KARI-LAAS Performance with Modernized GPS

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Abstract: KARI had developed an Local Area Augmentation System for aircraft precision landing as following ICAO SARPs(Standards and Recommended Practices) draft and FAA's recommended algorithm(carrier smoothing techniques). JPO in charge of managing GPS has introduced the signal structure of GPS modernization program. This paper estimates the accuracy performance of KARI-LAAS with modernized GPS signal but the same processing algorithm.

Keywords: GNSS, GPS Modernization, Third civil signal, GBAS, CNS/ATM, Accuracy estimation

1. INTRODUCTION

It has been agreed for several years that additional GPS signals are needed for civil applications. These signals are required for a) reducing the ionospheric errors by use of the two frequency correction technique, b) increased signal robustness, especially in aviation safety operations, and c) improved acquisition and accuracy.

The presidential Decision Directive (PDD) on GPS of March 29, 1996(Gore and Pena, 1996) stated that both the L1 and L2 frequency bands would be available for civil use and that a third civil signal would also be authorized. Although the L1 and L2 frequency bands can satisfy most civil users, aviation users need a third civil frequency to replace the L2 band and its limitations in safety-of-life applications.[1]

After an intensive search for new frequencies by the Department of Transportation (DoT), the Department of Defense (DoD) and other agencies, Vice President Gore announced on January 25, 1999 that a region in the ARNS band has been greed upon as the new (third) civil frequency. This frequency is referred to as L5 and is centered at 1176.45MHz. This selection appears to satisfy aviation safety uses.

This paper describes the estimated performance of KARI developed KARI-LAAS with the third civil signal of GPS modernization.

2. OVERVIEW OF CNS/ATM TECHNOLOGY

In the early 1980s, civil aviation recognized the increasing limitations of the present CNS/ATM systems, and the need to make improvements to overcome the present limitations and also meet the future needs resulting from exponentially increasing air traffic demand and air traffic jam. Thus the Council of ICAO established the special committee on Future Air Navigation System (FANS) in 1983 to study new concepts and new technologies and to recommend a system that would overcome the present and foreseen problems and take aviation into the 21st century. After an extensive study of existing systems and the applications of new technologies, the FANS Committee concluded that the limitations of the existing systems are intrinsic and were so restrictive that the problems could not be overcome on a cost-effective global basis without introducing the new concept and new CNS systems by the exploitation of satellite technology.

In September 1991, ICAO held the 10th Air Navigation Conference (ANC) to consider the shortcomings of the air navigation systems and examine the new concept of air navigation based satellite technology proposed by the ICAO Council's FANS Committee. The conference agreed that the new systems proposed by the FANS Committee, and referred to as the ICAO CNS/ATM systems, would meet the future needs of the international civil aviation community. Following the 10th ANC, the ICAO Assembly endorsed the new ICAO CNS/ATM systems and recommended that in each ICAO region the Planning and Implementation Regional Group (PIRG) concerned be tasked to develop the regional CNS/ATM implementation plan. Resulting from the agreement of ICAO, a variety of activities on research and development on the basis of the new concept have been being accomplished over many countries. According to the scheme made by ICAO, CNS/ATM will be integrated into the traditional navigation system from year 2000 and will be extensively implemented in 2010. [2]

CNS/ATM as defined by ICAO is "Communications, Navigation and Surveillance systems, employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global Air Traffic Management system." It provides aircrafts and air controllers with hardware and software, operational instructions, regulation and rules, etc.

Table 1 CNS/ATM Terminology

Abbr.	Terminology	Conventional System	CNS/ATM-based System
C	Communication	Voice (HF,VHF) AFTN	Data (HF,VHF) Mode S, ATN
N	Navigation	ILS VOR/DME	GNSS LAAS, WAAS
S	Surveillance	PSR/SSR Voice (HF)	SSR Mode S ADS-B
ATM	Air Traffic Management		

2.1 Aviation Navigation Aids

Traditional ground-based navigation aids (VOR, NDB, ILS, DME) have limited range and restrict aircraft flight paths along fixed routes. Ground-based approach aids must be at specific locations to provide the lowest possible minima. While VOR and DME can support area navigation (RNAV), they cannot support high levels of accuracy unless they are plentiful. Self-contained systems (INS and IRS) used in larger aircraft support RNAV operations, but these systems are expensive and they require position updating by external systems to maintain high accuracy.

RNAV capability is a pre-requisite for a flexible route system, "free-routes" and user-preferred trajectories. In the near future, RNAV is likely to be entirely supported by Global Navigation Satellite Systems (GNSS). GNSS (GPS, GLONASS) require varying degrees of augmentation to overcome inherent system limitations and to meet performance requirements for all phases of flight. GNSS augmentation systems are aircraft-based (ABAS), ground-based (GBAS) or satellite-based (SBAS).

The ground-based augmentation system (GBAS) was specifically developed to support precision approach and landing locally at airports.

With suitable augmentation, GNSS meets required navigation performance (RNP) requirements from en-route operations to precision approach and landing. A first set of SARPs will be restricted to Category I, but GNSS Category II and III capability is expected in the future.

GNSS will also support airport surface navigation, allowing pilots to taxi virtually without any outside references in low visibility conditions, and non-navigation services (such as ADS-B) that require high-accuracy and high-integrity navigation and time inputs.

RNAV capability also allows Air Navigation Service Providers (ANSPs) to offer the most cost-effective solutions to airspace users. GNSS support highly accurate RNAV everywhere, including over the oceans and in remote areas. GNSS avionics are relatively inexpensive, so all levels of users can participate in RNAV operations, thus allowing ANSPs to structure airspace for maximum capacity. GNSS also gives airspace designers a further option in developing procedures that support low minima, avoid noise sensitive areas and reduce flying time in the terminal area. Ultimately, GNSS could replace all traditional aviation navigation aids, although there are still technical, operational and institutional issues to be resolved before reaching this goal. Core navigation satellites, GPS and GLONASS, are already in service with many operators using GPS for en-route through non- precision approach operations. [3]

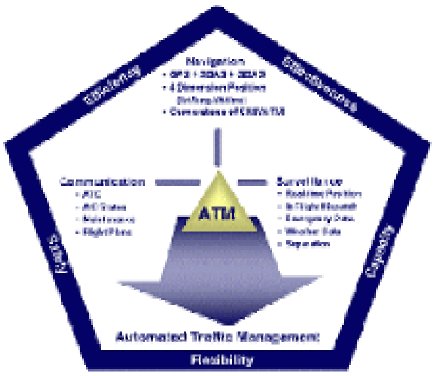

Fig. 1 Conceptual diagram of CNS/ATM

2.2 Local Area Augmentation System

The Local Area Augmentation System (LAAS) is an augmentation to GPS that focuses its service on the airport, broadcasts its GPS code correction message via a VHF data link from a ground-based transmitter. So the LAAS is classified as the typical type of GBAS.

LAAS will yield the extremely high accuracy, availability, and integrity necessary for Category I, II, and III precision approaches, and will provide the ability for more flexible, curved approach paths.

The LAAS will provide many benefits for all users. With LAAS, curved precision approach paths, impossible using the current instrument landing systems, will be possible. Also, approaches will be redesigned to avoid obstacles, restricted airspace, noise sensitive areas, or congested airspace. Unlike current instrument landing systems (ILS), a single LAAS ground station will provide precision approach capability to all runway ends at an airfield, eliminating the need for multiple ILS installations solely for the purpose of serving multiple runways.

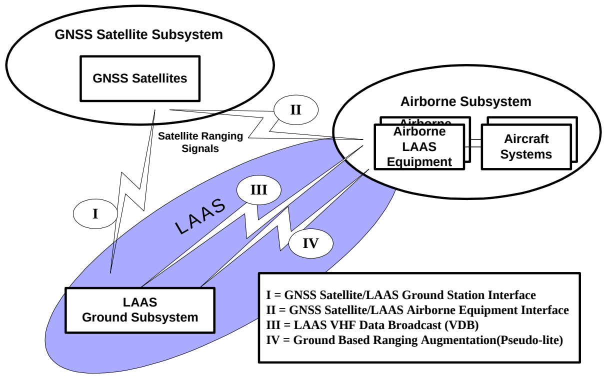

Fig. 2 LAAS signal-in-space interface diagram

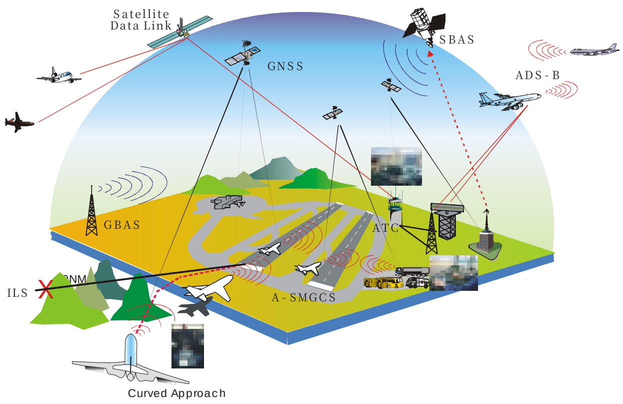

Fig. 3 Curved precision Approach based on DGNSS

3. GPS MORDERNIZATION

3.1 Modernizing GPS signals

The Modernization of GPS will provide many new capabilities, such as two new civil frequency bands (L2 and L5), new civil and military signals, higher signal power levels, more extensive ground tracking and more accurate spacecraft position updates. All of these dramatically improve accuracy, integrity and other aspects of system performance.

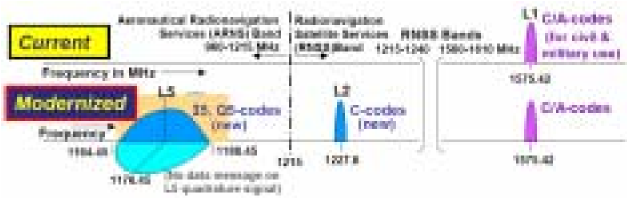

Fig. 4 GPS signal placement: L1, L2 and L5

The new civil signals at L5 are projected to support a code rate 10 times that of the C/A-code. This will improve code measurement accuracy, reduce code noise, reduce cross-correlation concerns, and provide improved multipath mitigation.

Precise Positioning Service (PPS) users have never suffered from SA. Dual-frequency PPS users also have the ability to directly measure ionospheric delays. PPS accuracy is approximately equivalent to what is expected for L1 C/A-L5 dual-frequency users.

The FAA for some time has opposed the use of L2 for aviation safety applications. Their concern is that since the ITU (International Telecommunications Union) has authorized this band for use on a co-primary basis with radiolocation services (including thigh power radars), that aircraft using the band may be subject to unacceptable levels of interference. Since this may compromise aviation safety operations, the FAA considers the L2 band unacceptable. The FAA requested a GPS aviation frequency in the Aeronautical Radionavigation Services (ARNS) band, which is located directly below the GPS L2 band. [4]

3.2 Operational benefits of L5

Aviation safety is an important national/international concern, and air commerce must operate at the highest level of safety practicable. The enormous growth in the number of aircraft operations worldwide will result in an accompanying increase in the number of serious accidents each year if the current accident rate is not reduced. To avoid this unacceptable consequence, numerous safety reviews have called for initiatives focused on reducing the accident rate. While improvements to aircraft alone yield a measure of safety improvement, advances in navigation capability will also be required.

Evaluation of safety data from the last twenty years has shown that controlled-flight-into-terrain (CFIT) accidents have predominated, especially during approach and landing. A leading intervention strategy to avoid CFIT is to provide precision approach (lateral and vertical guidance) capability for all runways. Satellite navigation is the only technology that can feasibly and economically delivers this capability at all locations.

In several regions of the world, ICAO-defined SBAS and/or GBAS are being implemented to deliver the required GPS performance to fulfill this safety objective. Though those augmentations will provide for precision approaches within specific coverage regions, the GPS signals are susceptible to interference and ionospheric fading. Incorporating GPS L5 into SBAS and GBAS offers a definitive means of mitigating those susceptibilities.

In areas without plans for SBAS/GBAS, the safety benefits of GPS L5 are even more significant. In those regions, using the some form of integrity monitoring and the combination of GPS L1 and GPS L5 to correct for ionospheric errors within the avionics, precision approaches will be possible throughout the world.

In addition to providing robust precision approach capability anywhere in the world and making satellite navigation more robust in areas with SBAS/GBAS, GPS L5 will offer many secondary safety benefits. It will enable surface surveillance and navigation to prevent runway incursions.

In summary, expected benefits of satellite navigation that will be enhanced/enabled by the introduction of GPS L5 include: [5]

■ **Approach/Landing/surface**

- Auto-landing capability under visual meteorological conditions
- Precision approach/landing worldwide with integrity monitoring, including vertical path and curved/segmented paths
- Improved precision approach/landing availability in SBAS /GBAS coverage
- Addition of GPS L5, and the attendant increases in accuracy, availability and robustness in the presence of interference would most likely allow satisfaction of the A-SMGCS (Advanced Surface Movement Guidance and Control System) surveillance and guidance performance requirements for visibility conditions 1, 2 and 3 without necessitating a GBAS or SBAS augmentation.

■ **Enroute**

- Reduced enroute separations (lateral/vertical)
- 3D/4D routes
- Off-airway navigation
- Dynamic use of airspace – airspace can be modified both horizontally and vertically to respond to traffic loads.

4. KARI-LAAS DEVELOPMENT

Since 1994, KARI has been conducting the research on the LAAS for precision approach and landing of aircraft based upon the concept of CNS/ATM. The LAAS system established by KARI includes LAAS ground subsystem, and airborne subsystem, which meets the requirements for precision approach and landing of aircraft, CAT-I, specified by FAA. The prototype of KARI LAAS system had been installed at the Ulsan airport in order to validate performances by taking ground-run test and flight test. The flight test was accomplished with Challenge CL-601 airplane equipped with airborne subsystem and Ashtech Z-12 GPS receiver for providing reference on the support of MOCT. The following figures show the block diagram and the actual layout of KARI LAAS system. [6]

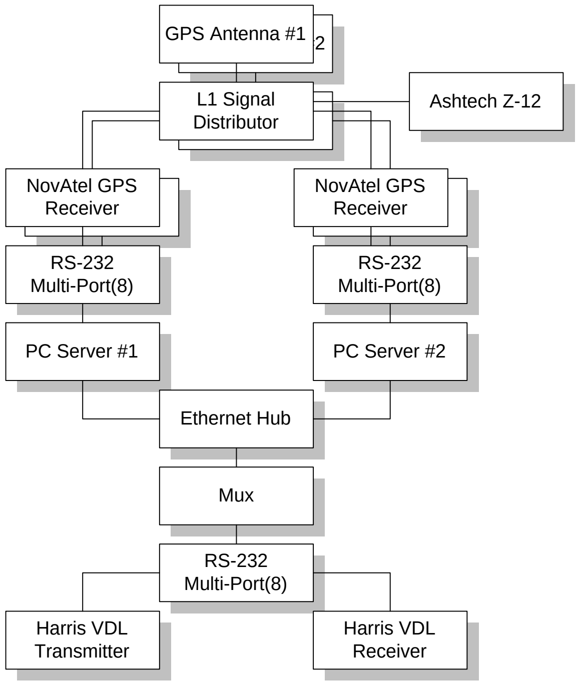

Fig. 5 Ground station system structure of KARI-LAAS

Fig. 6 Installed ground station at Ulsan airport

Table 2 Kari-LAAS flight test results

	Flight Test Procedure
3rd Flight test	☐Date : 9th NOV 2000 - 20NM away from runway threshold, height 10,000 ft, ±35° turn - 20NM away from runway threshold, height 1,500 ft, ±35° turn - 9 approach by ILS approach procedure ☐Test Results - Horizontal error: 2.701m (2dRMS) - Vertical error: 4.799m (RMS)
4th Flight test	☐Date : 21st NOV 2000 - 2 approach by ILS approach procedure ☐Test Results - Horizontal error: 1.805m (2dRMS) - Vertical error: 3.307m (RMS)

Fig. 7 Installed airborne KARI-LAAS subsystem

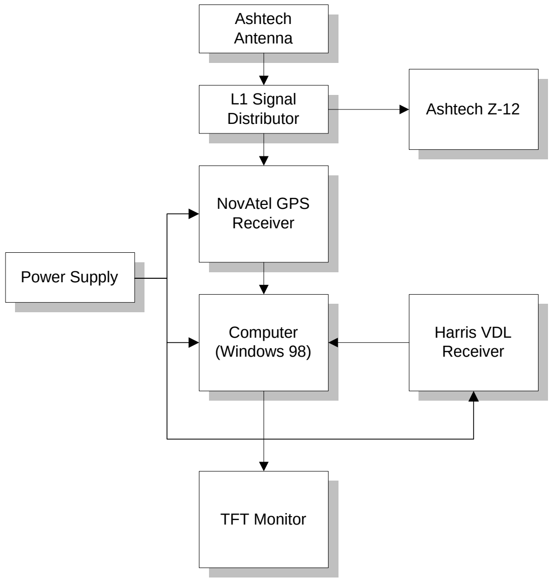

Fig. 8 Airborne subsystem structure of KARI-LAAS

5. KARI-LAAS PERFORMANCE WITH L5

In this paper, the accuracy performance of KARI-LAAS is estimated with modernized GPS signal but the same processing algorithm. The main features of KARI-LAAS processing algorithm are Carrier-smoothing process and hatch filtering.

The significant accuracy achieved through DGPS can be improved further if carrier smoothing is applied to the pseudoranges. In addition to multipath, thermal noise is independent between receivers and thus is not canceled in the differential correlation. However, unlike multipath, thermal noise is a wide band phenomenon and thus can be reduced through filtering. This filtering is accomplished through a process known as carrier smoothing. The main idea is to estimate the bias (ex; range ambiguity) in the integrated Doppler measurement in order to convert it into an absolute measurement of range.

The Hatch filter estimates the bias by a moving average of the difference between the pseudorange and integrated Doppler measurements of each satellite.

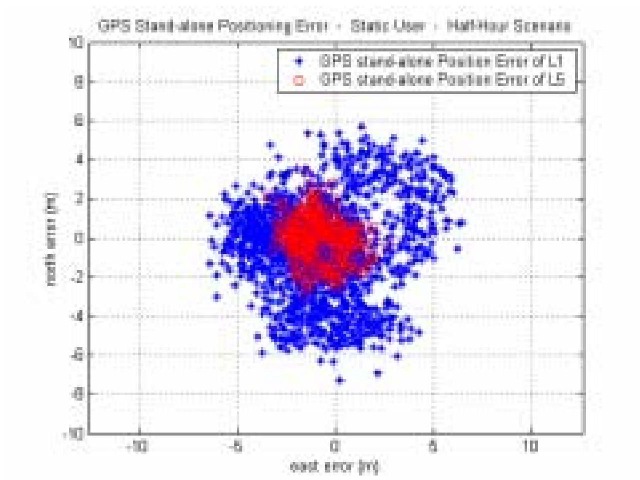

Fig. 9 Estimated SPS error of L1 and L5

The estimated horizontal position error with stand-alone L5 signal is 2.4221m(2drms), while carrier-smoothed DGPS accuracy of L5 is estimated as 0.1290m (2drms).

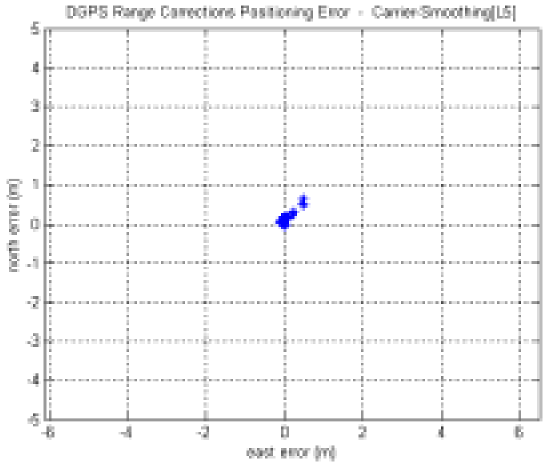

Fig. 10 Carrier-smoothed DGPS accuracy of L5

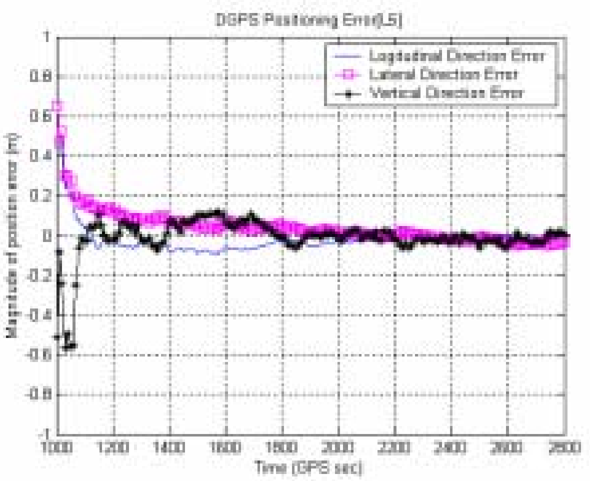

Fig. 11 Carrier-smoothed directional DGPS accuracy of L5

6. CONCLUSION

The expected improvements of GPS modernization will hardly affect on code differential GPS accuracy at all. (over short baseline:(<150km). Over short baselines, code DGPS is currently limited in performance by user equipment and multipath errors. Short-baseline DGPS users will mostly benefit from the robustness provided by the new civil signal (L5).

Over longer baselines (>1000km), DGPS users will benefit from the additional civil signals in that they will be able to compensate for ionospheric delay errors that are not common between their location and the reference station.

The use of two separated frequency signals (ex:L1 C/A-L5) essentially eliminates the effect of the ionospheric group delay on the receiver. The higher chipping rate (10 times) of the L5 codes provides a reduction in code noise and better measurement precision.

In the view of the position accuracy, by using only L1 C/A-L5 code signal information, it is possible to meet the current position accuracy requirements of precision approach for CAT I.

When the GPS modernization is done and Galileo start to service, stand-alone GNSS positioning performance will be like to that of today's DGNSS.

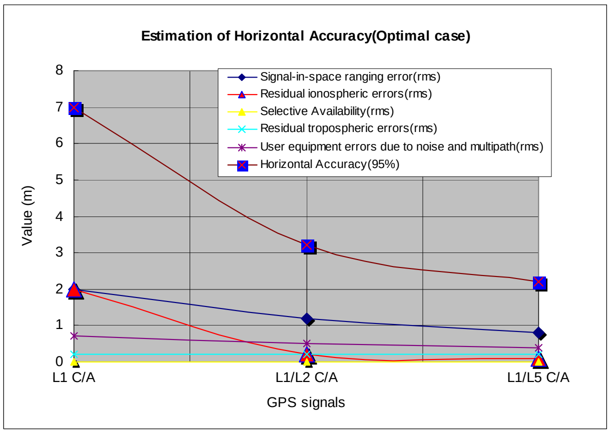

Fig. 12 Estimation of horizontal accuracy of dual-frequency

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REFERENCES

[1] Anon., Vice President Gore Announces New Global Positioning System Modernization Initiative, Press Release, The White House, Office of the Vice President, January 25, 1999.

[2] CANSO, "Demystifying CNS/ATM," Report Prepared by CNS/ATM Working Group, Final Version, June 1999.

[3] K. R. Oh, G.H. Ju, G.W. Nam and I.K. Ahn, "Overview of CNS/ATM Technology and Its Trends in Research and Development," *International Aerospace Conference*, Hankuk Aviation Univ., Nov. 2002.

[4] Keith D. McDonald, " The Modernization off GPS: Plans, New Capabilities and the Future Relationship to Galileo," *journal of Global Positioning Systems*, Vol. 1, No. 1, pp1-17, 2002.

[5] Michael Biggs, "An Overview of the New 1176.45MHz Civil Global Positioning System Signal (GPS L5)," White Paper of National Telecommunications and Information Administration, Washington, D.C, July 1999.

[6] Y.H. Shim, S.J. Lee, C.S. Yoo, J.C.Kim, K.R. Oh, "Research on the Local Area Augmentation System Ground Subsystem for Precision Approach and Landing of Aircraft," *Journal of the Korean Society for Aeronautical and Space sciences*, Vol. 28, No. 8, pp. 122-130, 2002.