Performance Analysis of the GPS Antenna for Satellite Launch Vehicles under the Hot -Temperature Environment

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Abstract

In order to use a GPS antenna for launch vehicles, it should be installed on the skin of the vehicle and be able to normally receive the live GPS signals during the vehicle's full flight mission. The GPS antenna on the surface of the launch vehicle is, however, exposed to higher temperature than inner equipments of the vehicle due to aerodynamic heating generated during the flight. Test specification of the GPS antenna for qualification of hot-temperature is determined to +95℃ that is higher than inner components by 25℃. Test results in this paper show that the GPS antenna normally operates under the above environment.

Keywords: Global Positioning System, GPS Antenna, GPS Receiver, Launch Vehicle, Environment Test.

1. Introduction

The GPS antenna for a launch vehicle developed by KARI (Korea Aerospace Research Institute) will be mounted on the KSLV-I, the first launch vehicle of Korea. All the components mounted on the launch vehicle should normally operate under the severe conditions differently from commercial components such as acceleration, vibration, shock, temperature, vacuum and EMI/EMC environment. Therefore the components of the launch vehicle have to be designed and manufactured in order to operate normally under the above severe environments, and various environment tests for the qualification must be carried out according to the environment specifications before flight.

In this paper, the procedures and results of the hot-temperature test of the GPS antenna are described. The GPS antenna is to be mounted on the skin of the launch vehicle and 3 GPS antennas are used to guarantee sufficient visibility of the GPS satellite [1]. Since the launch vehicle flies through the atmosphere with maximum velocity of 7 ~ 8km/sec, approximately, the temperature of the launch vehicle's surface rises drastically due to the aerodynamic heating effect. Therefore the GPS antenna mounted on the skin of the vehicle is exposed to the more severely hot-temperature environment compared to the inner equipments of the vehicle, so that the specification of the hot-temperature environment test becomes more severe than inner subsystems [2].

When the GPS antenna is exposed to the hot-temperature environment, antenna materials can be deformed physically and the performance of the LNA(Low Noise Amplifier) can be degraded. Therefore the physical and operational changes of the GPS antenna under high-temperature have to be checked and the performance should be confirmed through the hot-temperature environment test before flight.

The configuration of this paper is as follows: section 2 of this paper shows the figures and specifications of the developed GPS antenna, and section 3 includes the installation for the hot-temperature test: test specifications, hardware configurations and GPS simulator scenario setting. Test results are described in section 4 with respect to the performance of the GPS receiver connected to the GPS antenna and it is concluded in section 5.

2. GPS Antenna

2.1 Structure and Specifications

The GPS antenna for the launch vehicle is designed to operate normally under the severe environments of the launch vehicle without physical deformations and damages, and also the LNA in the antenna has a heritage of being mounted on the foreign satellite system. In order to guarantee normal operation of the GPS antenna under the hot-temperature environment, it is manufactured using specific materials which are strong for the hot-temperature condition. The layout of the GPS antenna is shown in Figure 1. The GPS antenna is constructed as 5 layers including an aluminum base.

- #1 Radome: ceramic filled polytetrafluoroethylene
- #2 Radome bonding film: FEP-fluorocarbon film
- #3 Antenna circuit/substrate: ceramic filled polytetrafluoro-ethylene
- #4 Circuit bonding film: FEP-fluorocarbon film
- #5 Aluminum Base

Composed material of radome and antenna circuit/ substrate(#1, #3) is RO3003 and its laminate dielectric constant is almost unchanged when the temperature range is from -100℃ to +250℃ [3]. The continuous service temperature range of the radome bonding film and circuit bonding film(#2, #4) is from -240℃ to +250℃ [4].

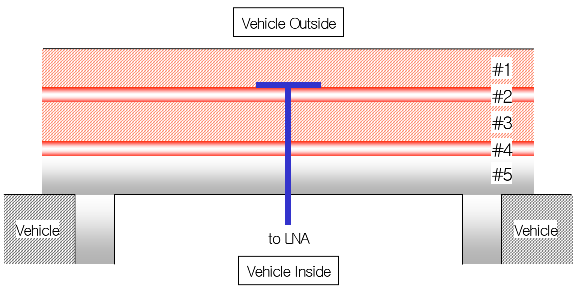

Figure 1. Layout of the GPS antenna.

Figure 2. GPS antenna.

Table 1. Specifications of the GPS antenna.

Antenna	
Frequency [MHz]	1,575
VSWR	1.5
Gain [dBc]	5.03
LNA	
Current [mA]	22
Gain [dB]	25
Noise Figure [dB]	0.9

The surface of the GPS antenna is located outside of the launch vehicle and the LNA is installed inside of the GPS antenna. The surface of the GPS antenna, therefore, is directly exposed to the hot-temperature generated by aerodynamic heating effect. But, the LNA is less affected than the surface of the GPS antenna because the heat has to pass through the 5 layers of the GPS antenna to arrive at the LNA.

The shape of the GPS antenna for a satellite launch vehicle is shown in Figure 2 which is an active patch-type. It is connected to a GPS receiver with SMA type connector. It includes 8 flat-headed bolt holes whose size is M5 in order to install on the skin of the launch vehicle.

The GPS antenna has a limitation of installation place on the launch vehicle that has the cylindrical shape. The installation place for the GPS antenna is the side of the cylindrical vehicle. In order to mount the GPS antenna on the surface of the launch vehicle, the patch type antenna is the most suitable [5]. It is noted that the curvature of the vehicle should be applied to the antenna shape.

The specifications of the GPS antenna are shown in Table 1. VSWR(Voltage Standing Wave Ratio) of the antenna is 1.5, and the internal LNA has the gain of 25dB. Figure 3 and Figure 4 show the elevation pattern and Azimuth pattern of the GPS antenna, respectively.

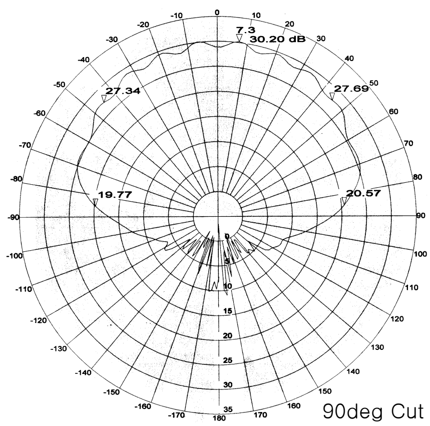

Figure 3. Magnitude vs. Elevation (at 1,575MHz).

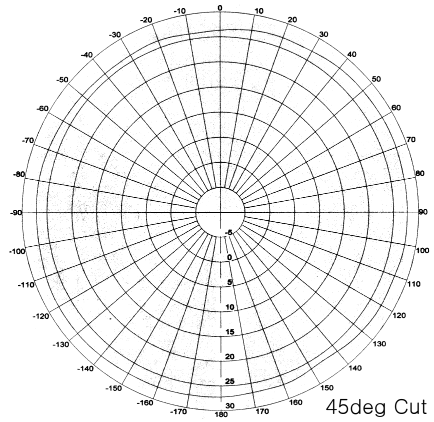

Figure 4. Magnitude vs. Azimuth (at 1,575MHz).

3. Test Installation

3.1 Test Specification

The specifications of the temperature environment test of the GPS antenna is determined by the analysis of the launch vehicle's aerodynamic heating effect based on the flight profile of the launch vehicle [2]. The temperature test of the GPS antenna is divided by hot-test and cold-test that have the conditions as follows [6]:

- Cold-Test
  - Qualification Test: maintaining more than 5 hours at -25℃(±2℃)
  - Acceptance Test: maintaining more than 5 hours at -15℃(±2℃)
- Hot-Test
  - Qualification Test: maintaining more than 30 minutes at +95℃(±2℃)
  - Acceptance Test: maintaining more than 30 minutes at +85℃(±2℃)

- Temperature change rate have to be 1℃/min ~ 2℃/min, less than 3℃/min

3.2 Hardware Configuration

There are several ways to carry out the temperature test of the GPS antenna. The first method is simple way to compare the operation and performance only before and after the test. It is very simple but it is impossible to check the condition of the GPS antenna during the temperature variation and dwell phase. The second method is to use an antenna hat which can provide GPS satellite signals to the GPS antenna directly. The antenna hat is a kind of antenna which can cover the GPS antenna, so that it can provide GPS satellite signals to the GPS antenna with minimum free space. This method has advantages that can check the condition of the GPS antenna during the test and there is no multi-path effect. To use the second method, however, the antenna hat has to be manufactured additionally and its performance does not have to be affected by the temperature change. The third method is to install the additional passive antenna in the temperature chamber to provide GPS satellite signals to the GPS antenna. This method is easy to set the test installation and can check the condition of the GPS antenna during the full test range, but the multi-path of the signals affects to the GPS antenna's performance because the transmitted signals from the passive antenna pass through the internal free space of the chamber to the GPS antenna. It is also that the passive antenna does not have to be affected by the temperature change. The test results have to be compared according to the test phase, before the test (Pre-Test), during the test (Main-Test) and after the test (Post-Test), relatively.

In order to carry out the hot-temperature test of the GPS antenna, the third method is used in this paper. The GPS antenna is installed in the temperature chamber with being fixed on the antenna fixture. As shown in Figure 5, additional passive antenna is installed in the temperature chamber in order to provide GPS satellite signals to the GPS antenna, and also a signal repeater and a line amplifier are installed on the place out of the temperature chamber in order to adjust the weak GPS satellite signals generated from the GPS simulator to the appropriate level. The signal repeater is LA20RPDC made by GPS Networking Inc. and the passive GPS antenna is S67-1575-20 made by Sensor Systems Inc. The operating temperature range of the passive antenna is from -55℃ to +85℃ [7]. Although temperature range of the passive antenna does not satisfy with the hot-temperature test specification, +95℃, there is no operation failure since its operation is not mainly affected by the temperature change because the passive antenna does not include an LNA.

In order to monitor the performance and operation of the GPS antenna, it is connected to the 1st RF front-end of the GPS receiver which is located out of the temperature chamber. Therefore the performance or abnormal operating condition of the GPS antenna is checked simultaneously by monitoring operation of the GPS receiver. The 2nd and 3rd RF front-end of the GPS receiver are terminated. The method to check the condition of the GPS antenna via operation of the GPS receiver has a limitation that the test result depends on the performance of the GPS receiver as well as that of the GPS antenna. When the performance degradation occurs during the test, therefore, it can be difficult to judge the reason of the degradation. Hot-temperature test is, however, carried out under the completely identical environment except temperature condition, therefore, it is possible to consider that the cause of the problem is the antenna.

Internal space of the temperature chamber is very small and all the side-wall is metal, so that the navigation solution errors could be larger than normal cases due to the multi-path effects.

Figure 6 shows the pictures of GPS antenna hot-temperature test foreground.

3.3 GPS Simulator Scenario

The scenario setting to provide satellite signals to the GPS antenna is as follows:

- Start Date & Time: 05/12/2005, 00:00:00

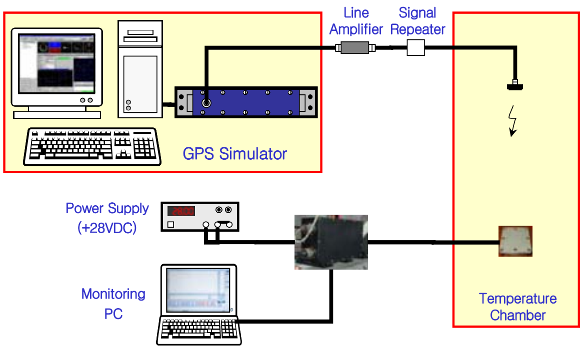

Figure 5. Hardware configuration.

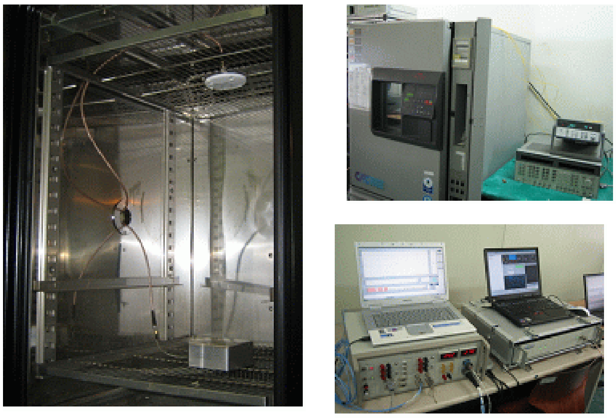

Figure 6. Foreground of the hot-temperature test.

- Uploaded Almanac File: 05/12/2005
- Signal Power: Fixed +15dB according to -130dBm
- Vehicle Type: Static motion
- Vehicle Location
  - Latitude: N 34° 25'
  - Longitude: E 127° 32'
  - Height: 300m

In the scenario, signal power is set to the fixed level as +15dB according to the -130dBm and vehicle type is static motion without dynamics, i.e. velocity / acceleration / jerk are all zero. If the scenario with dynamic motion is used, it is difficult to judge the cause of the performance change that can be occurred by the dynamics condition and also by the temperature environment.

The initial position of the vehicle in the scenario is decided to the real launch center of Korea, Goheung, JeollaNamdo which is being constructed.

3.4 Temperature Profile

After the hot-test profile is set on the temperature chamber according to the qualification test specification of the GPS antenna, several temperature sensors are installed on the GPS antenna and the fixture: sensor #1 is installed on the back of the GPS antenna and sensor #2 ~ sensor #5 are installed on the 4-sided surfaces of the fixture. Figure 7 and Figure 8 shows the measured temperature data, Figure 7 is the scan graph of the recording sheet of the chamber itself, Figure 8 is the graph drawn using acquired data of sensor #1 of the antenna and the other sensors of the fixture. The red line is the data of the antenna and the blue line is the averaged data of the 4 sensors of the fixture. As shown in Figure 8, the temperature change of the sensor #1 and sensor #2 ~ #5 is almost same. The LNA is installed in the GPS antenna close to the sensor #1, so that the temperature change of the LNA is similar to the sensor #1.

Room temperature is +20℃ and it takes about 50 minutes to raise and drop the chamber temperature between +20℃ and +95℃. The maintaining time at the room temperature which is included in the Pre-Test and Post-Test is 10 minutes each. Total test time is about 170 minutes and it is divided according to the test phases as follows:

- 0 min ~ 10 min: Pre-Test
- 10 min ~ 30 min: Temperature stabilization
- 30 min ~ 80 min: Temperature rising phase
- 80 min ~ 110 min: Hot-temperature maintaining phase
- 110 min ~ 160 min: Temperature decent phase

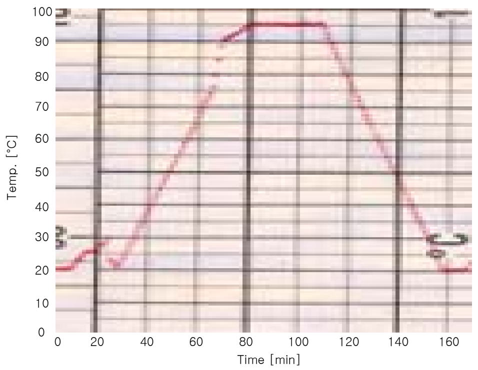

Figure 7. Temperature change of the chamber.

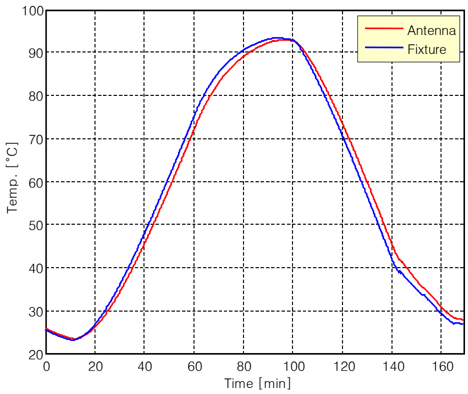

Figure 8. Temperature change of the antenna & fixture.

- 160 min ~ 170 min: Post-Test

4. Test Results

Performance of the GPS antenna under the hot-temperature environment is checked and analyzed using operation results of the GPS receiver installed out of the temperature chamber with being connected to the GPS antenna. The GPS antenna and the GPS receiver operate over the full test range. The operation status of the GPS antenna, therefore, can be checked during all the test phases. Analyzed items are SNR(Signal-to-Noise Ratio), the number of used GPS satellites, PDOP(Position Dilution of Precision) and accuracy. When the GPS receiver is not used for the test, the performance of the antenna such as VSWR and gain, could be monitored using a network analyzer. If possible, however, it is the best configuration of the test that the GPS antenna is tested with the GPS receiver as one system. If the performance degradation occurs, however, it is difficult to judge the cause of the problem.

4.1 Signal-to-Noise Ratio

The maximum and minimum SNR are shown in Figure 9. Theoretically at the hot-temperature, SNR is reduced due to the increase of thermal noise. However, test result shows that SNR increases a little amount of level at the range of hot-phase from 70 minute to 100 minute. One reason may be the multi-path signals generated due to the small and metally 4-sided walls of the temperature chamber. The other reason can be the temperature change of the GPS receiver. The temperature of the GPS receiver can be changed by operation itself, and the temperature-uncontrolled test room.

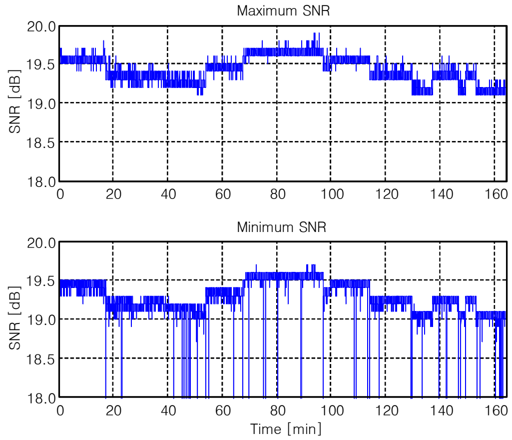

Figure 9. Signal-to-noise ratio.

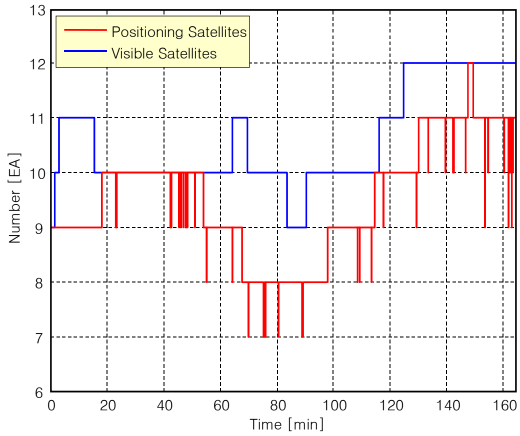

Figure 10. Number of visible and positioning satellites.

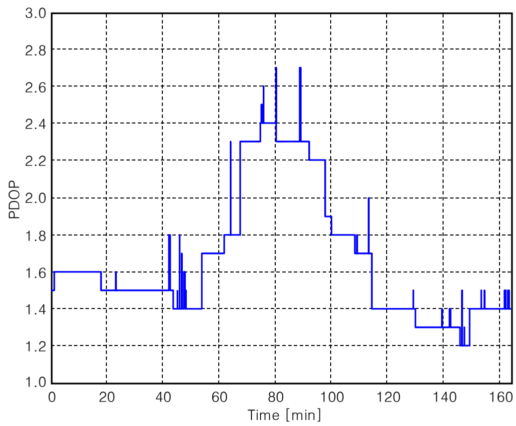

Figure 11. PDOP.

4.2 Number of Satellites and PDOP

The number of visible satellites and positioning satellites which is used to calculate navigation solutions are shown in Figure 10. At the range of hot-phase, the number of positioning satellites is less than before and after the hot-phase by 1 or 2. It is considered as the change of the satellites with respect to the time.

As shown in Figure 11, PDOP is increased at the hot-phase with above same reason. Over the full test range of the hot-test, however, more than 7 satellites are used to calculate navigation solutions, and PDOP is less than 3.0.

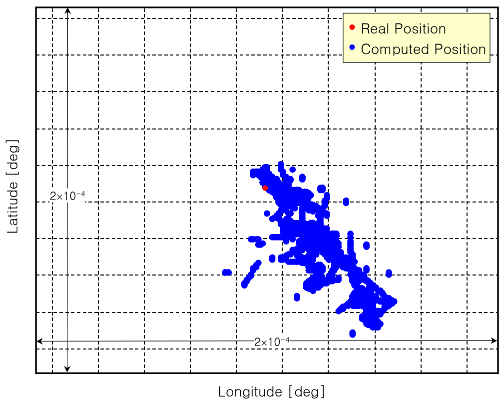

Figure 12. Calculated position (Longitude vs. Latitude).

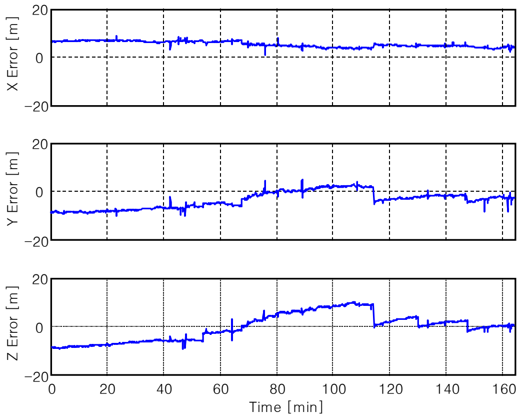

Figure 13. Position errors of ECEF frame.

4.3 Accuracy

Figure 12 shows the 2D result of the calculated latitude and longitude solutions. Latitude and longitude solutions are in the range of 1 x 10^{-4} [deg] according to the real position, red point.

Figure 13 shows the calculated navigation errors. The errors of ECEF-X, Y, and Z maintain almost same level during the full test range. The velocity error is shown in Figure 14. The momentarily big velocity error, 3.01m/sec, is occurred on the way of temperature rising-phase, at the point of 3230.3 sec after the starting point. The level of the error is, however, very small during the full test range to be accepted.

The navigation solution errors in the 3D fix mode are listed in Table 2. It shows that the solution errors during the hot-test are reasonable and the performance of the GPS antenna does not critically degraded under the hot-temperature environment.

5. Conclusion

This paper describes about the hot-temperature test of the GPS antenna. The test is carried out by the procedures that the GPS antenna is installed in the temperature chamber and connected to the GPS receiver placed out of the temperature chamber. The operation and performance results are compared relatively between before, during and after the hot-temperature test. SNR is increased a little amount of level at the hot-phase compared to the other phases and the number of positioning satellites is decreased by 1 ~ 2 because of the change of satellites. PDOP is increased due to the decrease of the positioning satellite, the position error and velocity error are almost maintained during the full test range.

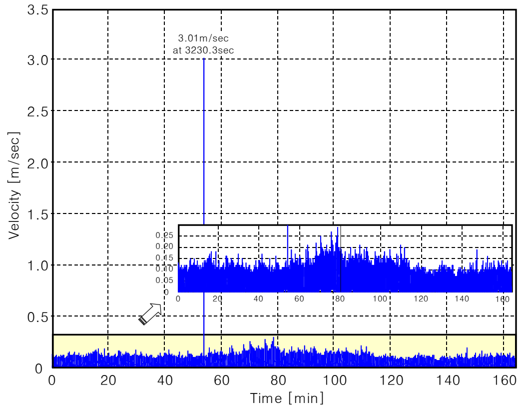

Figure 14. Velocity change.

Table 2. Accuracy.

	RMS	R95	Maximum
Latitude [deg]	3.776e-5	6.967e-5	7.867e-5
Longitude [deg]	2.593e-5	-4.567e-5	-5.467e-5
Altitude [m]	7.763e+0	-1.349e+1	-1.567e+1
ECEF-X [m]	5.311e+0	6.788e+0	8.823e+0
ECEF-Y [m]	4.947e+0	-8.543e+0	-1.009e+1
ECEF-Z [m]	5.551e+0	8.924e+0	9.968e+0
Velocity [m/sec]	4.882e-2	-9.000e-2	-3.010e+0

As a result, the GPS antenna has no performance degradation under the hot-temperature environment. Therefore developed GPS antenna is confirmed through this hot-temperature test and verified that it can operate normally under the hot-temperature environment of the launch vehicle.

Afterward, additional test for the GPS antenna will be carried out using aerodynamic heating device. The aerodynamic heating device is to generate the flight environment using flight profile of the launch vehicle. Generated heating environment by the device, therefore, is more similar to the real flight environment than that of hot-temperature test which is simply maintaining at the specific temperature for the specific period. Furthermore, the effect by the circumstances of the used temperature chamber, for example, multi-path effect can be reduced.

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