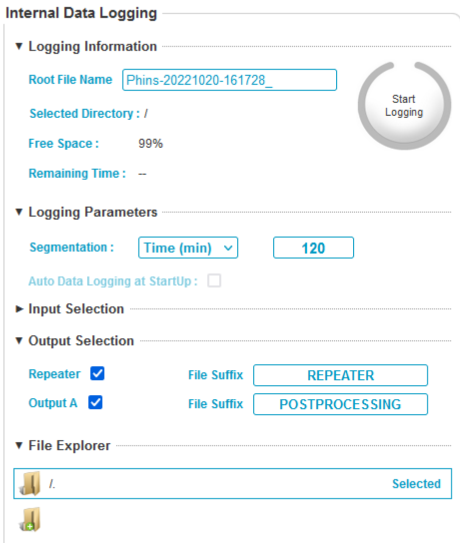
Check that DVL bottom track and water track sensors are **disabled** from the CONTROL page, if it is not the case, disable them and reboot the INS (detailed status pop-up of the INS Web-Based Graphical User Interface).

Step	Action
2.	Launch the datalogging.

For Rovins Nano and Phins Compact C3: with the internal data logging into the web-based user interface:

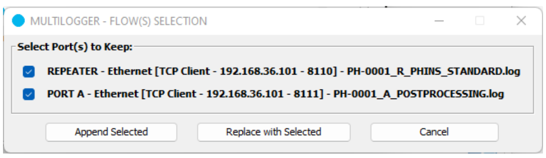
- Click on **DATA LOGGING** menu.
- In the **Logging Parameters**, select **Auto Data Logging** at Startup
- In the Output drop-down list, select **Repeater**.
- In the Output drop-down list, select **POSTPROCESSING**.log.
- In the File Explorer select the **logging directory**.



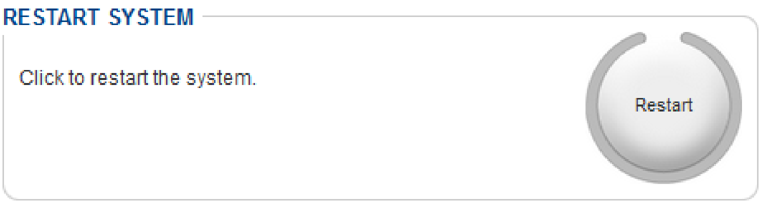


For products without the internal data logging into the web-based user interface, the iXblue MultiLogger tool provided in the product flash drive can be used.

- Launch the iXblue MultiLogger Tool.
- Click on  general configuration and select the folder to store the data. (Log folder)
- Click on  **Load Configuration** and enter the **system IP**.
- Select the post processing output and the repeater output.



- The flow is displayed on the main window.
- Click on the  icon.
- Select the flow to be logged then click on **Start Selected Flows** button.

Step	Action
3.	In the maintenance page, click on the **Restart** button 
4.	Check in the data logging page if the data logging has started. In the MultiLogger Tool, check if the file size is increasing. **Important:** POSTPROCESSING protocol data should be logged as soon as system is powered up so that real time data can be compared to post-processed-data. If needed reboot the INS before starting logging. **Do not stop logging until the end of the calibration and verification process.**

Step	Action

5. <u>**Alignment phase**</u>

The products in the following table are able to align in movement so the vehicle can move as soon as the coarse alignment phase starts.

Product	Part number
Phins Compact C3 G2 **Phins Compact C3 G2 IMU OPTION**	**00208377** **00214152**
Phins Compact C7 G2	**00203864 / 00197729**

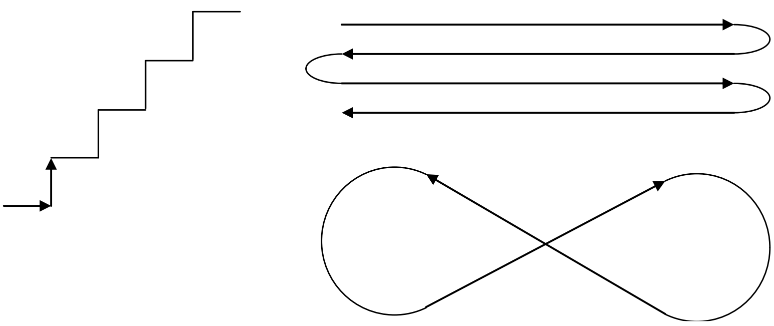
For the other products, keep the vehicle static (at harbor) at constant heading for at least 5 minutes until the initial coarse alignment phase completes, available through Algorithm Status 1 (bit 1).

Navigate with GNSS on the surface until the "Optimal flag" is ended, available through Algorithm Status 3 (bit 30), optimal flag is based for each product on the following criteria:

Product	Heading SD
Phins Compact C3 **Rovins Nano**	**0.10° seclat**
Phins Compact C5 **Rovins**	**0.04° seclat**
Phins Compact C7 **Phins Subsea**	**0.02° seclat**

The Optimal alignment flag is a further alignment stop from the traditional navigation mode to better estimate the mechanical offsets to achieve the new higher performance standard after calibration.

Heading standard deviation will decrease faster if you follow typical patterns as shown below:



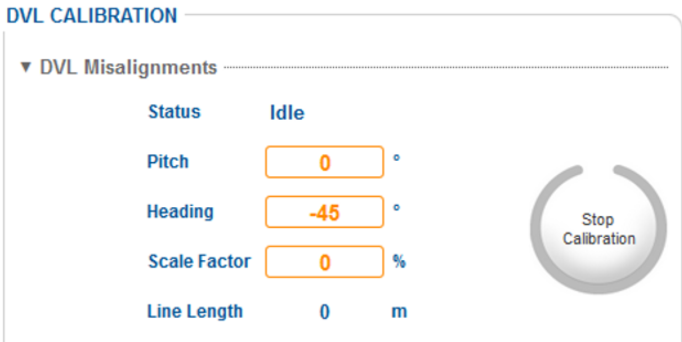
<u>**Note:**</u> We recommend to follow the "Figure Eight" sailing pattern for alignment, as it gives the best alignment quality in the minimum amount of time. The loop radius should be 100 times larger than the GNSS standard deviation with a minimum of 20 m. The minimum straight-line distance loop shall be > 400 m.

Step	Action

6. **Calibration phase**

Start Calibration process from the INS Web-Based Graphical User Interface:

- Click on **SETUP** menu then select **DVL CALIBRATION** option.
- Click on **Start Calibration** button. The Start Calibration button is replaced by a Stop Calibration button. The calibration parameters become orange and the current calibrated values are displayed:



Start Calibration process from interface repeater:

- Send $PIXSE,CONFIG,DDRECK,1*5F<CR><LF> through repeater command to start the calibration process and reset the previous parameters.
  The calibration status is given periodically by the "$PIXSE,ALGSTX" telegram on word "Algorithm status 4":
  - > DVL_CALIBRATION_NONE (bit 9)
  - > DVL_ROUGH_CALIBRATION (bit 10)
  - > DVL_FINE_CALIBRATION (bit 11)
  - > DVL_CALIBRATION_COMPLETED (bit 30)

  Or the calibration status is given also from this command:
  $PIXSE,CONFIG,DDRECK,,*42<CR><LF>

Note: The calibration starts and changes to Rough calibration when the bottom track data is available.

Step **Action**

7. The calibration process does not require specific pattern but **straight line** (going /back with position sensors enabled) and **Figure Eight** shapes is highly recommended to help algorithm to estimate the best accuracy of all DVL calibration errors.

A **stable** Range to bottom distance (distance between the DVL and the bottom) is required to optimize the scale factor estimation. A **minimum** speed of 2 knots is required to minimize errors due to DVL biases.

- **For surface calibration**, both GNSS and DVL BT must be available all along the calibration line until completed calibration is displayed from the INS Web-Based Graphical User Interface or through repeater command. Short GNSS or DVL BT outages however will not affect DVL calibration.
- **For subsea calibration with GNSS alignment at the surface**, it is recommended to:
  - > Disable GNSS few second before diving (to avoid bad GNSS fixes during submersion)
  - > Dive & navigate with DVL suffering no BT outage during the whole calibration line. The association of movement correlated to few fix position (USBL or MANGPS) will help the calibration process to converge toward the quality criteria.
  - > Go to surface at the end of the calibration line.
  - > Wait for 10 GNSS fixes before enabling the sensor.

Navigate at surface until calibration is completed.

8. The calibration process will change from "**Rough** calibration" to "**Fine** calibration" when algorithm finds the basic misalignments between the **DVL** bottom track data and elaborated Speed data computed with the INS and **positioning** sensors data.

Important: During the "Rough Calibration" phase, GNSS and DVL BT must not be **lost**:

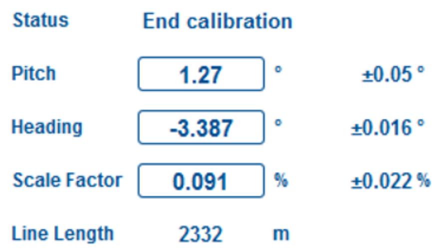
When "Fine calibration" is reached, the pitch, heading and scale factor standard deviation are displayed on the Web-based graphical user interface calibration page and also in the DDRECK telegram (repeater interface).

Step **Action**

9. The calibration process is completed when following standard deviation are reached:

Standard deviation	Phins Compact C3 Rovins Nano	Phins Compact C5 Rovins	Phins Compact C7 Phins Subsea
Heading Misalignment	**0.10°**	**0.05°**	**0.03°**
Pitch Misalignment	**0.15°**	**0.08°**	**0.05°**
Scale factor	**0.10%**	**0.06%**	**0.04%**

All parameters displayed on calibration page become blue and “CALIBRATION COMPLETED”:



The associated flag is raised through Algorithm Status 4 (bit3 0) and also from `$PIXSE,CONFIG,DDRECK,,*42<CR><LF>` response.

Note: The calibration process is still running until it receives a stop command.

One minute before the end of calibration line, stop calibration by clicking on the **Stop Calibration** button.

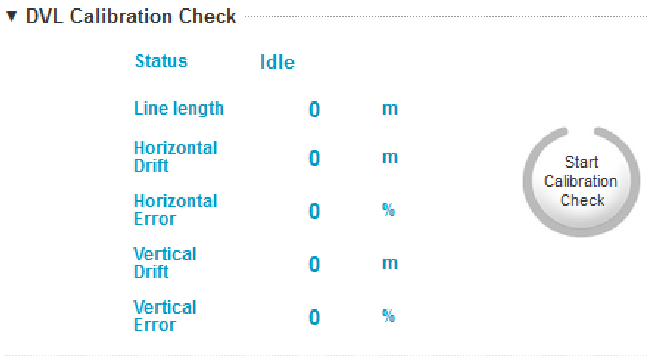
10. Note the values from the calibration in your calibration form.

If the DVL is mounted directly on the INS (DVL ready option) the heading misalignment should be approximately -45°± 1°.
If you are using an SVP sensor, DVL speed scale factor should be within ± 0.5%.

11. **Optional:** Calibration values found during first pass can be refined during a second pass from B to A. Perform calibration steps 1 to 12 starting from previous calibration values to get better misalignment estimation on second run. These values should hardly change during second pass. Save second pass calibration result and note the found values in your calibration form.

8.2.3 CHECKING THE CALIBRATION

Due to the inherent noise of USBL position and the frequent lack of accurate SD information on the position quality it is not possible to provide an accurate real time evaluation of the performance using USBL data.

Step	Action
1.	Start the calibration check. In the **DVL CALIBRATION** page, click on **Start Calibration Check** button.  *The Start Calibration Check button is replaced by a Stop Calibration Check button.* Through repeater interface, the calibration check can be started with following command: `$PIXSE,CONFIG,CALCHK,0*4F<CR><LF>` The real-time values of the calibration check is also available through repeater interface (CALCHK telegram). The INS will now calculate the difference between the INS+DVL trajectory and the position sensor each time the position sensor is received. The cumulated travelled distance will be also displayed. **Note**: in the Control page, the status of the GNSS is displayed as "**Rejected GNSS**".
2.	Start sailing between point C and D. Sail a sufficiently long distance at least equal or greater than the calibration distance A to B (refer to 7.2.2). When speed is higher than 5 knots the calibration check will be less affected by DVL speed biases.
3.	At the end of the line point D, let the ship drift for a minute so that the position of GNSS (resp. USBL) can be easily compared to the position of INS+DVL in the repeater or POSTPROCESSING data.
4.	Click on **Stop Calibration Check** button in the DVL Calibration page or through interface repeater with: `$PIXSE,CONFIG,CALCHK,1*4E<CR><LF>`
5.	Note the values found in your calibration Form.

Step	Action
6.	If you need to control the quality of the data from the Repeater data, you can calculate the position error at the end of the navigation: Error = distance (INS-GNSS) at the end of the line. The errors (horizontal and vertical ones in m or %) and the travelled distance while checking is displayed in the DVL Calibration page. The maximum error should be:

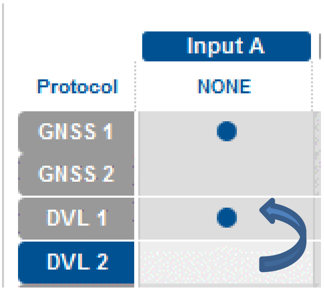
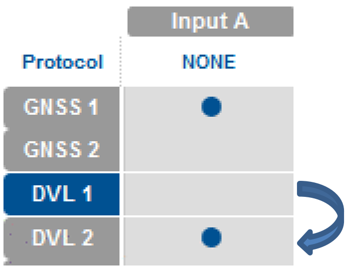
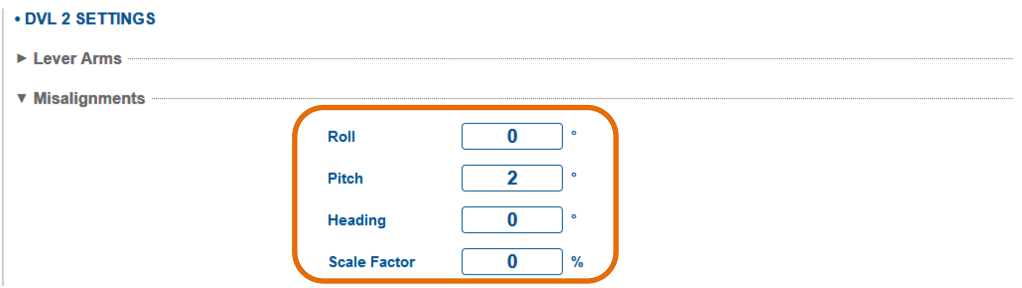
Product	RDI Workhorse + INS vs GNSS	Pioneer, Tasman & Nortek + INS vs GNSS
Phins Compact C3 **Rovins Nano**	**0.77% (*)**	**0.51% (*)**
Phins Compact C5 **Rovins**	**0.51% (*)**	**0.25% (*)**
Phins Compact C7 **Phins Subsea**	**0.25% (*)**	**0.13% (*)**

(*) Correspond to maximum error admissible at 3DRMS (2.55 * TD error CEP50 defined in commercial specification)

Step	Action
7.	<u>**Optional:**</u> Calibration verification values found during first pass can be performed again during a second pass from D to C. (in case of suspecting mechanical movement/interference or performance issues). Perform calibration verification steps 1 to 6. These values should be consistent with the previous calibration verification.
8.	Note the found values in your calibration form.

8.3 Calibrating DVL2

It is mandatory to calibrate DVL1 before calibrating DVL2.
Make sure you write down the calibration values and lever arms values from the previous DVL1 calibration.

Step	Action
1.	Under **INSTALLATION** menu choose **INPUTS** option then assign **DVL2 to DVL1** input: 
2.	**Follow the instructions of chapter 7 and 8** to configure and calibrate the DVL2.
3.	**Don't forget to change the DVL lever arms.**
4.	At the end of the step 9 of chapter 7.2.2, note the **DVL misalignment values** on the paper.
5.	Click on **Clear Values** button.
6.	Under **INSTALLATION** menu choose **INPUTS** option assign **DVL1 to DVL2** input. 
7.	Then enter the **DVL2 misalignment values** in the Misalignments area: 
8.	Click on the **OK** button, DVL2 is calibrated.
9.	Don't forget to set back the correct calibration and lever arms value for DVL1 & DVL2.

iXblue CONTACT - SUPPORT

For non-URGENT support:

By email: support@ixblue.com

Using the form on the iXblue web site: www.ixblue.com

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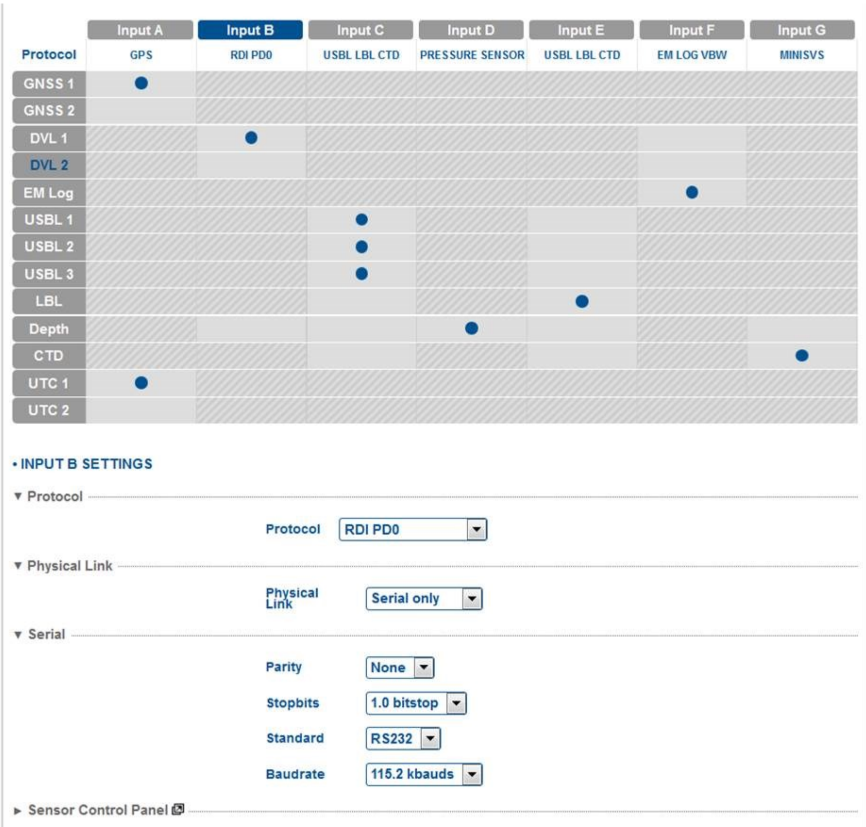
Appendices

A COMMUNICATION WITH RDI OR NORTEK DVL THROUGH SENSOR CONTROL PANEL

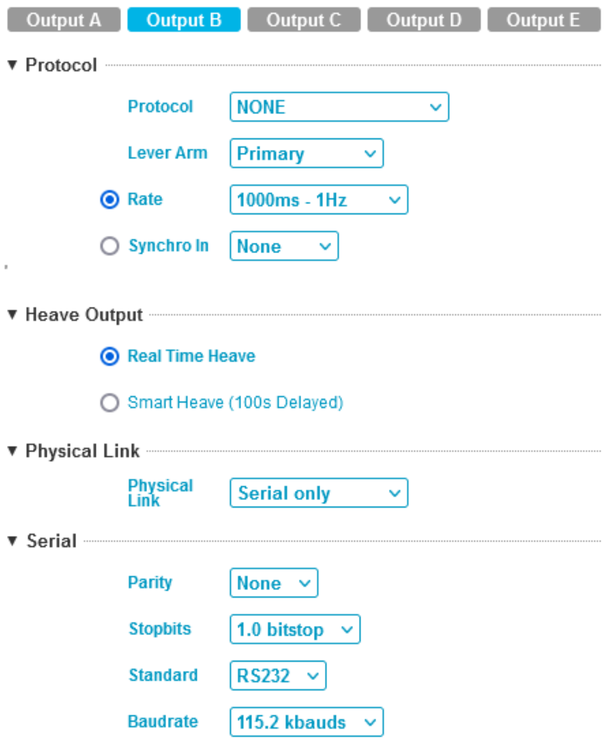
The simplest way to send commands to the DVL is to use the external sensor data window from the INS Web-based user interface.

Step	Action
1.	Click on **INSTALLATION** menu then select **INPUTS** option.
2.	In the first row of the INPUTS table, click on the **input** (i.e., Input A, Input B, Input C, Input D, Input E) to which the external sensor to monitor is connected. The Input X (X being A, B, C, D or E according to your choice) area is displayed:



Example of the DVL connected to Input B.

Step	Action
3.	Set the output to the following:



Step	Action
4.	Click on Sensor Control Panel label to display it. A separate window enabling to display the sensor data is displayed:

Step	Action
5.	**Send Request to the external sensor:**

- Select "Send LF (Line Feed) after CR (Carrier Return)" checkbox
- **For RDI DVL**:
  - > To break data emission send "@" character then send any command to the DVL.
  - > To start pinging send "CS" command.
- **For Nortek DVL**:
  - > To break data emission send "K1W%!Q" followed by "MC" (enter into "Command Mode"), then send any parameters command to the DVL.
  - > To save current parameters, send SAVE,CONFIG
  - > To start pinging send "START" command.
- Apply a CR (Carriage Return) after each command line
- Click **Send Request** Button to send the command typed in

Find below an example:

B COMMUNICATION WITH DVL THROUGH AN INS PORT (BROADCAST FEATURE)

In this example the DVL is set on port E and bi-directional communication with DVL is done through port C in Ethernet (you may also broadcast it in serial if required).
This procedure should not be necessary and used only if a problem occurs using the previous described method.

- To broadcast commands sent on port C to DVL on port E:
  - > Select OUTPUTS option under INSTALLATION menu
  - > Choose Output E tab then select Broadcast C for the output protocol.
- To broadcast DVL output from port E to port C
  - > Select **OUTPUTS** option under **INSTALLATION** menu
  - > Choose **Output C** tab then select **Broadcast E** for the output protocol.
  - > Set the output physical link to **Ethernet only** and leave Ethernet settings to default values: TCP Server on port 8113.

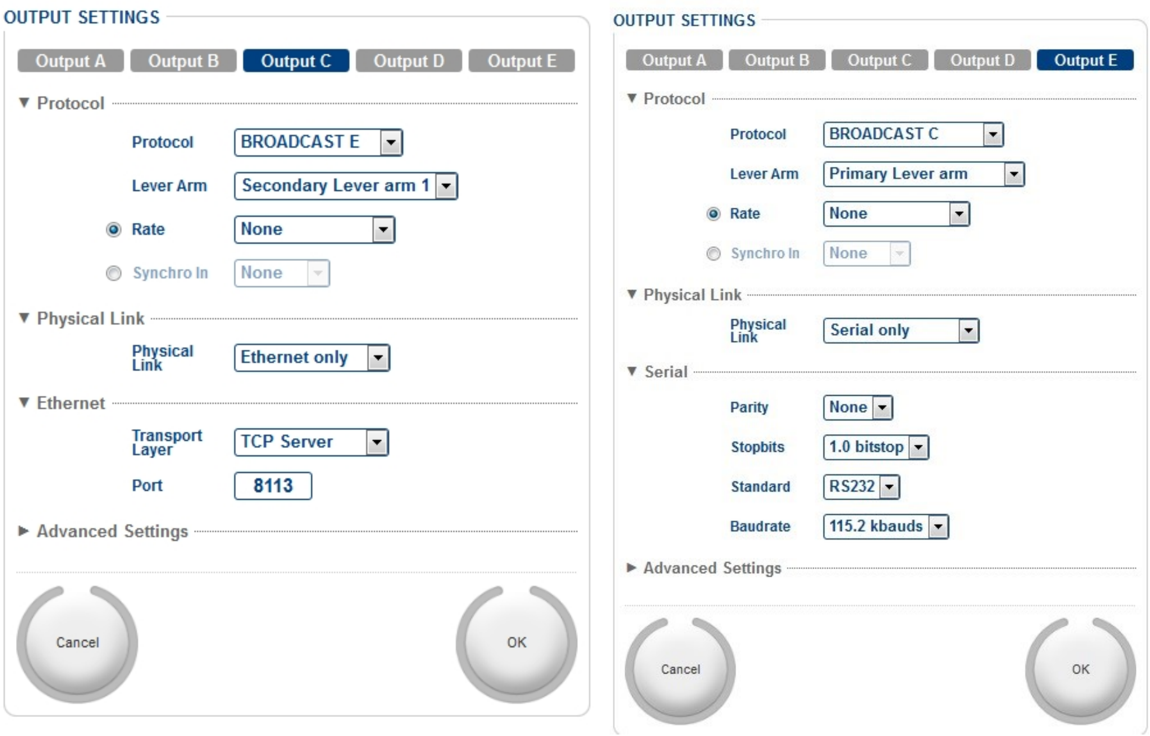


Figure 3 – Output settings on port C and E

- Select **INPUTS** option under **INSTALLATION** menu, set port C input physical link to **Ethernet only**. Leave Ethernet parameters to default values: TCP Server on port 8119.

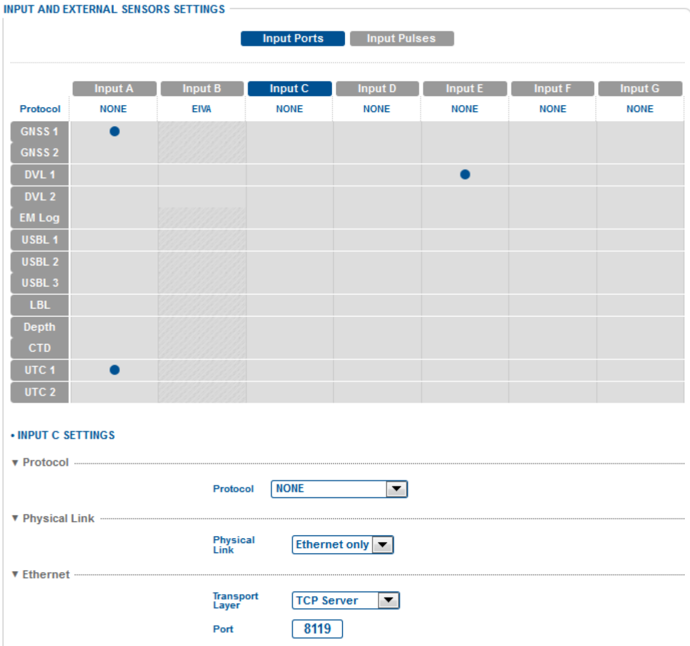


Figure 4 – Configuration of input port C

- Once port C is configured in both output and input in Ethernet, you can use any telnet client to connect to output and input port. For example, using HyperTerminal, select ‘Connect using TCP/IP’, and enter the INS IP address and port for input flow (in this example 8119). This window will then let you enter commands to the DVL. To send a break to the DVL, send ‘@’ character in command window.
- Open another HyperTerminal instance, select ‘Connect using TCP/IP’, and enter the INS IP address and port for output flow (in this example 8113). This window will receive output coming from the DVL. With these two windows, you will be able to configure your DVL through the INS.

To send and receive commands to the DVL you need to open to HERCULES SETUP windows on 2 COM ports of your computer. One window will be used to send commands and the other to receive replies from the DVL.

__Note:__ The broadcast function only works with ASCII protocols and will not broadcast binary data or protocols.

C HOW TO EXTERNALLY TRIGGER THE DVL

If you need to trigger the DVL due to synchronization with other acoustic equipment you need to refer to RDI application note (RDI, Application Note FSA018 (November 2004)).

D DVL LEVER ARMS FOR INS/DVL READY SYSTEMS

D.1 Rovins Nano Case

These values are given for a DVL close coupled to Rovins Nano with the interface plate. For other DVL models refer to iXblue for request.

Table 1 - DVL lever arms to be entered in Rovins Nano, when DVL ready option is chosen[5]

NORTEK part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
DCA00126 (500 kHz, 6000 m)	-0.029 m	-0.003 m	-0.138 m	PLA13596-AA.00
DCA00125 (1 MHz, 4000 m)	-0.029 m	-0.003 m	-0.168 m	PLA13584-AA.00

PIONEER part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
00126499 (300 kHz, 6000 m)	-0.045 m	-0.006 m	-0.341 m	00126567
00123462 (600 kHz, 6000 m)	-0.045 m	-0.006 m	-0.335 m	00126609

Tasman part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
96B-9141 (300 kHz, 6000 m)	-0.029 m	-0.003 m	-0.210 m	N/A
96B-9143 (600 kHz, 6000 m)	-0.029 m	-0.003 m	-0.210 m	N/A

[5] Calculated using Rovins Nano reference point P definition and RDI NORTEK drawings (refer to the product drawings provided on the flash drive).

D.2 Rovins Case

These values are given for a DVL close coupled to Rovins with the interface plate.
For other DVL models refer to iXblue for request.

Table 2 - DVL lever arms to be entered in Rovins, when DVL ready option is chosen[6]

WHN DVL part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
Actual models (common mechanical interface)				
967-1024-00 (300/600 kHz, 6000 m)	-0.003 m	+0.002 m	-0.182 m	PHI3TX_AS_009
967-1025-00 (300/600 kHz, 3000 m)	-0.003 m	+0.002 m	-0.182 m	PHI3TX_AS_009
967-1026-00 (1200 kHz, 3000 m)	-0.003 m	+0.002 m	-0.216 m	PHI3TX_AS_009
967-1027-00 (1200 kHz, 6000 m)	-0.003 m	+0.002 m	-0.216 m	PHI3TX_AS_009
Old models				
967-6003 (300/600 kHz,3000/6000 m)	-0.003 m	+0.002 m	-0.156 m	N/A
967-6004 (300/600 kHz, 1000/2000/6000 m)	-0.003 m	+0.002 m	-0.159 m	N/A
967-6006 (1200 kHz, 2000/4000/6000 m))	-0.003 m	+0.002 m	-0.193 m	N/A

NORTEK part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
DCA00126 (500 kHz, 6000 m)	-0.003 m	+0.003 m	-0.143 m	PLA14026-AA.00
DCA00125 (1 MHz, 4000 m)	-0.003 m	+0.003 m	-0.173 m	PLA14031-AA.00

PIONEER part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
00126499 (300 kHz, 6000 m)	-0.019 m	-0.000 m	-0.345 m	00126671
00123462 (600 kHz, 6000 m)	-0.019 m	-0.000 m	-0.340 m	00126680

TASMAN part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
96B-9141 (300 kHz, 6000 m)	-0.003 m	-0.003 m	-0.214 m	N/A
96B-9143 (600 kHz, 6000 m)	-0.003 m	-0.003 m	-0.214 m	N/A

[6] Calculated using Rovins reference point P definition and RDI/NORTEK DVL drawings (refer to the product drawings provided on the flash drive).

D.3 Phins Subsea Case

These values are given for a DVL close coupled to Phins Subsea with the interface plate. For other DVL models refer to iXblue for request.

Table 3 - DVL lever arms to be entered in Phins Subsea, when DVL ready option is chosen[7]

Teledyne DVL part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
Actual models (common mechanical interface)				
967-1024-00 (300/600 kHz, 6000 m)	+0.0128 m	+0.006 m	-0.221 m	4569500 Rev B
967-1025-00 (300/600 kHz, 3000 m)	+0.0128 m	+0.006 m	-0.221 m	4569500 Rev B
967-1026-00 (1200 kHz, 3000 m)	+0.0128 m	+0.006 m	-0.255 m	4569500 Rev B
967-1027-00 (1200 kHz, 6000 m)	+0.0128 m	+0.006 m	-0.255 m	4569500 Rev B
Old models				
967-6003 (300/600 kHz,3000/6000 m)	+0.0128 m	+0.006 m	-0.195 m	N/A
967-6004 (300/600 kHz, 1000/2000/6000 m)	+0.0128 m	+0.006 m	-0.198 m	N/A
967-6006 (1200 kHz, 2000/4000/6000 m))	+0.0128 m	+0.006 m	-0.232 m	N/A

NORTEK part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
DCA00126 (500 kHz, 6000 m)	+0.013 m	+0.006 m	-0.184 m	PLA14073-AA.00
DCA00125 (1 MHz, 4000 m)	+0.013 m	+0.006 m	-0.214 m	PLA14074-AA.00

PIONEER part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
00126499 (300 kHz, 6000 m)	-0.003 m	+0.003 m	-0.387 m	00126692
00123462 (600 kHz, 6000 m)	-0.003 m	+0.003 m	-0.382 m	00123404

TASMAN part number	X1 lever arm	X2 lever arm	X3 lever arm	iXblue assembly drawing
96B-9141 (300 kHz, 6000 m)	+0.013 m	+0.006 m	-0.254 m	N/A
96B-9143 (600 kHz, 6000 m)	+0.013 m	+0.006 m	-0.254 m	N/A

[7] Calculated using Phins Subsea reference point P definition and RDI/NORTEK DVL drawings (refer to the product drawings provided on the flash drive)

E INFLUENCE OF TEMPERATURE, SALINITY AND DEPTH ON SOUND VELOCITY

DVL is a Doppler sensor and needs to know the sound velocity at the location of its sensor.

You may use the following equation to compute sound velocity (Urick, 1983):

$C = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016D$ (8) where

T is the temperature in °C

S is salinity in parts per thousand (‰)

D is the depth in meters

Velocity is very **sensitive to temperature (3.10^{-3}/°C),** three times **less sensitive to Salinity(10^{-3} /(°/°°))** and **not sensitive to depth (10^{-5}/m)**. Note that salinity does not usually vary very much over water column (< 1°/°°) so surface salinity can be entered as a constant value for a mission.

By letting DVL calculate velocity measuring temperature with its internal probe we should have the maximum accuracy.

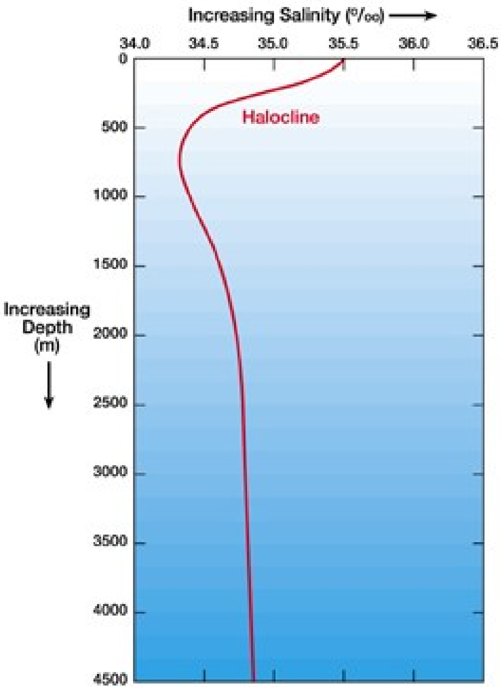


Figure 5 – Typical salinity profile for south Atlantic Sea

Let's consider the case of setting DVL to calculate its own velocity.

If we want a navigation drift < 10^{-3} of travelled distance, sound velocity relative accuracy must also be better than 10^{-3}. This leads to the following constraints:

- Temperature measured (with internal probe) accuracy << 0.3°C
- Salinity accuracy << 1°/°°
- Depth accuracy << 100 m