GPS Data Application of the KOMPSAT-2

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Abstract

The use of GPS receiver at outer space becomes common in low earth orbit. The KOrea Multi-Purpose SATellite-1 (KOMPSAT-1) which was launched in December 1999 has used GPS receiver's navigation solution to perform the Orbit Determination (OD) in the ground. At the circumstance of using only one ground station, the Orbit Determination using GPS receiver is good method. Because the accuracy of navigation solution acquiring directly from GPS receiver is not enough in satellite application such as map generation, post-processing concepts such as the Precise Orbit Determination (POD) are applied to satellite data processing to improve satellite position accuracy. The POD uses GPS receiver's raw measurement data instead of GPS receiver's navigation solution. The KOrea Multi-Purpose SATellite-2 (KOMPSAT-2) system newly uses the POD technique for large scale map generation. The satellite was launched in the end of July 2006. The satellite sends high resolution images in panchromatic band and multi-spectral bands to the ground. The satellite system uses GPS receivers as source of time synchronization and command reference in the satellite, provider of navigation solution for the OD, and provider of raw measurement data for the POD. In this paper, mechanical configuration and operations of the GPS receiver will be presented. The GPS data characteristics of the satellite such as time synchronization, command reference, the OD using GPS receiver's navigation solution, and the POD using GPS receiver's raw measurement data will be presented and analyzed. The enhancement of performance compared with it of the previous satellite will also be analyzed.

Keywords: KOMPSAT-1, KOMPSAT-2, GPS data application, time synchronization, Orbit Determination, Precise Orbit Determination

1. Introduction

The use of GPS receiver for space applications is now widely achieved for Low Earth Orbit satellite through both scientific and commercial programs.

The KOMPSAT-1 which was developed by KARI with the collaboration with TRW Inc. has been operated since December 1999. The mission of the satellite is imaging of Korean peninsula. The GPS navigation solutions from Motorola's Viceroy GPS receiver are used for the Orbit Determination. The GPS receiver gathers worldwide navigation solutions and records it to mass memory of the satellite. And then later, those are dumped from the satellite to the ground station. Because orbit determination of the satellite is based on navigation solutions of the GPS receiver, the accuracy is limited but met to the mission of the satellite. Orbit determination scheme using GPS navigation solutions provides the static orbit information and reduce the position and velocity errors of the GPS navigation solutions. The primary errors of such as Low Earth Orbit satellite are the errors of the geo-potential model and that of the drag [1][2]. The orbit determination of the satellite is mainly performed on the data that the GPS receiver provides. The GPS receiver is capable to track the signal from GPS satellites and achieves 3 dimensional position fix within less than 30 minutes if it was properly initialized [3]. This is an advantage that can reduce the workload such as ranging and the necessity of global ground station networks.

The KOMPSAT-2 was launched in July 28 2006. The mission of the satellite is high resolution imaging of Korean peninsula. The satellite provides 1) surveillance of large scale disasters and its countermeasure in Korean region, 2) acquisition of independent high resolution images for GIS, and 3) composition of printed maps and digitized maps for domestic and overseas territories to users [4]. The satellite is sun synchronous orbit. The purpose of satellite orbit determination at the satellite is antenna tracking of ground stations to the satellite and image processing. The satellite uses an Alcatel's TOPSTAR 3000 GPS receiver for positioning and timing in normal operations at the satellite in orbit. GPS navigation solutions such as position and velocity, and GPS raw data such as C/A pseudo range and L1 carrier phase measurements are transmitted to the ground station via playback of onboard mass memory. The ground station is located in Daejeon, South Korea. Two types of orbit determination are performed using GPS data. One is the orbit determination using GPS navigation solutions and this is same technique to it of the previous satellite. The other is the Precise Orbit Determination using GPS raw measurement data by DGPS technique. A batch of the navigation solutions is used in the orbit determination, which is used for antenna tracking and image processing. A batch of the pseudo range and carrier phase data from the satellite and the international GPS service stations in ground are used at the Precise Orbit Determination for the precise image processing [5].

In this paper, the GPS data application experience of the satellite will be presented. The characteristics of time synchronization and navigation solutions will be analyzed. The performance of the OD and POD will be analyzed. The comparison of GPS applications between the previous satellite and the current satellite will be presented.

2. GPS Receiver Characteristics

The GPS receiver is a TOPSTAR 3000 GPS receiver which is made by the Alcatel. The Alcatel had developed it under a joint ESA/CNES contract during development period, 1997 – 1999. The TOPSTAR 3000 GPS receiver which is a new generation GPS receiver is dedicated to spacecraft applications. The receiver uses L1 C/A and features modular and multi mission applications. The receiver has been designed as autonomous and independent equipment that enables easy adaptation to mission requirements and spacecraft interfaces. Embedded orbital navigator provides reliable and highly accurate navigation solutions, and is able to cope with poor visibility conditions as well as spacecraft maneuvers [6]. Table 1 shows key parameters of the GPS receiver.

Table 1. GPS Receiver Key Parameters

Item	Key Parameters
Position Accuracy	< 30m (3 sigma)
Velocity Accuracy	< 0.03m/s (3 sigma)
Time Accuracy	< 100 µs (3 sigma)
Raw Data	pseudo-range, carrier-phase, etc.
PPS accuracy	< 1.5 µs
Communication Method	MIL-STD-1553B
Operational constraints	limited warm start

Mechanical accommodation and configuration of GPS receivers and antennas is based on heritage of the previous satellite. Two set of antennas are mounted on +X +Y and +X –Y body panel of the satellite. As figure 1, Field Of View of each antenna is 140 degrees. Figure 1 shows GPS antenna accommodation. During mission, Z axis of spacecraft points perpendicularly earth.

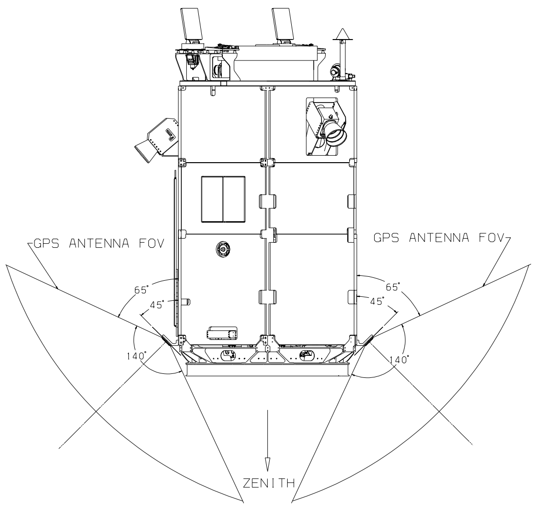

Figure 1. GPS Antenna Accommodation

3. GPS Data Applications

GPS data are used for time synchronization in order to synchronize time of all processors including payload. Navigation solutions of the GPS receiver are used for orbit estimator of the satellite and source data of the OD at ground. The OD which is performed at ground is used for antenna tracking of ground station and rough image processing. The POD which is also performed at ground is used for high resolution image processing. Figure 2 shows concept of GPS data applications. Analysis of GPS data applications was based on the GPS data of the satellite located in target orbits.

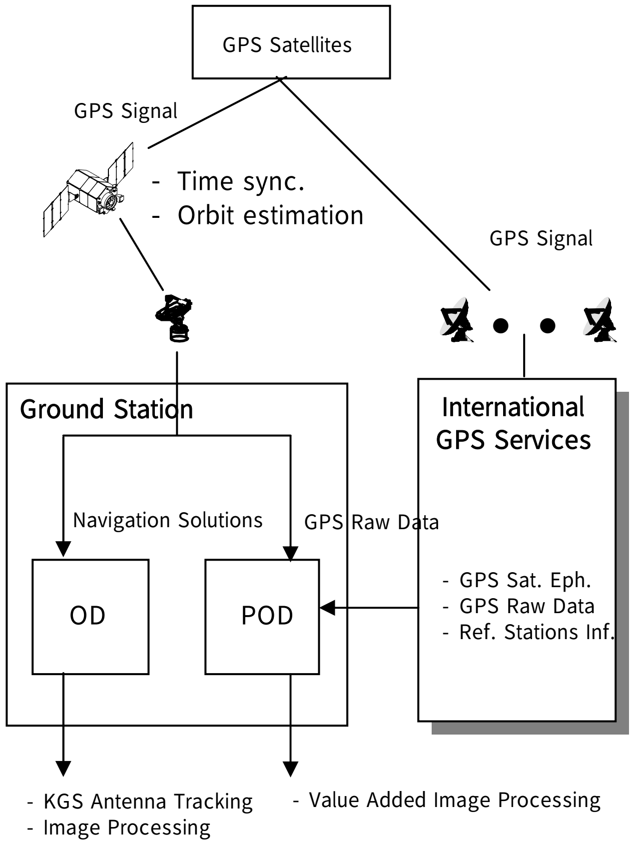

Figure 2. GPS Applications Concept

3.1 Time Synchronization

Generally, a GPS receiver provides very accurate time and time interval to users. The time synchronization of the satellite occurs at 1PPS. The EPS Control Unit (ECU) processor by means of Digital Phase Lock Loop (DPLL) and Front End Processor (FEP) is synchronized to 1 PPS coming from the GPS receiver. The FEP monitors errors of 1 PPS and provides available 1 PPS to DPLL by filtering. The On Board Computer (OBC) and Remote Drive Unit (RDU) processors are in turn synchronized to the ECU. Figure 3 shows concept of time synchronization in the satellite. Figure 4 shows the measurement of GPS 1 PPS interval. Figure 5 shows time difference between GPS 1 PPS and ECU 1 Hz.

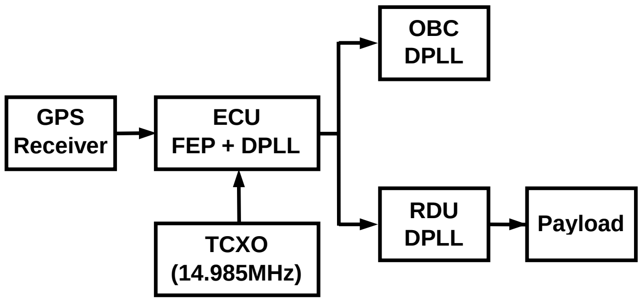

Figure 3. Time Synchronization Scheme

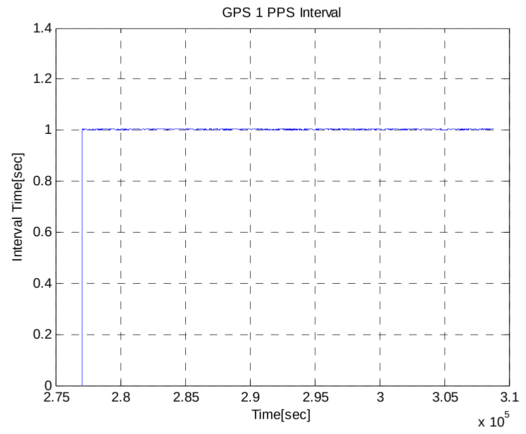

Figure 4. GPS 1 PPS Interval

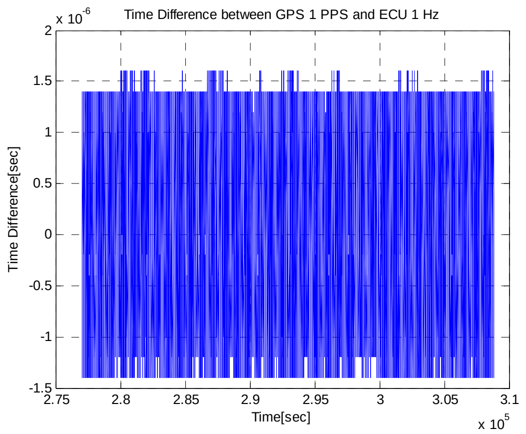

Figure 5. Time Difference between GPS 1 PPS and ECU 1 Hz

3.2 Navigation Solutions of GPS Receiver

Navigation solutions of the GPS receiver used for two purposes. All of navigation solutions are recorded to mass memory of the satellite and then dumped to the ground station for the OD. Parts of navigation solutions are used for command reference of the Attitude and Orbit Control Subsystem (AOCS).

The GPS receiver implements two concurrent localization algorithms: snapshot least square resolution and orbital navigator. The snapshot resolution uses least square method for acquiring position, velocity, clock bias and clock drift from pseudo range and pseudo range rate measurements. It requires at least 4 GPS satellites in view. Accuracy is related with GPS satellites geometry and range error. The benefit of the snapshot resolution is to provide a first fix after a cold start as soon as 4 satellites are tracked and this first fix can be used for the initialization of the orbital navigator [6]. The orbital navigator implemented in the TOPSTAR 3000 GPS receiver is called DIOGENE which is based on KALMAN filter. It performs propagation of the state vector with an accurate propagation model of forces and updates the state vector with available GPS measurement data. The state vector is composed of the position, velocity, the clock drift and the clock bias. The propagation model includes a 40 X 40 earth gravitational field model, Moon and Sun gravitational effect, and solar pressure effect. Figure 6 and 7 show the characteristics of DIOGENE in real orbit. Figure 8, 9 and 10 show the performance of DIOGENE in real orbit. Both localization algorithms outputs are continuously monitored and the GPS receiver provides best solution with the lowest estimated error. Typically the snapshot resolution outputs are selected as long as the orbital navigator is not converged or maneuvers with large errors.

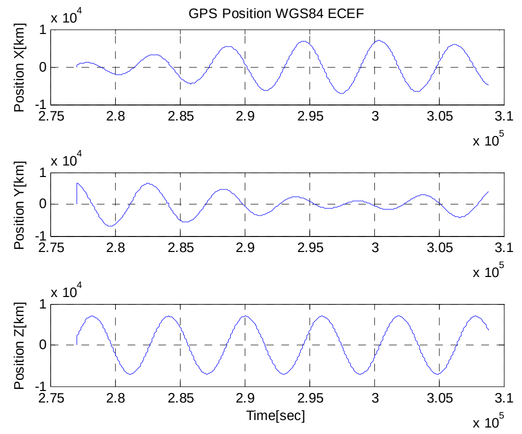

Figure 6. Position Characteristics of the GPS Receiver

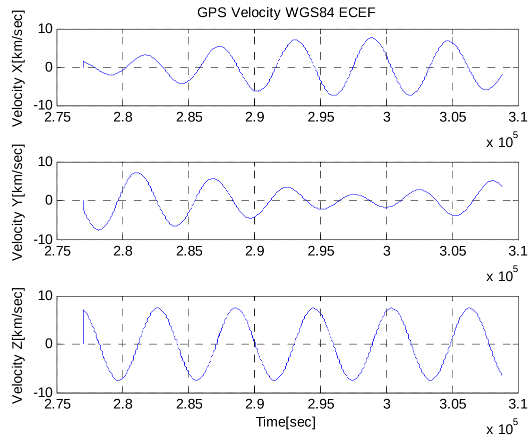

Figure 7. Velocity Characteristics of the GPS Receiver

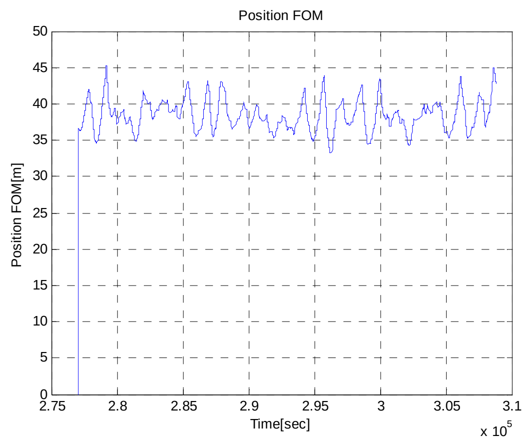

Figure 8. Position FOM of the GPS Receiver

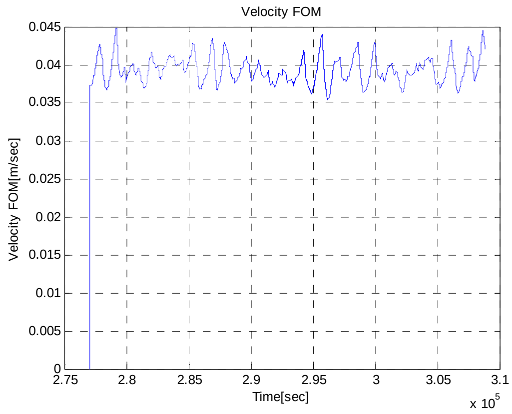

Figure 9. Velocity FOM of the GPS Receiver

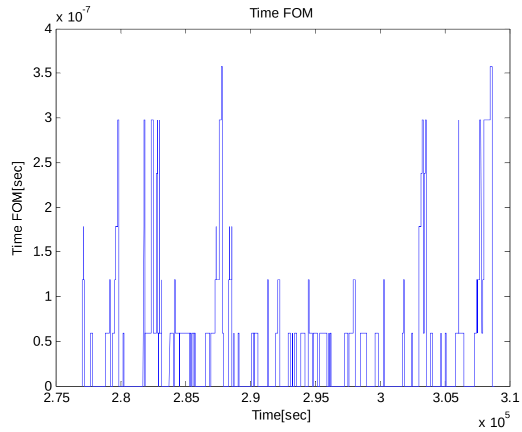

Figure 10. Time FOM of the GPS Receiver

Figure 11 shows number of tracked GPS satellites during nadir point of the satellite.

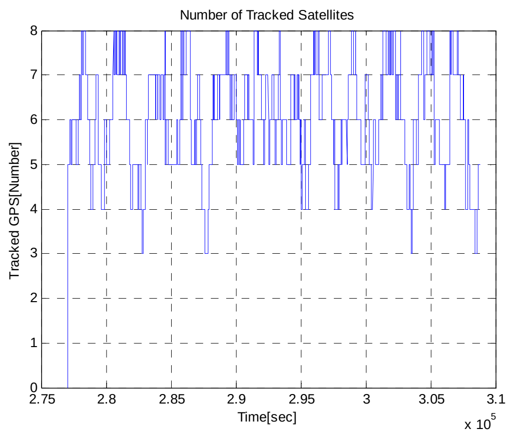

Figure 11. Tracked GPS Satellite

The AOCS is designed to use GPS navigation solutions as command reference. Navigation solutions of ECEF coordinate form GPS receiver is transformed into position and velocity in ECI for computing the local orbital coordinate. Thus, the improvement of attitude pointing accuracy is expected.

3.3 Orbit Determination using GPS Navigation Solutions

Navigation solutions provided by the GPS receiver are used for source data for orbit determination at the ground. The ground station performs orbit determination using navigation solutions of the GPS receivers.

The orbit determination uses batch type minimum variance estimator for acquiring definitive orbit of the satellite. The process consists of editing and smoothing the measurement data followed by a batch least squares curve fit using iterative differential correction to optimize the estimated trajectory. GPS navigation solutions in ECEF system are coordinate transformed to True-Of-Date(TOD) ECI system for the OD.

The OD for obtaining the Keplerian six orbital elements uses Cowell's numerical method. The force models include the geo-potential upto 70 X 70, lunar-solar potentials, solar radiation pressure, atmospheric drag using Jacchia 71 model, and general accelerations. The numerical integration procedure is a predictor-corrector type [7].

The characteristics of the OD are slightly different from those of the previous satellite because GPS receivers of the previous satellite and the current satellite are not same. But, the contents and frequency of GPS navigation solutions from the current satellite are same as those of the previous satellite although the different GPS receiver is used. Figure 12 shows the characteristics of the OD.

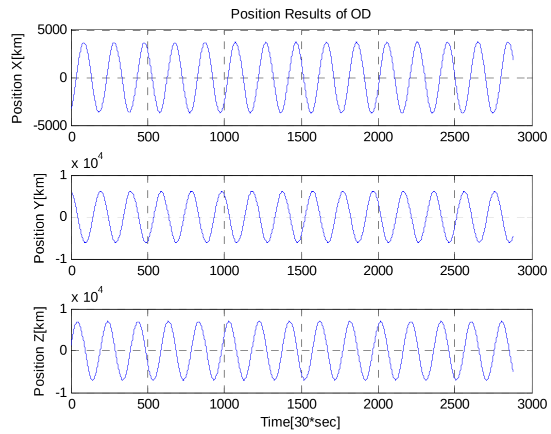

Figure 12. Position Results of OD

As assessing performance of the OD, overlapping method was adapted [8][9]. Figure 13 shows position difference of the overlapping period. Position differences of overlapping method are along track 2.78 m RMS, cross track 3.89 m RMS, and radial 0.43 meter RMS.

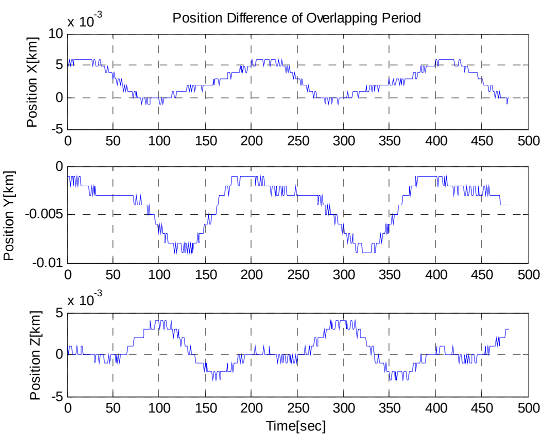

Figure 13. Position Difference of Overlapping Method

The results of the orbit determination are used for antenna tracking of ground station and image processing for users.

3.4 Precise Orbit Determination using GPS Navigation Solutions

The GPS receiver also provides raw measurement data such as pseudo range data and carrier phase data. Raw measurement data are recorded to mass memory and dumped down to the ground station.

One of GPS applications is the POD using raw measurement data. This application was demonstrated in the experiment on TOPEX/Poseidon program carrying a six channel GPS receiver capable of making dual frequency P code pseudo range data and continuous carrier phase measurements [10]. The POD concept of the satellite is based on the concepts of TOPEX/Poseidon and is illustrated in Figure 2. The POD requires continuous data of the visible GPS satellites by ground and flight GPS receiver. The POD processing uses raw measurement data of the GPS receiver and data collected from International GPS Service (IGS).

The precise orbit determination is composed of two parts. One is a pre-processing of the measurement data for error correction and double differenced data generation. The other is an estimation process based on dynamic parameters estimation and weighted least square batch filter.

Pre-processing performs pre-processing of measurement data for the error correction and double differenced data generation, and consists of cycle slip detection and repair, bad point detection and deletion, time tagging error correction, and differential GPS technique. Cycle slip detection and repair algorithms are forming cycle slip sensitive linear combinations of the available observable and detect to fit a low order polynomial over the time series. The differential GPS technique applied in the preprocessing uses L1 carrier phase data measured the GPS receiver and the data of the IGS stations over the world for the generation of double differenced data on the 30 second interval.

Estimation process is based on dynamic parameters estimation and weighted least square batch filter, and consists of dynamic modeling, measurement modeling, and estimation scheme. The GRAPHIC [11] and Total Electron Content (TEC) scale factor estimation [12] are used in orbit estimation process for the elimination or reduction of the ionospheric path delay in GPS measurements.

The precise dynamic models are derived as the equations of motion and variation equations of satellites. The equations of motion and the variation equations are numerically integrated in J2000 reference coordinates using Adams-Cowell 11th order predictor corrector method. The gravitational forces, sun and moon gravity, solid earth and ocean tides, relativistic effect, drag, solar radiation and earth radiation pressure are modeled.

GPS measurement models are composed of ionospheric delay, tropospheric delay, relativistic effect, phase center offset and variation of GPS receiver antenna, and position variation of the ground stations due to the solid Earth tide, ocean loading, and tectonic plate motions.

The epoch state batch filter, where all measurements obtained at different times are mapped to a single epoch in order to estimate the epoch state, has to be modified to be able to adjust the dynamic parameters such as coefficients of solar radiation, drag, and general acceleration, the measurement biases such as phase ambiguity and scale factors of TEC value, and station related parameters such as tropospheric zenith delay parameters at user specified subdivided epochs. Estimating the dynamic related parameters once per specific period has an important role on accounting for deficiencies in the dynamic models.

Figure 14 and 15 show carrier phase and pseudo-range data characteristics of GPS PRN measured by the GPS receiver during the Launch and Early Operations Phase. Results of the POD were compared with navigation solutions of the GPS receiver. According to previous results of performance of section 3.2 about navigation solutions, navigation solutions are roughly guaranteed as order of 20 meters. Figure 16 shows orbit difference between POD and navigation solutions. The performance of the POD at the ground was tested and analyzed [13]. But, the performance of the POD at the space was not fully verified and will be guaranteed under certain value of accuracy.

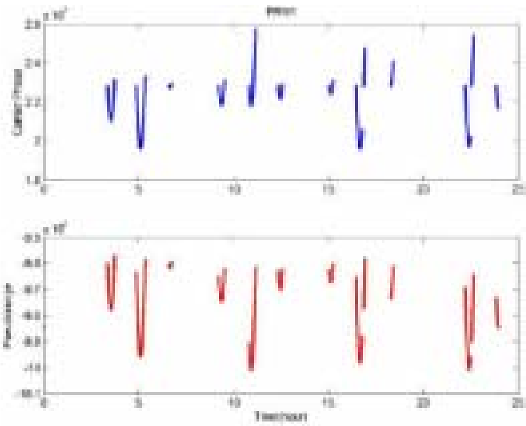

Figure 14. GPS PRN 1 Carrier Phase and Pseudorange Data Characteristics

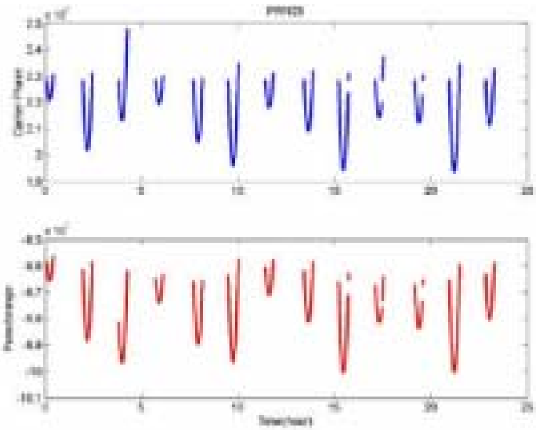

Figure 15. GPS PRN 28 Carrier Phase and Pseudorange Data Characteristics

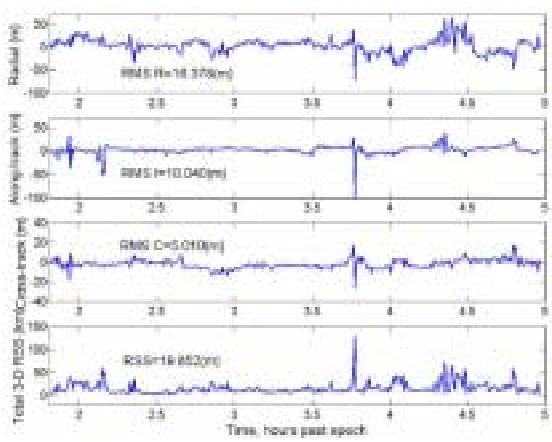

Figure 16. Orbit Difference between POD and Navigation Solutions

4. Conclusion

The GPS data of the previous satellite was used for the Orbit Determination and prediction on ground. In the current satellite, new GPS applications such as time synchronization, on-board usage for attitude control, and POD are added for the program.

The experience of GPS applications in the satellite was just started. The characteristics and performance of the GPS receiver was shown and partially analyzed. A GPS will be used for next satellite series which will be launched 2009.

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Reference

1. Bradford W. Parkinson, James J. Spilker Jr., Penina Axelrad, and Per Enge, "Global Positioning System : Theory and Application," *Volume II Chapter 21, Volume 164 Progress In Astronautics And Aeronautics*, 1994.
2. Jae-Cheol Yoon, Byoung-Sun Lee, and Kyu-Hong Choi, "Spacecraft Orbit Determination using GPS Navigation Solutions," *Aerosp. Sci. Technol.*, 2000, pp. 215-221.
3. J. H. Lee, M. J. Baek, J. C. Koo, K. L. Yong and Y. K. Chang, "KOMPSAT-1 Satellite Orbit Control using GPS Data," *KSAS International Journal*, 2000, Vol. 1, No. 2.
4. S. R. Lee, E. H. Kim, and H. J. Kim, "GPS Data Applications in the Development and Operations of the KOMPSAT-1 and KOMPSAT-2 Satellite System," *International Symposium on GPS/GNSS 8th Workshop*, 2001, pp. 130-133.
5. D. W. Chung, S. R. Lee, and S. J. Lee, "KOMPSAT-2 Orbit Determination using GPS Signals," *International Symposium on GPS/GNSS*, 2004, pp. 164-173.
6. Gerner J. L., Issler J. L., Laurichesse D., Mehlen C., and Wilhelm N., "TOPSTAR 3000 – An Enhanced GPS Receiver for Space Application," *Alcatel Document*.
7. B. S. Lee, J. C. Yoon, and J. H. Kim, "GPS Based Orbit Determination System for the KOMPSAT-2," *14th AAS/AIAA Space Flight Mechanics Conference, Maui, Hawaii*, 2004.
8. Meek, M.C., Gold, K.L., Hwang, Y., Axelrad, P., Born, G.H., and Engelhardt, D., "Orbit Determination for the Quickbird Spacecraft," *Proceedings of 2002 Core Technologies for Space Systems Conference*, 2002.
9. Willy Bertiger, Yoaz Bar-Server, Bruce Haines, Rodrigo Ibanez-Meier, et al., "The First Low Earth Orbiter with Precise GPS Positioning : Topex/Poseidon," *Proceedings of ION GPS 93, Utah*, 1993, pp. 269-277.
10. Berger W. I., Bar-Sever Y. E., and et al, "GPS Precise Tracking of TOPEX/POSEIDON : Results and Implementation," *Journal of Geophysical Research*, 1994, Vol. 99, No. 2, pp. 449-462.
11. C. E. Cohen, B. Pervan, and B. Parkinson, "Estimation of Absolute Ionospheric Delay Exclusively Through Single Frequency GPS Measurements," *Proc. of 92 ION GPS Conference, Kansas, Missouri*, 1997, pp. 325-330.
12. J. C. Yoon, K. M. Roh, E. S. Park, B. Y. Moon, K. H. Choi, J. S. Lee, B. S. Lee, J. H. Kim and Y. K. Chang, "Orbit Determination of Spacecraft Using Global Positioning System Single Frequency Measurements," *J. of Spacecraft and Rockets*, 2002, Vol. 39, No. 5, PP. 796-801.
13. D. W. Chung and S. J. Lee, "Performance Test of Spaceborne GPS Receiver," *GNSS Workshop 12th*, 2005, pp. 11.