Performance Assessment of Single and Dual-Frequency, Commercial-based GPS Receiver for LEO orbit

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Background

- Previous GPS receivers
  - Many of GPS receivers operate on L1 frequency and its navigation accuracy is limited by ionospheric path delay.
  - Earlier studies proposed the correction method for its delay using an ionospheric model for LEO altitude.

- Dual Frequency GPS receivers
  - Direct correction of ionospheric path delay.
  - The onboard navigation accuracy is much better than that of single frequency GPS receivers.
  - Limitaion on available selection of space-capable one.

We've adopted the low cost commercial dual frequency GPS receiver NovAtel "OEM4-G2L"

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Description of NovAtel OEM4-G2L

➢ <u>Remarkable points</u>

- Small size, weight, and low power consumption
- 24 tracking channel (12ch for L1 C/A & 12ch for L2 P-code frequency)

➢ <u>Firmware modification</u>

- Removal of altitude and velocity limitation and correction of tropospheric delay.

  (The study※ of "OEM4-G2" reports the large position error of 13m with tropospheric delay correction. ※O.Montenbruck, DLR)

60mm

100mm

item	specification
size[mm]	60 x 100 x 16
Weight [g]	56
Power [W]	1.6W @ 3.3V
Frequency	1575.42MHz (L1) 1227.60MHz(L2)
interface	RS232, RS422, TTL, PPS
Data rate [Hz]	20

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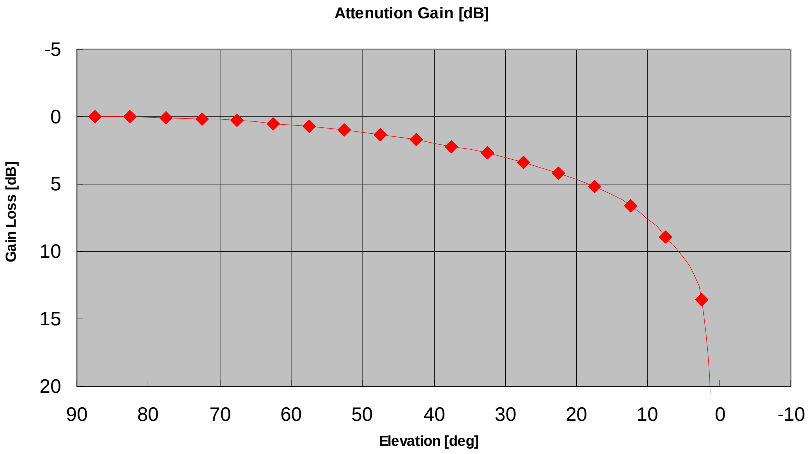
Performance Test of OEM4-G2L

- GPS signal simulator : Spirent STR4760
- Test item :
  1. Initial acquision test
  2. Error free scenario test
  3. Ionospheric error scenarios (constant TEC model)
     - case1 : TEC value = 1e17 electron/m^2
     - case2 : TEC value = 1e18 electron/m^2

Common setting of simulator

ITEM	Setting
Orbit	Sun Syncronous Oribt Altitude : 650km Inclination : 97.99deg semi-major axis : 7028km
tropospher model	OFF
GPS constellation position error	Disable
GPS clock divergence	Disable



Initial Acquisition Performance Test

➢ Objective

To evaluate the Time To First Fix (TTFF) from cold start.

➢ Simulation configuration

- 12ch output
- Ionosphere model : constant TEC (1.0e17 electron/m2)

➢ Results

- TTFF is about 2 to 8min. (5 to 40min @ MGPSR)
- OEM4-G2L is well able to operate under low earth orbit

Case	TTFF [sec]	Latitude at receiver activation [deg]
1	315	-0.03314
2	118	75.76264
3	497	26.62787
4	115	-47.9419
5	111	-55.8707

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Performance Assessment (Error Free Scenario Test)

➢ Objective

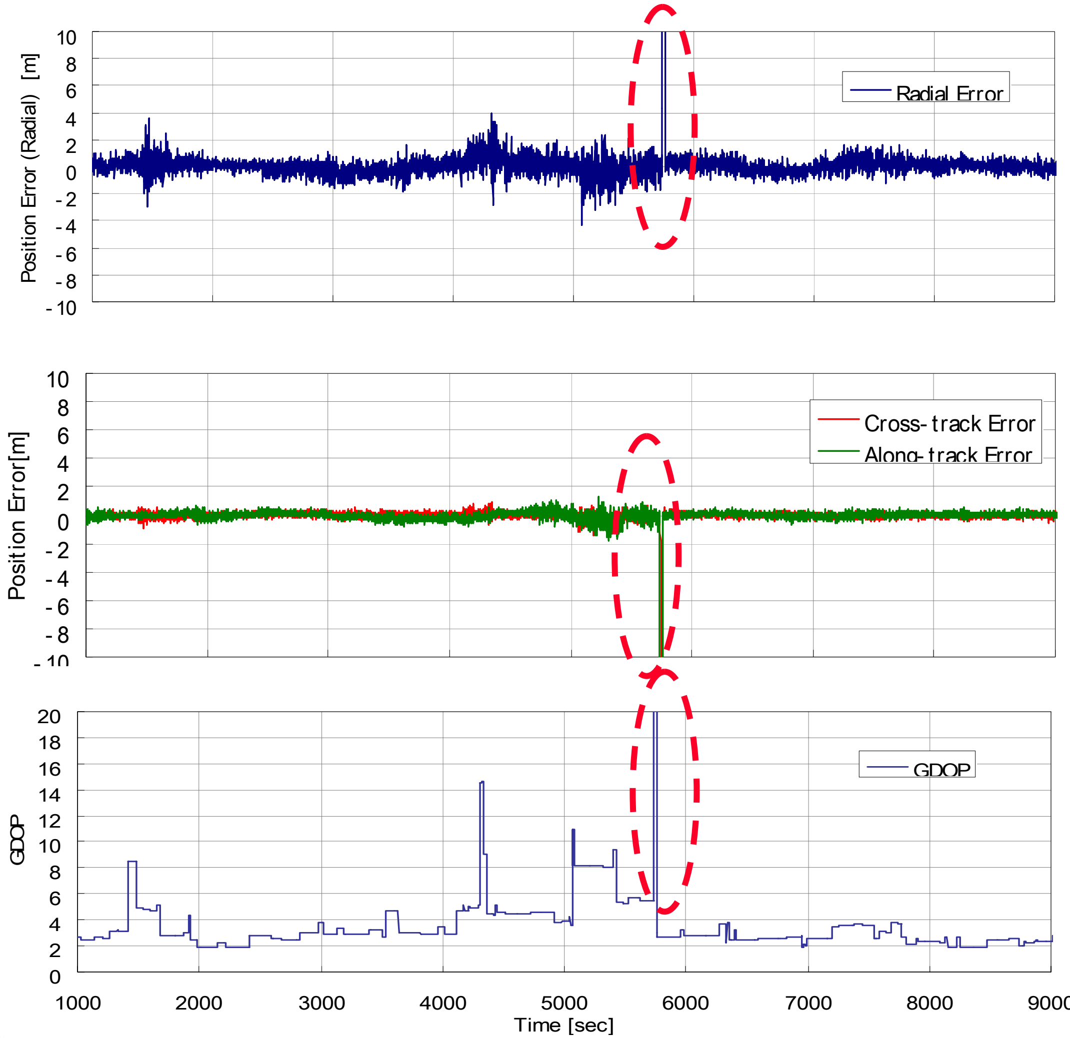
To provide the reference data for the other test cases and verify the effect of the removal of tropospheric delay correction on the firmware.

➢ Simulation configuration

- 8ch output
- Ionospheric error : OFF

→ Error sources are recevier clock and measurement noise.

Error Free Scenario (Position Error)



(a) Radial error

(b) Cross and Along Track error

(c) GDOP

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Summary of Error Free Scenario

- Removal of Tropospheric delay lead to good accuracy
- Navigation accuracy is deteriorated when GDOP is high.

→　Antenna layout and filter design should be considered carefully.

Summary of the results

	Radial	Cross-track	Along-track
Mean Position Error	0.0258 [m]	-0.0127 [m]	-0.00919 [m]
Position Error S.D.	0.571 [m]	0.186 [m]	0.252[m]
Mean velocity Error	0.0579 [m/s]	0.00264[m/s]	0.00498[m/s]
Velocity Error S.D.	0.0766[m/s]	0.0282[m/s]	0.0322[m/s]

※S.D. ： Standard Deviation

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Ionospheric Error Scenario Test

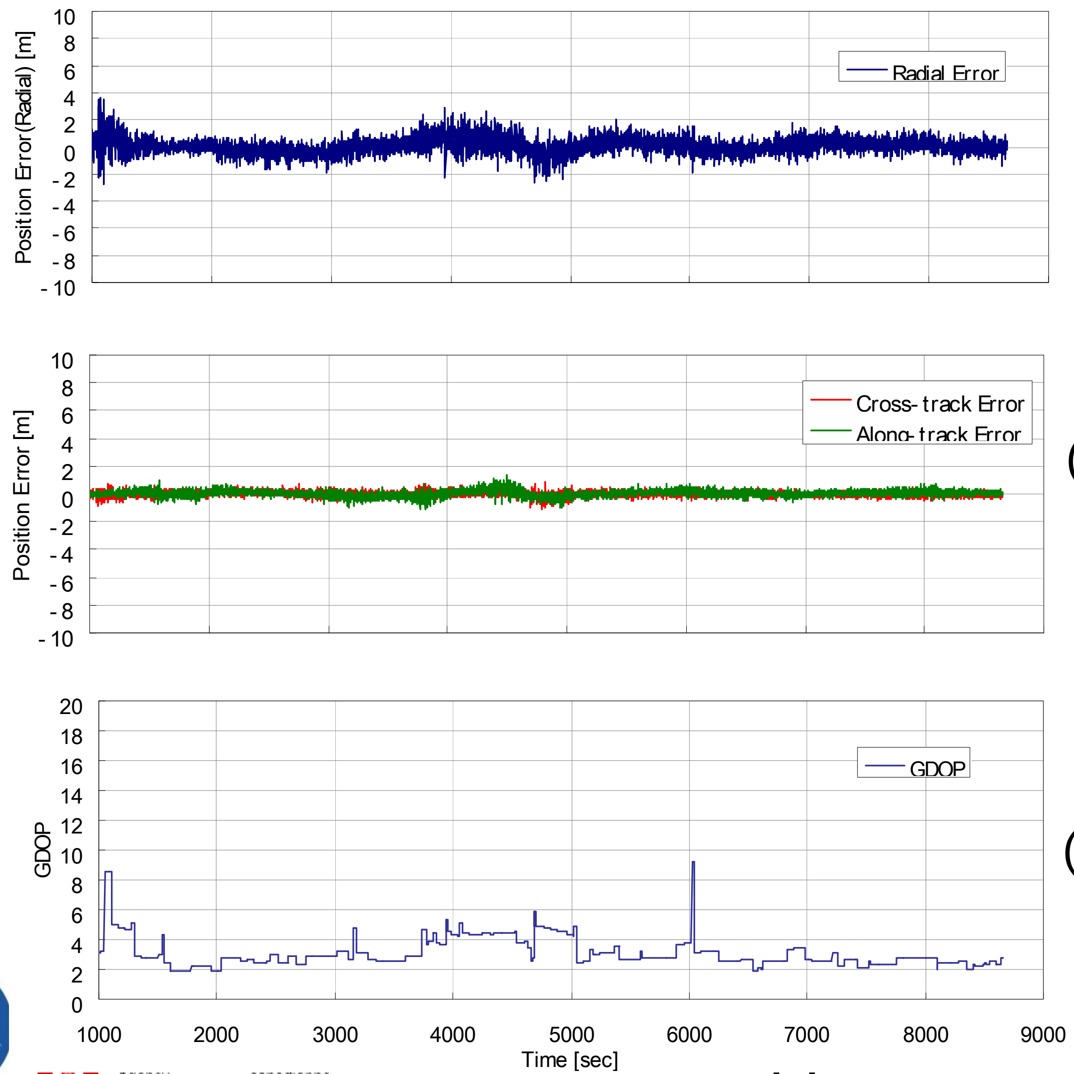
➢ Objective

To evaluate the effectivity of the dual frequency (L1 & L2) observation to remove the ionospheric delay.

➢ Simulation configuration

- 8ch output
- Ionospheric model : constant TEC (1.0e17 electron/m2)

Ionospheric Error Scenario (position errror)



(a) Radial error

(b) Cross and Along Track error

(c) GDOP

Summary of Ionospheric Error Scenario

- Navigation accuracy is still good even in ionospheric path delay.
- Dual frequency observation is well able to remove the Ionospheric path delay.

Summary of results

	Radial	Cross-track	Along-track
Mean Position Error	0.0624 [m]	-0.00982[m]	-0.0292 [m]
Position Error S.D.	0.584 [m]	0.186 [m]	0.247[m]
Mean velocity Error	0.0604 [m/s]	0.00039[m/s]	-0.0091[m/s]
Velocity Error S.D.	0.0744[m/s]	0.0229[m/s]	0.0256[m/s]

High TEC Scenario Test

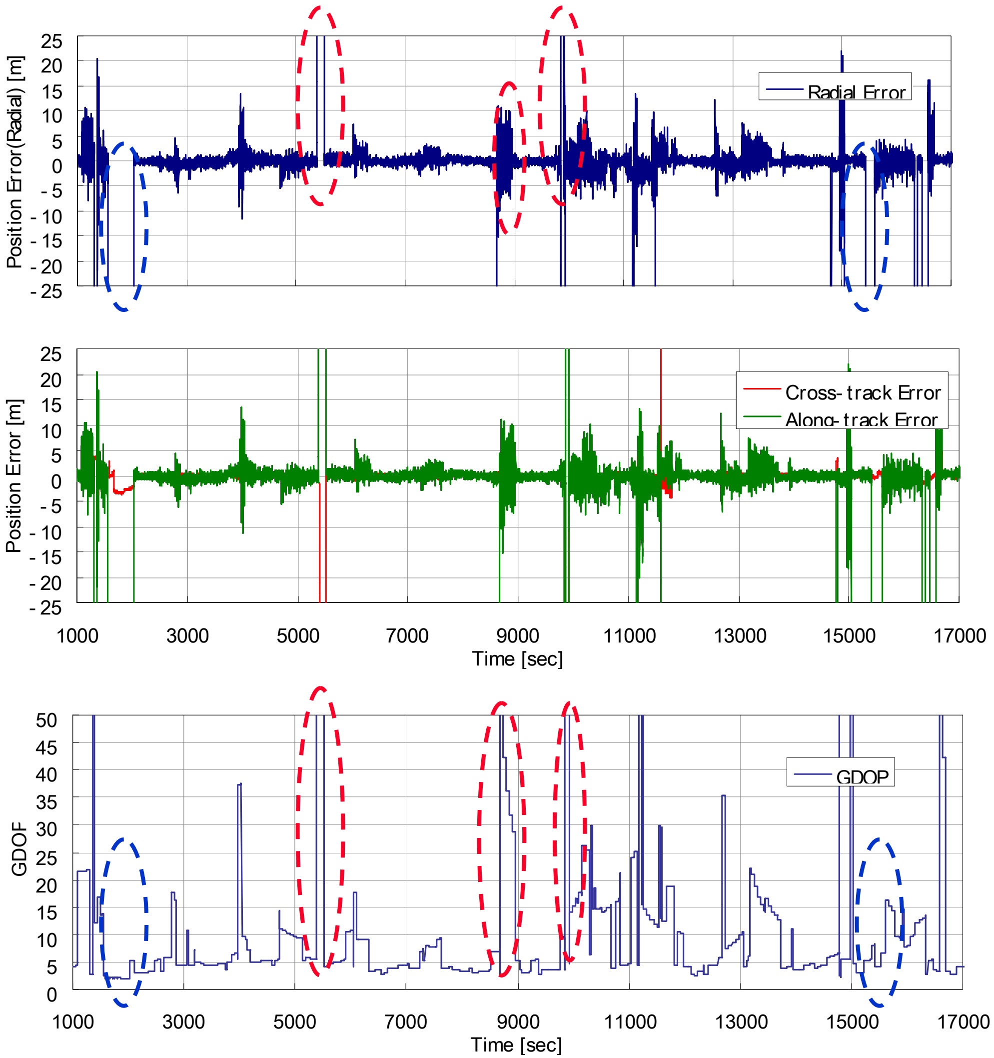
➢ Objective

To evaluate the effect of the large ionospheric delay on the GPS receiver.

➢ Simulation Configuration

- 8ch output
- ionosphere model : constant TEC (1.0e18 electron/m2)

High TEC Scenario (Position error 1/2)

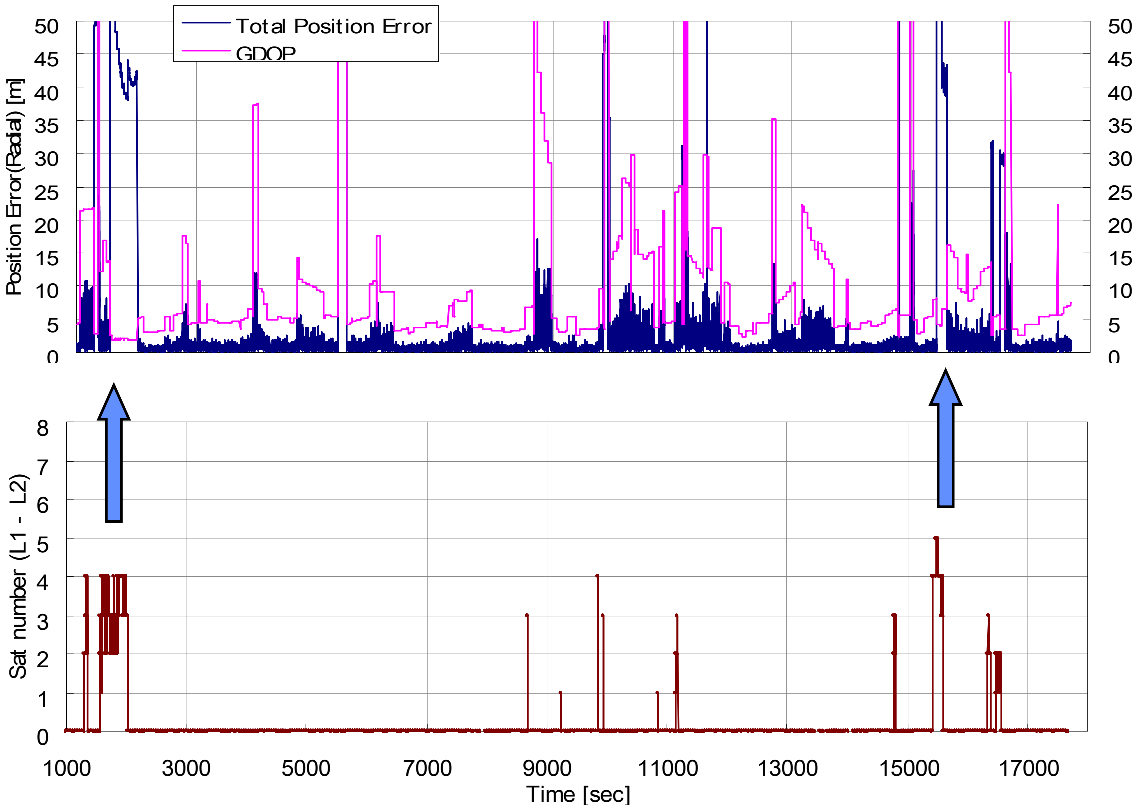


(a) Radial error

(b) Cross and Along Track error

(c) GDOP

High TEC Scenario (Position Error 2/2)



Position error remarkably **increased with loss of L2 signal**

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Summary of High TEC scenario

- Navigation errors are mainly due to poor DOP.
- But..., some data shows large position error in relatively good DOP.
- These position errors are due to loss of L2 signal
  - OEM4-G2L switches to the model based ionospheric delay correction.
  - The model (Klobcar model) used in this case does not suitable to space use.

Summary of results

	Radial	Cross-track	Along-track
Mean Position Error	0.00479 [m]	-0.00753[m]	-0.141 [m]
Position Error S.D.	1.06[m]	0.294 [m]	0.549[m]
Mean velocity Error	0.124 [m/s]	0.0129[m/s]	-0.080[m/s]
Velocity Error S.D.	0.179[m/s]	0.0581[m/s]	0.109[m/s]

JAXA Micro-GPS Receiver (MGPSR)

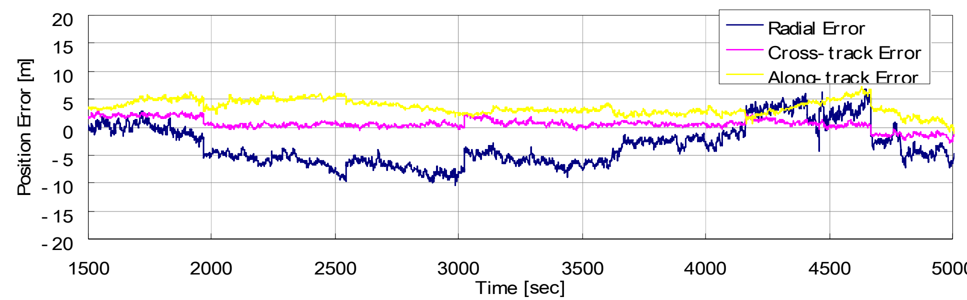
- The COTS based single frequency GPS receiver
- Firmware modification
  - Carrier phase output is added.
  - removal of altitude limit, Tropospheric and Ionospheric delay correction

Item	Specifications
Size	72 x 50 x 40 mm
Mass	215g
Power	1.5W (typical)
Frequency	1575.42 MHz (L1)
No. of channels	8 ch
Output data	PPS signal Navigation data Raw data Ephemeris data
Interface	RS-422, +5VDC

Ionosphere Scenario Tests (compared with OEM4-G2L)

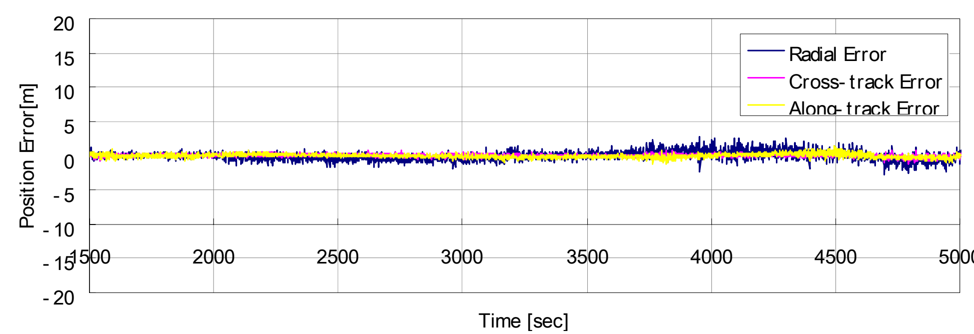
➢ Navigation accuracy of MGPSR is affected by the Ionospheric delay especially in radial direction.

	Radial	Cross-track	Along-track
Mean Position Error	-2.95[m]	0.542[m]	3.41[m]
Position Error S.D.	3.75[m]	0.956[m]	1.39[m]



Results of MGPSR

	Radial	Cross-track	Along-track
Mean Position Error	0.0624 [m]	-0.00982[m]	-0.0292 [m]
Position Error S.D.	0.584 [m]	0.186 [m]	0.247[m]



Results of OEM4-G2L

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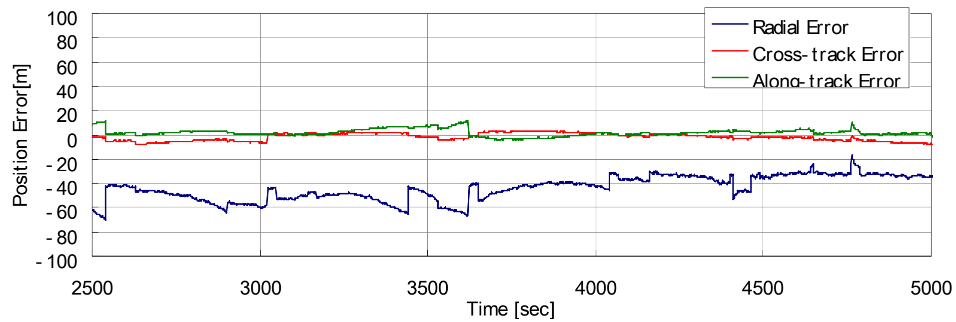
High TEC Scenario Test (compared with OEM4-G2L)

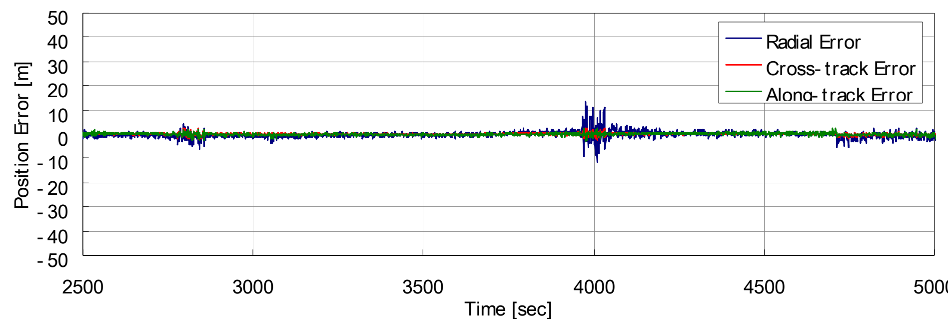
➢ Ionospheric delay affect the navigation error of the MGPSR more significantly than that of OEM4-G2L.

	Radial	Cross-track	Along-track
Mean Position Error	-46.8 [m]	-2.98[m]	1.84[m]
Position Error S.D.	11.3 [m]	3.57[m]	2.89[m]



Results of MGPSR

	Radial	Cross-track	Along-track
Mean Position Error	0.00479 [m]	-0.00753[m]	-0.141 [m]
Position Error S.D.	1.06[m]	0.294 [m]	0.549[m]



Results of OEM4-G2L

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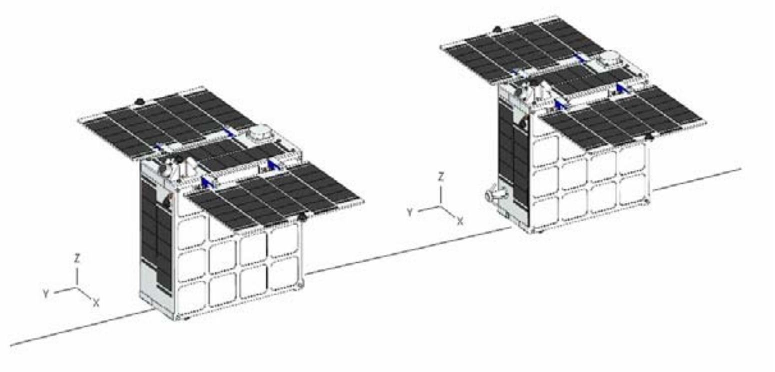
JC2Sat-FF Mission

- JC2Sat-FF Mission
  - International joint research between CSA and JAXA.
  - A nanosat formation flying mission based on differential drag technique and GPS based relative navigation.
  - The orbit information of each nanosat is obtained by its respective GPS receiver. This information is then transmitted via a S-band antenna to the other nanosat.
  - On-orbit Attitude & Orbit Determination Systems software will then compute the separation between the nanosats and then determine the needed control authority to maintain the baseline.



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SUMMARY

- Simulation based performance assessment of a commercial dual frequency GPS receiver NovAtel “OEM4-G2L” is performed. The result shows ;
  - OEM4-G2L shows well initial acquisition performance in LEO.
  - Under the condition in which Ionospheric delay is correctly removed by the dual frequency observation, the OEM4-G2L provides accurate navigation solution.
- The comparison of the performance between OEM4-G2L and JAXA MGPSR shows some advantages of the dual frequency receiver.
- More detailed study such as assessment of raw measurement accuracy will be performed in the future works.