Application Note on Pseudorange/Delta-Phase (PDP) and ***GL1DE*** Filters

Introduction

This application note contains NovAtel Pseudorange/Delta-Phase (PDP) filter details and general guidance on how to use it. Revision 4 of this document also introduces ***GL1DE*** (relative PDP) to the PDPFILTER command and the PDPMODE command (see *Pages 7-8*).

About PDP

The PDP filter provides a filtered position and velocity solution based on assumed vehicle dynamics. The advantage of this approach is smoother solution output and greater solution availability. The PDP solution optimizes the absolute positioning accuracy of the GPS code observation and leverages the excellent relative stability of the GPS carrier phase and Doppler observations. By optimally combining these satellite signal observations, the solution stability improves over a traditional code-only positioning algorithm.

PDP differs from a standard instantaneous positioning algorithm, which will only give a solution when more than 3 satellites are visible. The PDP allows a solution to be generated for short periods when fewer than 4 satellites are visible using what observations are available and assumptions about vehicle dynamics. Having more observations available allows better observation error detection so that poor observations are rejected before making it into the solution.

In conditions where GPS signal tracking is hampered by obstructions such as trees or buildings, the PDP filter will bridge through brief partial or even complete GPS outages while providing a continuous position/velocity solution. In conditions where satellites are coming in and out of the solution, the PDP helps minimize position solution jumps often associated with satellite geometry changes.

The PDP is not intended to provide a solution in all conditions. In conditions where satellite signals are completely blocked for extended periods, such as in a tunnel or severe urban settings, the PDP will have the same problems as all satellite based navigation systems and a solution will not be possible.

*About **GL1DE***

While the PDP filter optimizes a solution in multiple conditions, the ***GL1DE*** filter design works for one major purpose. This is ideally in clear sky conditions where the user needs a tight, smooth, and consistent output. The ***GL1DE*** filter works best with single point, CDGPS or WAAS models rather than DGPS.

The PDP filter is smoother than a least squares fit but is still noisy in places. The ***GL1DE*** filter produces a very smooth solution with consistent rather than absolute position accuracy. See *Figure 1* on *Page 2* for a comparison of a least squares, PDP, and ***GL1DE*** solution. There should be typically less than 1 cm difference from epoch to epoch.

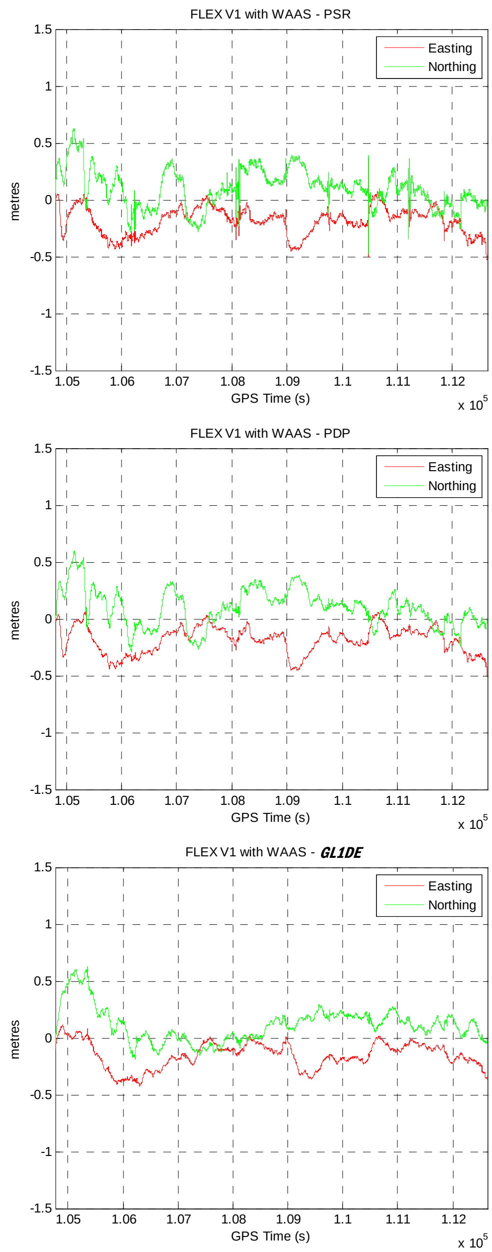

Figure 1 Least Squares vs. PDP vs. *GL1DE*

For the comparisons above, we used a FlexPak-V1 receiver with a GPS-702-GGL antenna mounted on a vehicle traveling east to west at speeds of 5 to 12 km/hour. We collected approximately 2 hours of data. Notice how the PDP solution is much less noisy than the least-squares pseudorange (PSR) solution. Then, the GL1DE solution is even smoother.

The ***GL1DE*** effect is most noticeable when using a SMART-V1 antenna, which has a lower quality antenna than the 700-series antenna we used in the above comparison. Its PSR solution is much noisier and the ***GL1DE*** solution smoothes it exceptionally well. Please refer to our ***GL1DE*** white paper, available on our website at http://www.novatel.com/products/whitepapers.htm, for more results and comparisons using different products.

Consider the case of an agricultural user plowing rows in a field. This user, with clear skies, prefers to have minimal differences in position between now and 15 minutes ago rather than knowing the exact position to within millimeters. See also *Figure 2* below.

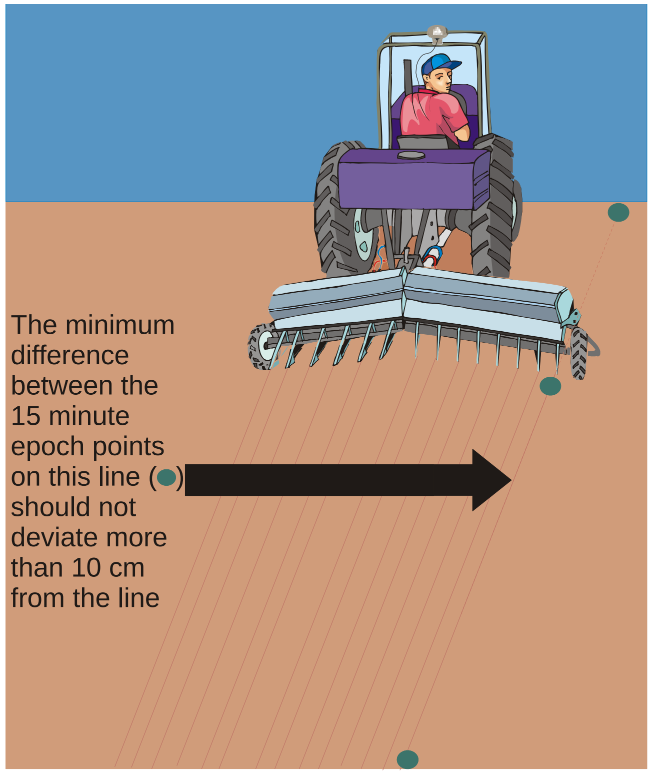

Figure 2 Agricultural User and *GL1DE*

History

The motivation for the PDP filter approach came from Sportvision, a customer of NovAtel Inc. Sportvision brought NovAtel a set of racing environment requirements. They wanted to have meter-level positioning accuracy on NASCAR racecars so they could provide real-time computer graphics that followed the cars as they went across the television screen. The difficulty in this problem was that better-than-normal pseudorange positioning was required, but the duration of the satellite constellation was too short for either fixed ambiguity positioning or accurate floating ambiguity positioning. PDP satisfied the requirements to the extent that Sportvision uses the technology and the results can be seen during televised NASCAR races on either FOX or NBC.

Test Results

The plots in *Figure 3* and *Figure 4* show data from a residential Calgary neighborhood known for its mature trees. The plots in *Figure 7* and *Figure 8* on *Page 6* show data position improvement through downtown Calgary, with its associated urban canyon geography.

Data from a Residential Neighborhood with Mature Trees
Compare the least-squares trajectory with the inertial control trajectory in *Figure 3* and the PDP trajectory in *Figure 4* on *Page 4*. NovAtel's inertial system generated the inertial control and consisted of the integration of an OEM4 receiver operating in differential carrier mode and a Honeywell HG1700-AG11 inertial measurement unit. The PDP trajectory shows the output of the PDP Kalman filter.

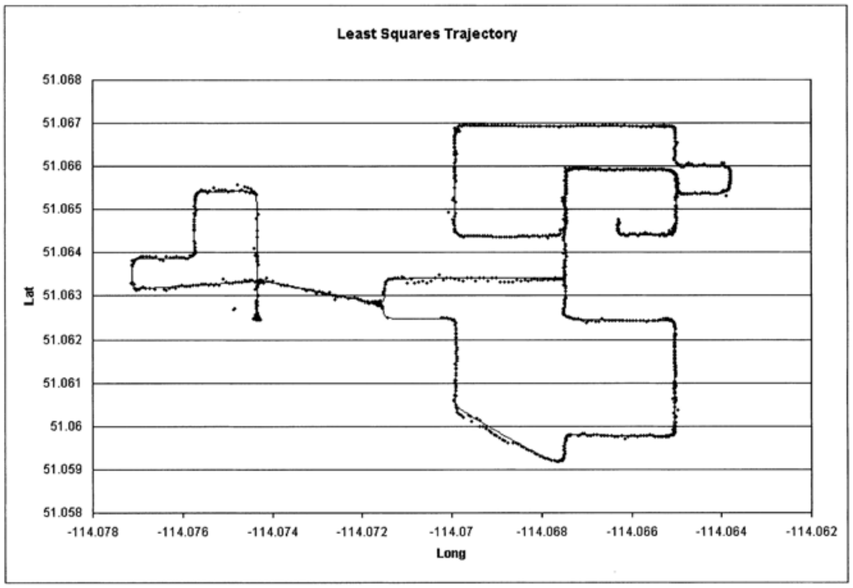

Figure 3: Residential Neighbourhood Least Square Plot of Inertial Trajectory

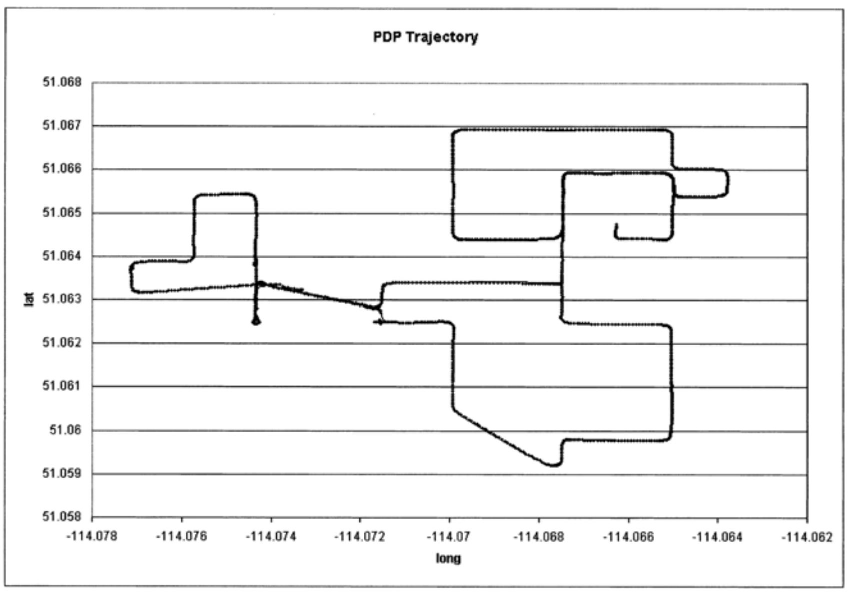

Figure 4: Residential Neighbourhood PDP Plot of Inertial Trajectory

The result is a much smoother and more accurate trajectory. The filter also bridges through the portions of the test when fewer than four satellites are in view. The maximum horizontal position error for this test has been reduced by half—from over 40 m to approximately 20 m. The position availability percentage has increased from 87 to 100 percent (see *Table 1* below and *Table 2* on *Page 5*).

Table 1: Residential Neighbourhood Solution Availability

Parameter	Least Squares	PDP Filter, All Solutions
Computed Solution Epochs	1,270	1,459
Total Possible	1,459	1,459
% Achieved	87	100

Table 2: Residential Neighbourhood Position Accuracy

Parameter	Least Squares	PDP Filter, All Solutions
Latitude Error RMS	3.814	2.788
Longitude Error RMS	1.784	0.786
Height Error RMS	13.721	12.508
2D Position Error RMS	4.210	2.896

Data from an Urban Canyon

In the urban canyon setting, improvements are even more evident. *Figure 5* and the satellite visibility plot in *Figure 6*, below, shows the tracking environment in the urban core. Not only is the constellation masked, but the receiver must also occasionally track a reflected signal rather than the direct signal. *Figure 6* shows that there are fewer than four satellites available for a significant portion of the time.

Figure 5: Urban Canyon (4th Avenue, Calgary, facing west)

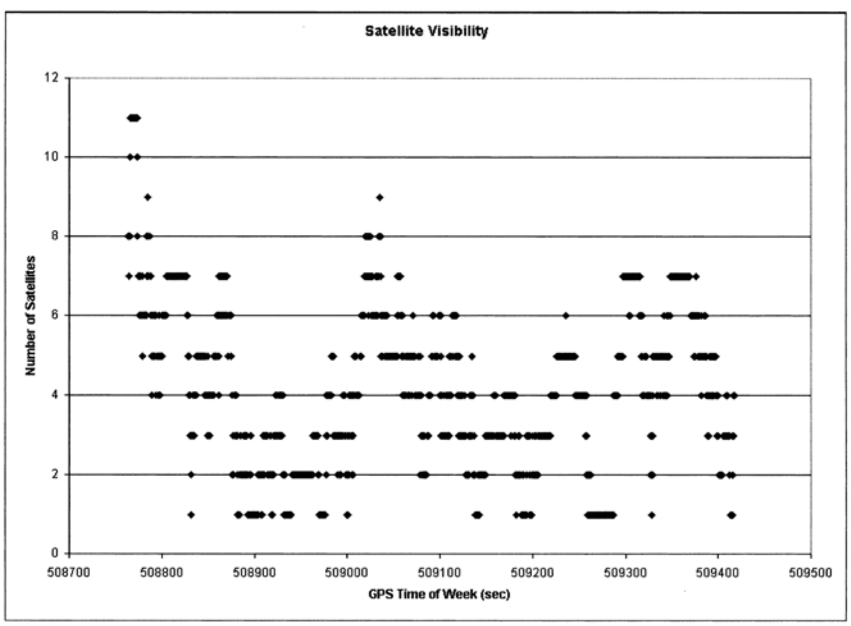

Figure 6: Urban Canyon Satellite Visibility

Figure 7 shows least-squares-derived horizontal positions in the downtown corridors. The least squares trajectory for the first downtown dataset shows very noisy data and clearly demonstrates the effect of unchecked multipath errors. Maximum horizontal position error is approaching 600 m during portions of this dataset.

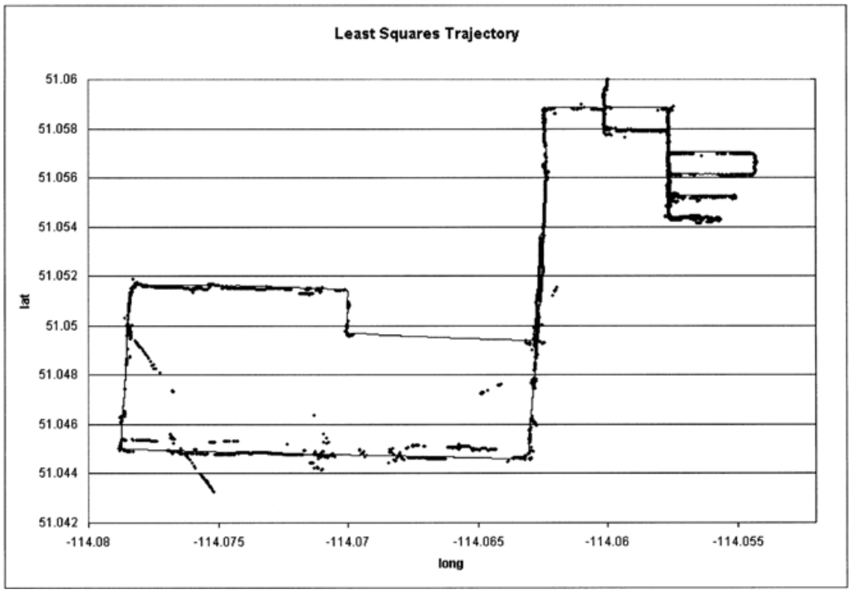

Figure 7: Urban Canyon Least-Squares Plot of Inertial Trajectory

The PDP trajectory in *Figure 8* below shows the results of filtering the GPS observations and the solution availability with fewer than four satellites are in view. The solution availability improves - to 99 percent (see *Table 3* below). The maximum horizontal position error reduces from 600 m to 95 m. The position accuracy (see *Table 4* below) in the north/south direction is significantly higher than that in the east/west direction. Since this test is performed primarily driving in east/west directions with high buildings on the north and south of the vehicle, the satellite geometry is such that the along-track direction (east/west) will be better constrained than the across-track (north/south).

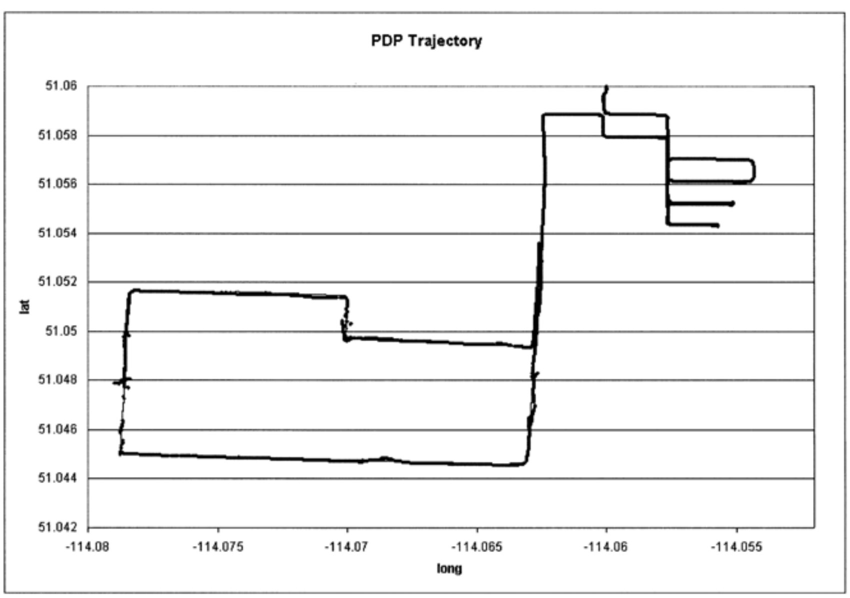

Figure 8: Urban Canyon PDP Plot of Inertial Trajectory

Table 3: Urban Canyon Solution Availability

Parameter	Least Squares	PDP Filter, All Solutions
Computed Solution Epochs	5,021	7,103
Total Possible	7,180	7,180
% Achieved	70	99

Table 4: Urban Canyon Position Accuracy

Parameter	Least Squares	PDP Filter, All Solutions (m)
Latitude Error RMS	58.359	19.632
Longitude Error RMS	26.443	4.454
Height Error RMS	42.038	26.218
2D Position Error RMS	64.070	20.130

Test Conclusions

There are improvements in solution availability with the PDP filter. This is evident in the reduction of both the amount of time a solution is not available and the position spikes from multipath. With PDP, satellites that lose lock can be reacquired without significant loss in performance provided that at least four satellites (the same or various) are maintained across the delta time between epochs.

The test results show that PDP improves positioning availability in established residential neighborhoods by over 10 percent and in urban canyon settings by 40 percent. PDP has also improved single-point horizontal accuracy from 4 m (2 dRMS) to 3 m (2 dRMS) in residential neighborhoods. In urban canyon settings, with PDP, accuracy has improved significantly, from 64 m (2 dRMS) to 20 m (2 dRMS) in one test and from 7.6 m (2 dRMS) to 6.0 m (2 dRMS) in another.

PDP Commands

These commands are available on all OEMV-based products with 3.400 firmware or higher.

PDPFILTER Set the PDP filter

Command: `PDPFILTER` (enable/disable/reset)

Logs: `PDPPOS`
`PDPVEL`
`PDPXYZ`

The main advantages of the Pseudorange/Delta-Phase (PDP) implementation are that it smoothes a noisy position solution and bridges outages in satellite coverage (the solution is degraded from normal but there is at least a reasonable solution without gaps).

If you enable the PDP filter, the PDP solution is output in the BESTPOS, BESTVEL and NMEA logs.

Abbreviated ASCII Syntax: **Message ID: 424**

```
PDPFILTER switch
```

Factory Default:

```
pdpfilter disable
```

ASCII Example:

```
pdpfilter enable
```

Field	Field Type	ASCII Value	Binary Value	Description	Binary Format	Binary Bytes	Binary Offset
1	PDPFILTER header	-	-	This field contains the command name or the message header depending on whether the command is abbreviated ASCII, ASCII or binary, respectively.	-	H	0
2	switch	DISABLE	0	Enable, disable or reset the PDP filter (command default = ENABLE)	Enum	4	H
		ENABLE	1				
		RESET	2				

PDPMODE Set the PDP mode

Command: `PDPMODE` (normal/relative) (auto/static/dynamic)

Logs: `PDPPOS`
`PDPVEL`
`PDPXYZ`

This command allows you to select the mode and dynamics of the PDP filter. You must first issue a PDPFILTER ENABLE command. See also *Page 7*.

If you choose RELATIVE while in WAAS or CDGPS mode, you should force the *iono* type to GRID in the SETIONOTYPE command. See also *Page 10*.

Abbreviated ASCII Syntax: **Message ID: 970**

```
PDPMODE mode dynamics
```

Factory Default:

```
pdpmode normal auto
```

ASCII Example:

```
pdpmode relative dynamic
```

Field	Field Type	ASCII Value	Binary Value	Description	Binary Format	Binary Bytes	Binary Offset
1	PDPMODE header	-	-	This field contains the command name or the message header depending on whether the command is abbreviated ASCII, ASCII or binary, respectively.	-	H	0
2	mode	NORMAL	0	In relative mode, (***GL1DE***), performance is optimized to obtain a consistent error in latitude and longitude over time periods of 15 minutes or less rather than to obtain the smallest absolute position error. [1]	Enum	4	H
		RELATIVE	1				
3	dynamics	AUTO	0	Auto detect dynamics mode	Enum	4	H+4
		STATIC	1	Static mode			
		DYNAMIC	2	Dynamics mode			

[1] ***GL1DE*** is a mode of the PDP filter, which optimizes the position for consistency over time rather than absolute accuracy. If the position is in error by a constant bias, but the bias is not changing at all, ***GL1DE*** is working perfectly. Over a 15-minute period, the error is consistent to about 20 cm in latitude and 15 cm in longitude for WAAS and CDGPS modes. ***GL1DE*** also works in single point and DGPS modes, but the errors are somewhat higher.

SETIONOTYPE Enable ionospheric models

Use this command to set which ionospheric corrections model the receiver should use.

Abbreviated ASCII Syntax: **Message ID: 711**

SETIONOTYPE model

Factory Default:

```
setionotype auto
```

ASCII Example:

```
setionotype grid
```

Field	Field Type	ASCII Value	Binary Value	Description	Binary Format	Binary Bytes	Binary Offset
1	SETIONO-TYPE header	-	-	This field contains the command name or the message header depending on whether the command is abbreviated ASCII, ASCII or binary, respectively.	-	H	0
2	model	See *Table 5* below		Choose an ionospheric corrections model (default = NONE)	Enum	4	H

Table 5 Ionospheric Correction Models

ASCII	Binary	Description
NONE	0	Don't use ionospheric modeling
KLOBUCHAR	1	Use the broadcast model, for example Klobuchar
GRID	2	Use the SBAS/L-band model
L1L2	3	Use the L1/L2 model
AUTO	4	Automatically determine the ionospheric model to use

PDPPOS PDP filter position

This log contains the pseudorange position computed by the receiver with the PDP filter enabled. See also the PDPFILTER command on *Page 7*.

Message ID: **469**

Log Type: **Synch**

Recommended Input:

```
log pdpposa ontime 1
```

ASCII Example:

```
#PDPPOSA,COM1,0,75.5,FINESTEERING,1431,494991.000,00040000,a210,35548;
SOL_COMPUTED,SINGLE,51.11635010310,-114.03832575772,1065.5019,-16.9000,
WGS84,4.7976,2.0897,5.3062,"",0.000,0.000,8,8,0,0,0,0,0,0*3cbfa646
```

Field #	Field type	Data Description	Format	Binary Bytes	Binary Offset
1	PDPPOS header	Log header		H	0
2	sol status	Solution status	Enum	4	H
3	pos type	Position type	Enum	4	H+4
4	lat	Latitude	Double	8	H+8
5	lon	Longitude	Double	8	H+16
6	hgt	Height above mean sea level	Double	8	H+24
7	undulation	Undulation - the relationship between the geoid and the WGS84 ellipsoid (m) [2]	Float	4	H+32
8	datum id#	Datum ID number	Enum	4	H+36
9	lat σ	Latitude standard deviation	Float	4	H+40
10	lon σ	Longitude standard deviation	Float	4	H+44
11	hgt σ	Height standard deviation	Float	4	H+48
12	stn id	Base station ID	Char[4]	4	H+52
13	diff_age	Differential age in seconds	Float	4	H+56
14	sol_age	Solution age in seconds	Float	4	H+60
15	#SVs	Number of satellite vehicles tracked	Uchar	1	H+64
16	#solnSVs	Number of satellites in the solution	Uchar	1	H+65
17	Reserved		Uchar	1	H+66
18			Uchar	1	H+67
19			Uchar	1	H+68
20			Uchar	1	H+69
21			Uchar	1	H+70
22			Uchar	1	H+71
23	xxxx	32-bit CRC (ASCII and Binary only)	Hex	4	H+72
24	[CR][LF]	Sentence terminator (ASCII only)	-	-	-

2 When using a datum other than WGS84, the undulation value also includes the vertical shift due to differences between the datum in use and WGS84.

PDPVEL PDP filter velocity

This log contains velocity computed by the receiver with the PDP filter enabled. See also the PDPFILTER command on *Page 7*.

Message ID: **470**

Log Type: **Synch**

Recommended Input:

```
log pdpvela ontime 1
```

ASCII Example:

```
#PDPVELA,COM1,0,75.0,FINESTEERING,1430,505990.000,00000000,b886,2859;
SOL_COMPUTED,SINGLE,0.150,0.000,27.4126,179.424617,-0.5521,0.0*7746b0fe
```

Field #	Field type	Data Description	Format	Binary Bytes	Binary Offset
1	PDPVEL header	Log header		H	0
2	sol status	Solution status	Enum	4	H
3	vel type	Velocity type	Enum	4	H+4
4	latency	A measure of the latency in the velocity time tag in seconds. It should be subtracted from the time to give improved results.	Float	4	H+8
5	age	Differential age in seconds	Float	4	H+12
6	hor spd	Horizontal speed over ground, in meters per second	Double	8	H+16
7	trk gnd	Actual direction of motion over ground (track over ground) with respect to True North, in degrees	Double	8	H+24
8	height	Height in meters where positive values indicate increasing altitude (up) and negative values indicate decreasing altitude (down)	Double	8	H+32
9	Reserved		Float	4	H+40
10	xxxx	32-bit CRC (ASCII and Binary only)	Hex	4	H+44
11	[CR][LF]	Sentence terminator (ASCII only)	-	-	-

PDPXYZ Pseudorange Cartesian position and velocity

This log contains Cartesian coordinates position in X, Y and Z computed by the receiver with the PDP filter enabled. See also the PDPFILTER command on *Page 7*.

Message ID: **471**

Log Type: **Synch**

Recommended Input:

```
log pdpxyza ontime 1
```

ASCII Example:

```
#PDPXYZA,COM1,0,75.5,FINESTEERING,1431,494991.000,00040000,33ce,35548;
SOL_COMPUTED,SINGLE,-1634531.8128,-3664619.4862,4942496.5025,2.9036,
6.1657,3.0153,SOL_COMPUTED,SINGLE,-2.5588e-308,-3.1719e-308,3.9151e-308,
0.0100,0.0100,0.0100,"",0.150,0.000,0.000,8,8,0,0,0,0,0,0*a20dbd4f
```

Field #	Field type	Data Description	Format	Binary Bytes	Binary Offset
1	PDPXYZ header	Log header		H	0
2	P-sol status	Solution status	Enum	4	H
3	pos type	Position type	Enum	4	H+4
4	P-X	Position X-coordinate (m)	Double	8	H+8
5	P-Y	Position Y-coordinate (m)	Double	8	H+16
6	P-Z	Position Z-coordinate (m)	Double	8	H+24
7	P-X σ	Standard deviation of P-X (m)	Float	4	H+32
8	P- Y σ	Standard deviation of P-Y (m)	Float	4	H+36
9	P-Z σ	Standard deviation of P-Z (m)	Float	4	H+40
10	V-sol status	Solution status	Enum	4	H+44
11	vel type	Velocity type	Enum	4	H+48
12	V-X	Velocity vector along X-axis (m)	Double	8	H+52
13	V-Y	Velocity vector along Y-axis (m)	Double	8	H+60
14	V-Z	Velocity vector along Z-axis (m)	Double	8	H+68
15	V-X σ	Standard deviation of V-X (m)	Float	4	H+76
16	V-Y σ	Standard deviation of V-Y (m)	Float	4	H+80
17	V-Z σ	Standard deviation of V-Z (m)	Float	4	H+84
18	stn ID	Base station ID	Char[4]	4	H+88
19	V-latency	A measure of the latency in the velocity time tag in seconds. It should be subtracted from the time to give improved results.	Float	4	H+92
20	diff_age	Differential age in seconds	Float	4	H+96
21	sol_age	Solution age in seconds	Float	4	H+100
22	#SVs	Number of satellite vehicles tracked	Uchar	1	H+104
23	#solnSVs	Number of satellite vehicles used in solution	Uchar	1	H+105
24	Reserved		Uchar	1	H+106
25			Uchar	1	H+107
26			Uchar	1	H+108
27			Uchar	1	H+109
28			Uchar	1	H+110
29			Uchar	1	H+111
30	xxxx	32-bit CRC (ASCII and Binary only)	Hex	4	H+112
31	[CR][LF]	Sentence terminator (ASCII only)	-	-	-

Final Points

If you require further information, regarding the topics covered by this document, please contact:

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