

ELEVENTH AIR NAVIGATION CONFERENCE

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Agenda Item 6 Aeronautical navigation : issues

PERFORMANCE ASSESSMENT OF THE GBAS THROUGH FLIGHT TEST AND INTEGRITY MONITORING TEST

(Presented by Republic of Korea)

SUMMARY

This paper presents the hardware and the software configuration of GBAS developed in the Republic of Korea and the experimental results of ground and flight tests.

1. INTRODUCTION

1.1 ICAO decided to use global navigation satellite system (GNSS) instead of the navigation aids that have been used up to the present. This system is based on GPS, GLONASS and the augmentation systems to provide better performance. For standardization of the system, ICAO has provided the technical standards for GPS, GLONASS, satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS) and advised each country to develop and utilize the system.

1.2 To prepare for the future satellite navigation system, Civil Aviation Safety Authority (CASA) of the Republic of Korea decided to develop GBAS in 1997. The first GBAS prototype was developed according to the three-year research program. Since then, several flight tests have been conducted to evaluate and improve the performance of the prototype.

1.3 This paper provides the hardware (H/W) and software (S/W) configuration of the GBAS system and various analyses about the performance through flight tests and integrity monitoring tests.

2. SYSTEM CONFIGURATION

2.1 This section describes the configuration of the GBAS ground system and the airborne system used in performance evaluation of the ground system.

2.2 GBAS ground system

2.2.1 The ground system includes a GNSS receiver, a wireless modem for data link with the airborne system and a PC. The PC controls the H/Ws, processes the GNSS measurements and displays the status of the entire ground system. Figure 1 describes this configuration, and Figure 2 is the screenshot of the ground system S/W operating.

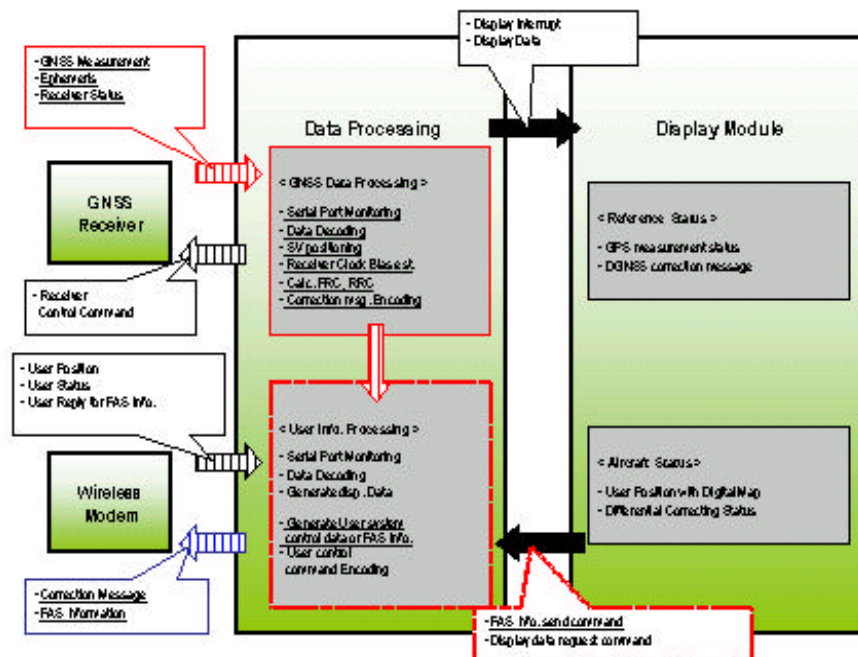


Figure 1. Configuration of ground system

2.2.2 This is similar to general DGNSS reference station, which meets the ICAO Standards. This system uses the GBAS standard data transmission protocol of ICAO's SARPs. Compared with the basic DGNSS correction transmission protocol (RTCM), SARPs can provide higher resolution correction data, more precise statistical confidence level of the correction, and more tightened integrity monitoring parameter. Four message types are defined currently.

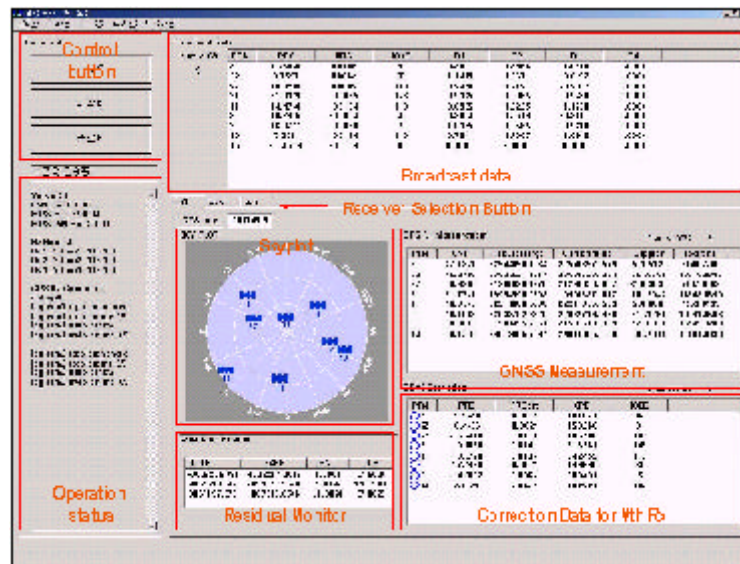


Figure 2. Screenshot of ground system S/W

2.3 Airborne system

2.3.1 Like the ground system, airborne system also includes a GNSS receiver, a wireless modem and a PC. The PC controls the H/Ws, processes the GNSS measurements, and shows the data on cockpit display. Figure 3 describes the configuration of the airborne system.

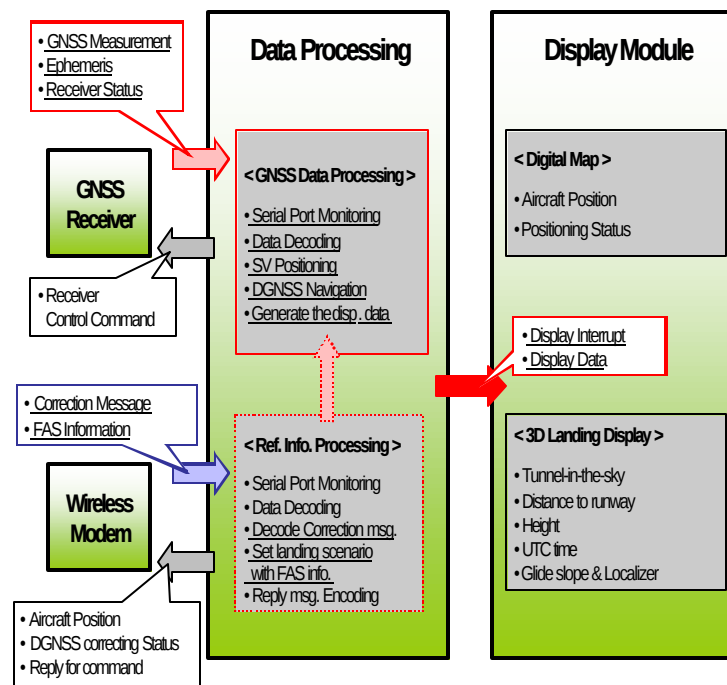


Figure 3. Configuration of airborne system

2.3.2 Airborne system S/W consists of two parts: the navigation module and cockpit display module. The navigation module determines the various nav-solutions including the position, velocity, and attitude of the aircraft from the GNSS measurements and correction data. The cockpit display module transforms the nav-solutions into geometrical and spatial information via tunnel-in-the-sky over the background to which the virtual reality is applied. Figure 4 and 5 are the screenshots of each S/W module in airborne system.

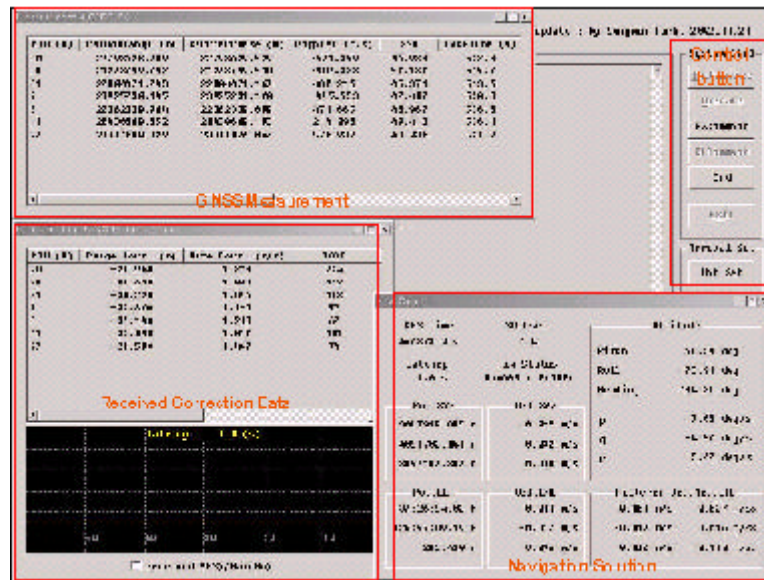


Figure 4. Screenshot of airborne system: navigation

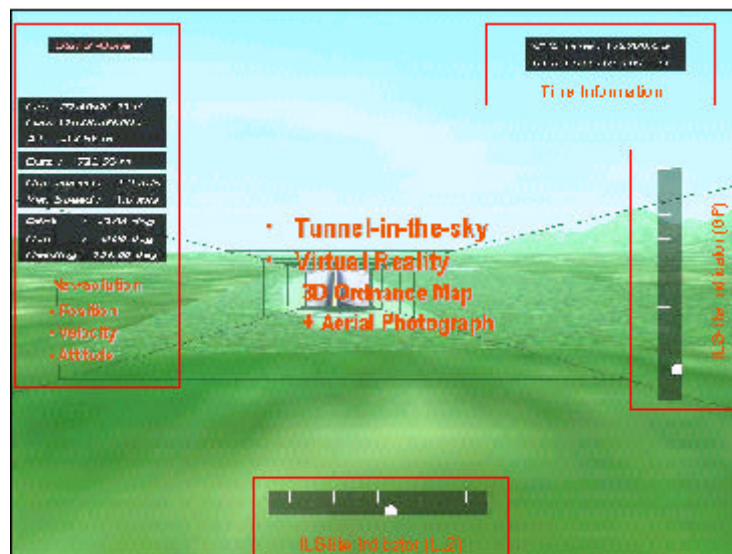


Figure 5. Screenshot of airborne system: cockpit display

3. PERFORMANCE ASSESSMENT

3.1 We implemented the ground and airborne system. From 2000 to 2002, we conducted several flight tests for the performance assessment of accuracy, and integrity. This chapter includes the two processes and analytical results of each test.

3.2 Flight test (accuracy)

3.2.1 Flight tests were performed at the Ulsan airport with the inspection aircraft (Challenger 601/3R) owned by CASA (Figure 6).



Figure 6. Inspection aircraft : Challenger 601/3R

Flight Scenario: The GBAS coverage volume presented by FAA consists of two sub-volumes. One is the approach coverage volume. The other is the VHF data broadcast coverage volume. The volumes may be sketched roughly like a cylinder as presented in Figure 7. We designed a flight scenario for the approach coverage volume: 1) approaching to the origin of the Ulsan airport with level flight at the altitude of 10 000 ft, 2) bypassing the origin and flying out along the line of positive 35° direction, 23 nm radius and the altitude of 1 300 ft. 4) After the flight test for approach coverage volume, the aircraft repeats the precision approach procedure.

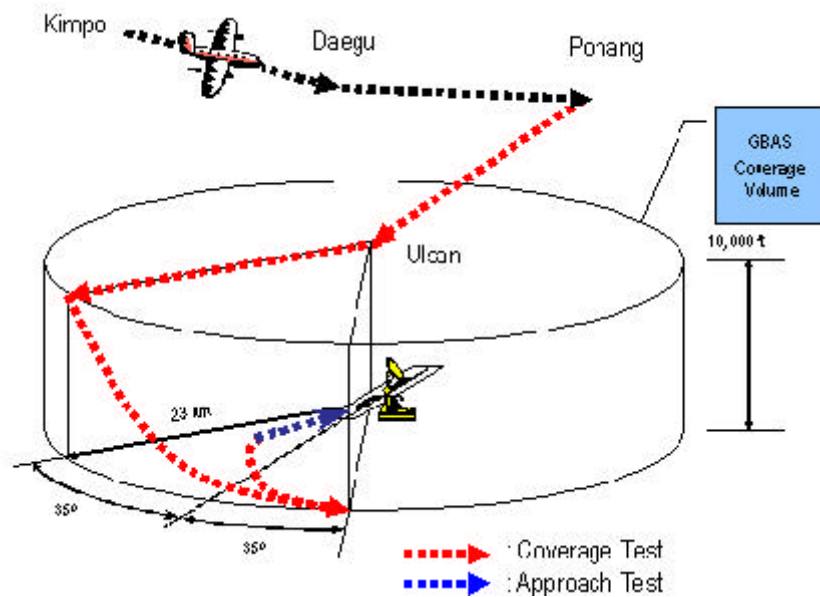


Figure 7. Flight scenario

Accuracy Analysis : To obtain the true trajectory of the vehicle, we adopted Ashtech Z-12 receiver, which shared the GNSS antenna with GBAS airborne system. If the data collected by the Ashtech receiver are post-processed, we can get the vehicle's trajectory that has the accuracy at centimeter-level. It is sufficient to analyze the GBAS accuracy performance of meter-level.

We considered only the epochs at which the aircraft are within the GBAS coverage volume and the real-time positions were computed without failure of data link caused by the local terrain.

However, in case of the flight test, the aircraft is maneuvering from right above the ground to more than altitude 10 000 ft. It resulted in the varying accuracy level according to the height of the aircraft because the correlation of the GNSS error sources, especially tropospheric delay is gradually lowered in proportion to the difference between the GNSS antenna of ground and airborne system.

Of the documents that describe the GBAS, RTCA/DO-245 suggests the horizontal and vertical accuracy level, that is, NSE (Navigation Sensor Error) with 95% error limit value as a function of the distance and height from the touchdown point. Table 1, 2 show the horizontal and vertical NSE limits for the three types of precision approaches.

Table 1. Horizontal NSE limit

CAT-III	≥ 11.3	$D > 1515$
	$\geq 0.000104 \cdot D + 0.5$	$0 < D \leq 1515$
	≥ 0.5	Along runway
CAT-II	≥ 15.1	$D > 1515$
	$\geq 0.000832 \cdot D + 0.00$	$501 < D \leq 1515$
	< 0.0	$0 < D \leq 501$
CAT-I	≥ 15.5	$D > 1515$
	$\geq 0.00110 \cdot D + 14.00$	$813 < D \leq 1515$
	≥ 10.0	$501 < D \leq 813$
Performance Type	(meters) 95% Horizontal NSE	(meters) Reference Distance

Table 2. Vertical NSE limit

CAT-III	≥ 12.0	$H > 1500$
	$< 0.0111 \cdot H + 0.83$	$100 < H \leq 1500$
	≥ 0.5	$H \leq 100$
CAT-II	≥ 12.0	$H > 1500$
	$\geq 0.0111 \cdot H + 0.83$	$100 < H \leq 1500$
	≥ 0.5	$00 < H \leq 100$
CAT-I	≥ 12.1	$H > 1500$
	$\geq 0.0111 \cdot H + 1.00$	$500 < H \leq 1500$
	≥ 1.0	$100 < H \leq 500$
Performance Type	(meters) 95% Vertical NSE	

Considering the suggested requirements, we can find that the vertical error limit is more threatening to the GNSS-based sensors than horizontal one. Generally, the GNSS positioning error is less accurate in vertical direction because of the satellite constellation. Here, it is presented only the vertical NSE value of the developed GBAS system in Figure 8.

This figure shows that the GBAS system can meet sufficiently the Category I precision approach requirement in the accuracy aspect out of the parameters of required navigation performance (RNP). More flight tests will be scheduled to prove the actual performance of the system.

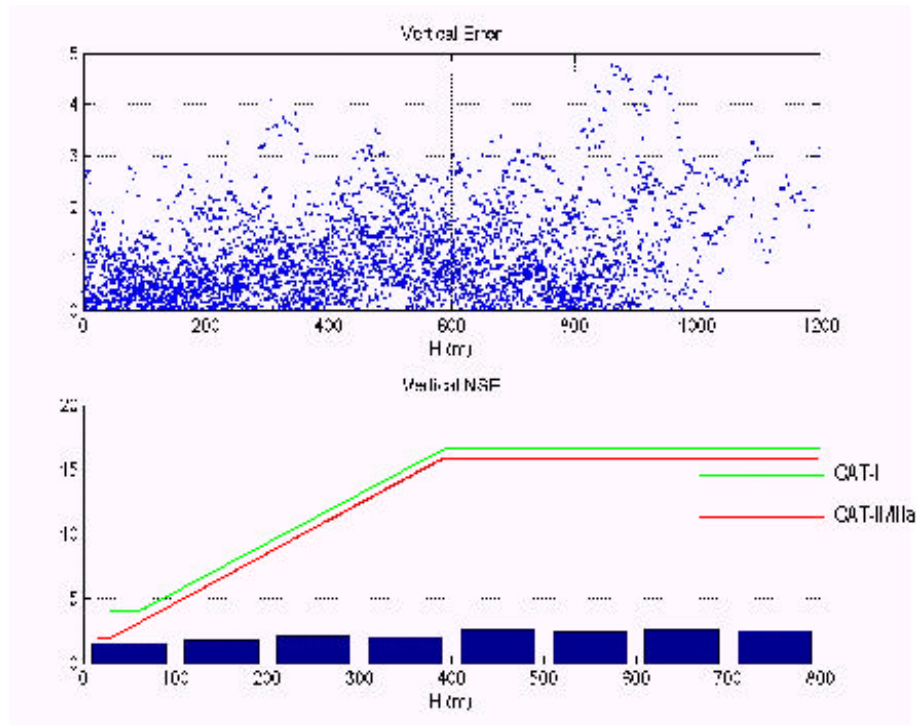


Figure 8. GBAS vertical error and NSE

Until now, we have focused on the GBAS system by comparing with the true system, Ashtech Z-12 receiver. However, the true system is also based on the GNSS. Therefore, we have to follow a different way to verify the consistency between the developed GBAS and conventional nav-aids. The GBAS is devised to replace the systems that serve as a guide for precision approach of aircraft, such as ILS, MLS, etc. Therefore, we can verify the previously analyzed GBAS performance by comparing with those systems.

Theodolite is a measuring or surveying device by reading the elevation and azimuth angle of the target object from a reference, also used in the inspection of ILS. Our objective is to compare the theodolite measurement with our GBAS navigation solution, and confirm the consistency between them.

The most different feature of the GNSS against the conventional systems is the coordinate system. GNSS is based on the WGS-84 ellipsoid. Whereas the others are based on the locally defined ellipsoid (ex. Bessel ellipsoid) or other coordinate system such as TM (Transverse Mercator) projected coordinates. The differences are not dealt successfully with only a few simple transformations between them.

According to the documents related to the GBAS or GNSS, the final approach segment (FAS) parameter will be defined with the WGS-84 ellipsoid and its coordinate system. Therefore, it is necessary to transform the conventional coordinate values of the reference points in each airport after the minute investigations, or re-survey them totally.

Figure 9 shows an inspector with a theodolite measuring the true trajectory - described by GP (Glide Path) and LLZ (Localizer) angle - of an aircraft approaching the runway to land.



Figure 9. Theodolite

The theodolite measurements are transmitted to the inspection aircraft via wireless modem, compared with received ILS measurements, and recorded for the post-processing. We compared the recorded theodolite data with the GP and LLZ angles computed from the GBAS navigation solutions. These are presented in Figure 10 (GP) and 11 (LLZ).

In calculation of the GP and LLZ angle from the GBAS nav-solution, we considered the distortion of the reference plane (WGS-84 ellipsoid or Mean Sea Level), and solved the inherent problem to a sufficient extent. Therefore, there is no serious problem caused by the reference plane. Yet, the comparison results still contain some error sources:

- a) Theodolite-operational error caused by the inspector, generally 0.02 deg.
- b) Lever arm between ILS antenna and GNSS antenna installed on the aircraft. It is varying according to the attitude of aircraft.
- c) 0.01 deg resolution of the theodolite measurement.

The errors of GBAS nav-solutions with respect to the theodolite measurements are less than 0.04 deg excluding the region where the measurements are not confidential (around the GP antenna), and the error values changed to the length unit are still below the requirements of Category I. Although there are the above-mentioned limitations, we can find that the GBAS system is consistent with the conventional systems.

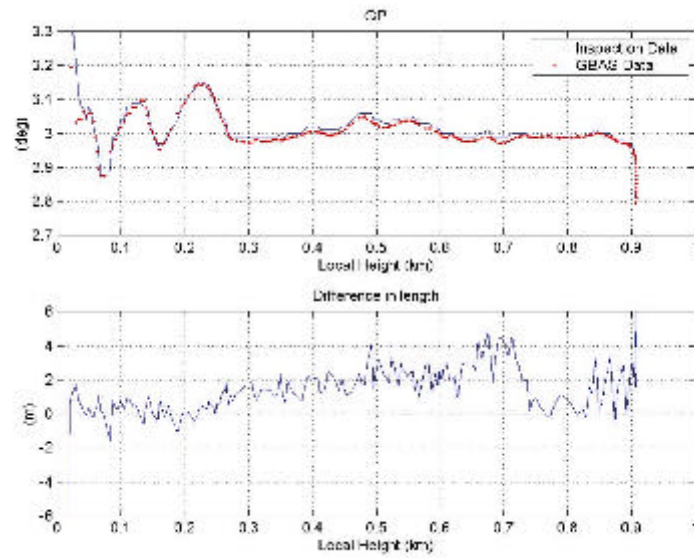


Figure 10. Comparison of glide path angle

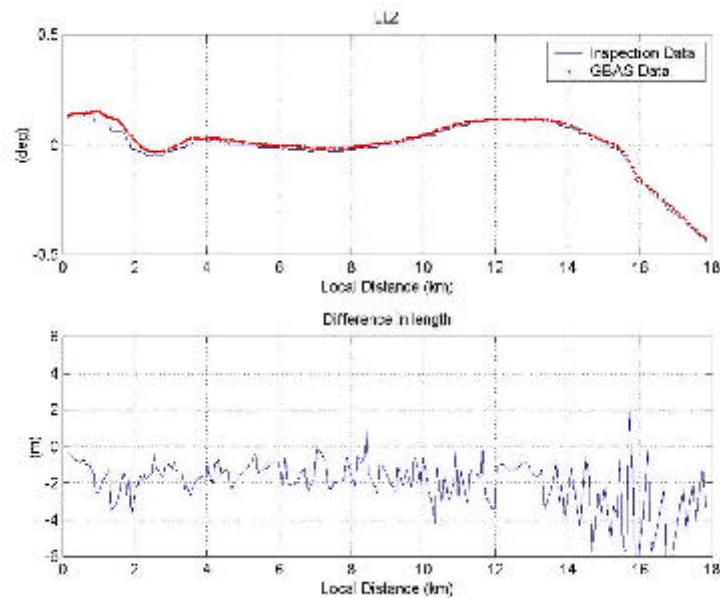


Figure 11. Comparison of localizer angle

3.3 Integrity monitoring test (integrity)

GBAS integrity monitoring functions: Figure 12 shows the GBAS integrity monitoring procedure. Three GNSS antennas and receivers have been installed and each antenna and receiver receives the GNSS signal to process measurements. QM (Quality Monitoring) functions work while the measurements are under process. Then, the system generates broadcast data with the measurements that have been processed in each receiver and passed to MRCC (Multiple Receiver Consistency Check). At last, VDB broadcasts the correction messages to the airborne subsystem.

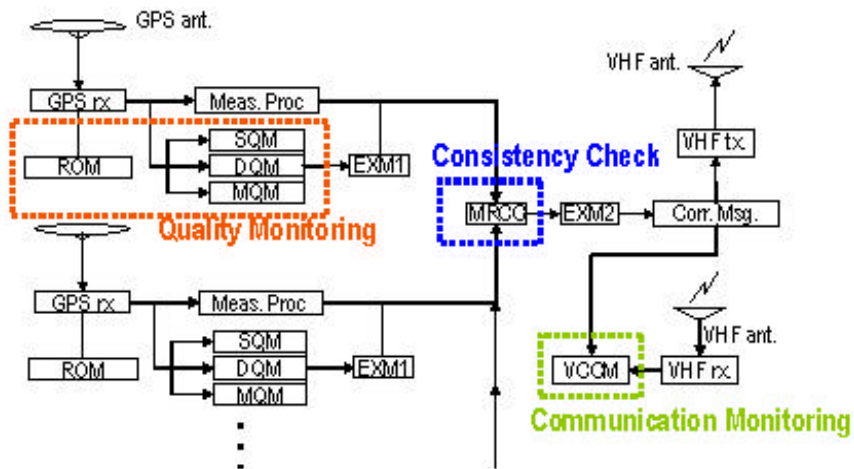


Figure 12. GBAS integrity monitoring procedure

The system has six monitoring functions. ROM (Receiver Operation Monitoring) monitors the receiver operation status. QM function has three parts: SQM (Signal Quality Monitoring), DQM (Data Quality Monitoring), and MQM (Measurement Quality Monitoring). SQM assess power and code structure of received signal to confirm that they are within specifications. DQM checks the navigation messages to confirm that the calculated satellite positions are valid. MQM monitors the pseudorange and carrier phase measurements to detect excessive acceleration, such as step or other rapid changes of them. And MRCC checks the consistency of the measurements from each reference receivers to detect failures of receivers. VCCM (VHF Communication Channel Monitoring) monitors the broadcasting status. This integrity monitoring system shall cease the broadcast of a failed ranging source measurement block within 3 seconds of the onset of the failure.

Quality Monitoring Test: To test QM functions, we constructed a test bed as shown in Figure 13. For the nominal and failure test, GNSS simulator (STR 4500) was used in generating simulated GNSS signals. The GNSS simulator system is GSS STR4500 of Spirent Communication LTD. The specifications of GNSS simulator is described in Table 3. The system consists of two part-RF signal generators and computer controller. A simulator control software in the computer controls the RF signal part (Figure 14) and shows position, attitude, GNSS satellite information and simulated measurements. For failure test, some faults are injected into the simulation scenario-by-scenario generation system-GSS STR4760 of Spirent Communications LTD. With this test, we could conclude that the QM functions work as we expected.

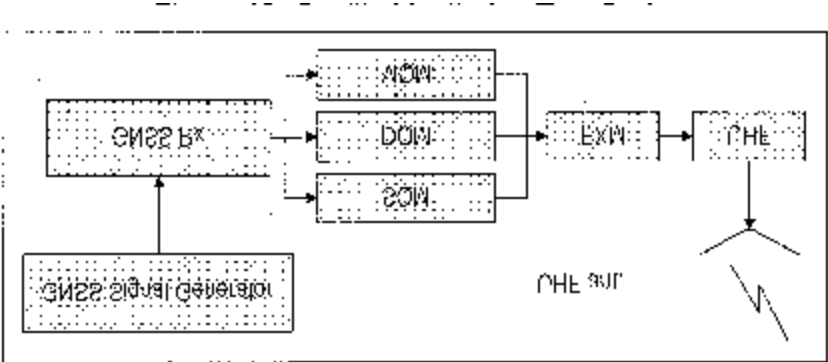


Figure 13. Quality monitoring test bed



Figure 14. GNSS simulator: RF signal part

Table 3. Specification of GNSS simulator

Computer Controller	RAM : 84MB
	USB port
RF signal generator	OS : Microsoft Windows 8.1
	CPU : 433MHz
sup-systems	Level : -130dBm nominal
	GPS C/A with data at 20bps
spec.	45 Channels
	11 1272.45MHz

MRCC Test: To test MRCC function, we used three GNSS antennas and receivers. In this test, we used real GNSS signals instead of a GNSS simulator. To simulate a faulted situation, we intentionally injected biases into pseudo-ranges of a receiver. Figure 15 shows PRCs (PseudoRange Corrections) from three receivers and the averaged PRC. In this test, biases were injected into Rx 1, so the PRC of Rx 1 is far from those of other receivers. To detect the fault, we calculated B-values which are receiver failure check indexes and the fault detection threshold of them. In Figure 16, we can decide that the B-value of Rx 1(B1) is over the threshold and Rx 1 has some faults. Then, we can exclude the faulted measurement, and generate correct averaged PRCs for broadcasting (Figure 17).

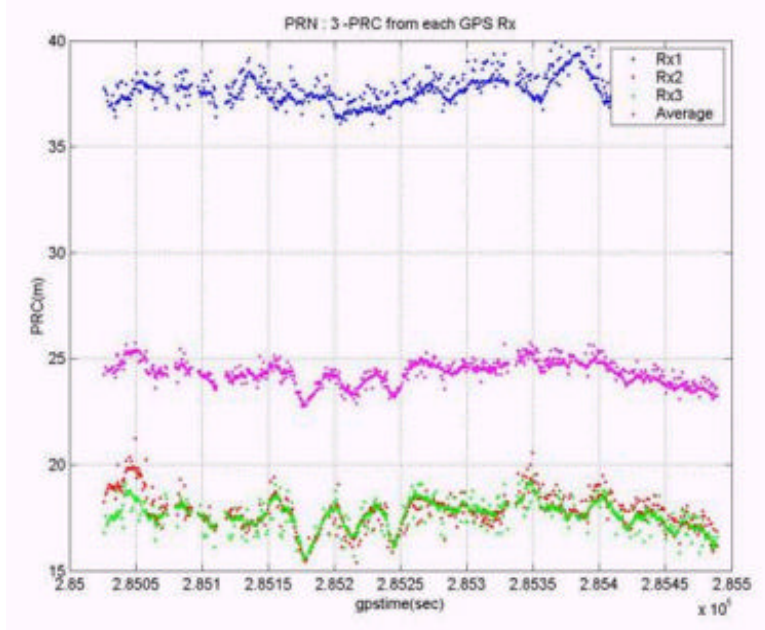


Figure 15. PRCs from each receiver and averaged PRC

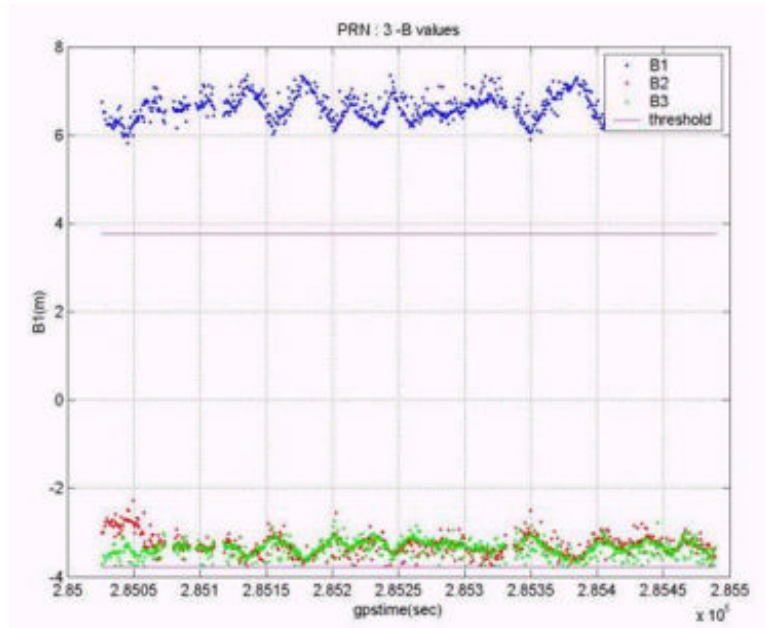


Figure 16. B-values for each receiver

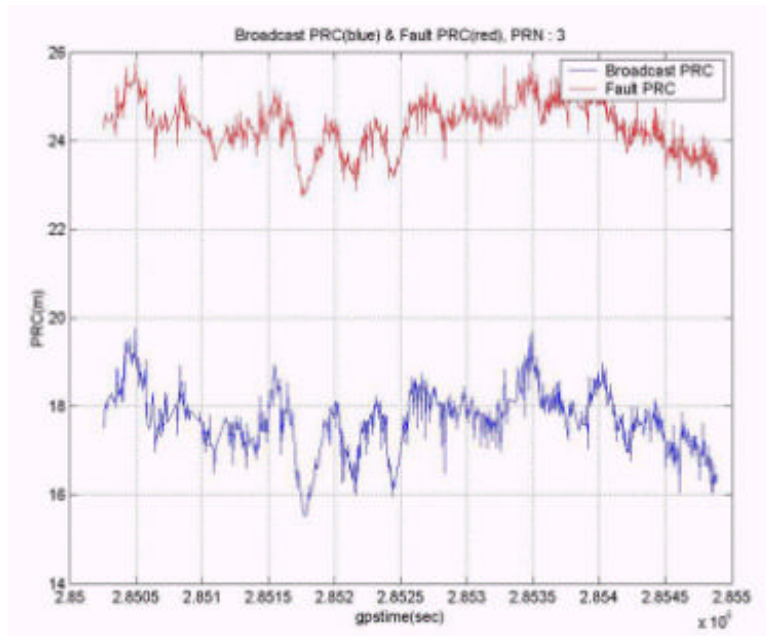


Figure 17. Exclusion of faulted measurement

4. CONCLUSIONS

4.1 In this paper, the Republic of Korea presented the performance of GBAS ground system and airborne system developed in domestic. The systems are based on the differential GNSS method satisfying the ICAO SARPs. The Republic of Korea conducted the flight tests including GBAS coverage volume tests and precision approach tests. However, more flight tests have to be conducted to increase the confidence level of the GBAS performance of accuracy.

4.2 Additionally, the Republic of Korea compared the GBAS nav-solutions with the measurements of the ILS inspection device, and found the consistency between them. However, there are some inevitable limitations of the device and error sources added in its operation. More systematic test and analysis will be scheduled for the next flight.

4.3 Monitoring functions is implemented in the system to monitor integrity of the system. To test this function, a GNSS simulator was used to generate simulated GNSS signal and inject arbitrary faults into the signal. The simulation scenarios for nominal and failure tests were generated. Several tests were performed and it was found that the integrity monitoring functions implemented in the system worked well as expected. For evaluation of the system, more tests should be performed on a long-term basis and for many different cases.

4.4 In addition, it is expected that CASA's R&D efforts relating to GNSS will contribute to the development of international civil aviation.

4.5 The conference is invited to note the information contained in this paper; and urge States to share information and experience regarding GBAS and to develop an international cooperative research program on GNSS for the sake of global benefit.

— END —