Japanese SBAS Program: Current Status and Dual-Frequency Trial

Takeyasu Sakai, *National Institute of Maritime, Port and Aviation Technology*, sakai@mpat.go.jp

***Abstract*—**Japanese SBAS service called MSAS (MTSAT satellite-based augmentation system) has been operational continuously since September 2007. Recently the Japanese government has decided to replace geostationary satellites for MSAS service as a part of the QZSS regional satellite navigation program to continue the service. Additionally, MSAS will have the second geostationary satellite for LPV service in accordance with the expansion of the QZSS constellation with 7-satellite planned in 2023. In this paper, the author introduces the current status of MSAS and the dual-frequency SBAS trial using QZSS L5 signal planned in 2018.

Keywords*—SBAS; MSAS; MTSAT; QZSS*

I. Introduction

The satellite navigation is an essential technology for implementation of Performance-Based Navigation concept which is one of elements of the future air transport system. The SBAS, satellite-based augmentation system, is an international standard navigation service with a continental service coverage [1]-[3]. It provides RNP (required navigation performance) integrity-assured navigation service by augmenting GPS constellation. We already have four operational SBAS; The US WAAS [4] has been operated since 2003 and providing LPV approach service with vertical guidance down to 200FT above the ground; Japanese MSAS is operating for Enroute to NPA (non-precision approach); European EGNOS began its operation for safety-of-life application in March 2011; and most recently India has made their GAGAN system operational since February 2014.

In Japan, the development of its own SBAS was officially decided in 1993. The system named MSAS, or MTSAT-based Satellite Augmentation System, was originally planned to begin its operation in 2000. After a failure of the launch of the geostationary satellite in 1999, finally MSAS began its operation in 2007 with two spare satellites launched in 2005 and 2006, respectively. Since then, MSAS has been operational continuously up to now [5]-[7].

After 10-year operation, recently MSAS needs to replace its geostationary satellites. The first satellite for MSAS, MTSAT-1R, launched in 2005 terminated its operation and was already decommissioned in December 2015. The other satellite, MTSAT-2, launched in 2006 is still operational, but its operation will terminate by 2020. Is it also necessary to update ground facilities for MSAS because some equipment inside the current facilities are no longer available.

Recently the Japanese government has decided to replace geostationary satellites for MSAS service as a part of the QZSS regional satellite navigation program. A geostationary satellite of QZSS (QZS-3) will have an additional transmitter for the SBAS signal. The ground facilities will be completely replaced by the new system with increased number of ground monitor stations. The transition to the new geostationary satellite and new system will occur in 2020. The MSAS will continue the service by a geostationary satelite and have the second geostationary satellite in accordance with the expansion of the QZSS constellation with 7 satellites planned in 2023.

Additionally, the new MSAS system will have an L5 SBAS signal. It is planned to conduct a trial of DFMC (Dual-Frequency Multi-Constellation) SBAS with this signal. Thanks to dual-frequency signals, it is expected that the effects of the ionosphere are greatly eliminated and the vertical navigation is enabled even in the equatorial regions. Usage of multi-constellation also improves availability of navigation. The first L5 SBAS experiment with the real signal from the space is planned in 2018 and many participations from East-Asia are greatly expected.

II. Development of MSAS

A. *Development History*

In 1983, ICAO (International Civil Aviation Organization) organized the special committee for FANS (Future Air Navigation Systems) in order to study the limitation of conventional, basically ground-based, air navigation facilities and potential solutions. After discussions for 5 years, the report of the committee summarized recommendations that CNS (communication, navigation, and surveillance) service for civil aviation should be modernized in a global manner. The solution was, in the FANS concept, introduction of AMSS (aeronautical mobile satellite service), GNSS (global navigation satellite system), and ADS (automatic dependent surveillance), based on satellites.

Following the FANS concept, the US and Russia stated, at the 10th ANC (Air Navigation Conference) of the ICAO, to make GPS and GLONASS available to civil aviation use for free of direct user charges. Using GPS and GLONASS, often called 'core constellations', for air navigation, the problem to be solved was integrity which means the capability to generate alert in case that the navigation system does not operate with the intended performance. In the ICAO manner, 'GNSS' means global satellite navigation service with accuracy and integrity available for civil aviation.

A realization of integrity was the GIC (GPS integrity channel), i.e., monitoring GPS signals at the ground stations and transmitting integrity information to the airplane. The ICAO finally standardized GIC as SBAS (Satellite-Based Augmentation System), using geostationary satellites for wide area service, and GBAS (Ground-Based Augmentation System) with VHF datalink near an airport.

In Japan, JCAB (Japan Civil Aviation Bureau) of Ministry of Transport (Reorganized in 2001 to Ministry of Land, Infrastructure, Transport and Tourism) decided the development of its own SBAS in 1993. The system named MSAS [5]-[7], or MTSAT Satellite-based Augmentation System, was originally planned to begin its operation in 2000. The name of geostationary satellite 'MTSAT' stands for Multi-functional Transport Satellite, which means it has aviation and weather missions. For aviation, MTSAT works for AMSS and SBAS services.

The manufacturers of MTSAT-1 (and MTSAT-1R) and MTSAT-2 spacecraft were Space Systems Loral and Mitsubishi Electric Corporation, respectively. The launch of the MTSAT-1 was tried on November 15, 1999, but unfortunately failed due to trouble of the main engine of H-II launcher, then the MSAS program suffered a large delay of several years. Finally the spare satellite, MTSAT-1R, was launched in February 2005 and the second one, MTSAT-2, on the orbit in February 2006. They have nickname 'Himawari' meaning sunflower in Japanese, because of succeeding nickname of weather satellites before MTSAT. MTSAT-1R and MTSAT-2 are called Himawari-6 and Himawari-7, respectively.

The ground facilities for MSAS were completed by 1999, to be in time for the launch of MTSAT-1. The prime contractor of the system called MSAS-96 is NEC Corporation. As described later, MSAS has 2 master stations in the eastern and western parts of Japan to improve redundancy.

In summer 2005, MSAS began test broadcasting with MTSAT-1R. The certification activities had been conducted for 2 years. Finally, following online of AMSS mission in July, MSAS began its operation in September 27, 2007. On the same day, SBAS becomes available for air navigation use officially in Japanese law. MSAS has been operational continuously for Enroute to NPA (Non Precision Approach) flight modes since then up to now.

In March 2011, due to the great earthquake occurred in the eastern part of Japan, HASC, one of MCS for MSAS, has stopped its operation temporary. During this condition, the PRN 137 signal has discontinued for a while, but KASC, the other MCS, continued transmission of PRN 137 via MTSAT-1R until recovery of HASC.

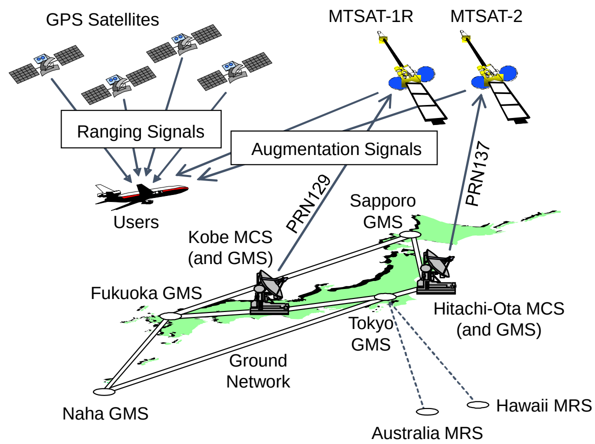


Figure 1. The original configuration of MSAS.

After 8 years stable operation, in December 2015, MTSAT-1R finally has run out of its life time of 10 years. The re-orbit operation (disposal of space vehicle) was conducted to the satellite to vacant geostationary orbit position. In contrast, they made success to extend the life time of MTSAT-2 until 2020. Currently, both KASC and HASC are transmitting SBAS signals using MTSAT-2 via the dual PRN operation.

B. *System Configuration*

Figure 1 illustrates the original architecture of MSAS. At first, 2 geostationary satellites MTSAT-1R and MTSAT-2 are at the longitudes of 140E and 145E, respectively. These longitudes were selected for requirements from the weather mission. For the current MSAS mission, geostationary satellites works simply as L-band transponders with the bandwidth of 2.2MHz. Different from other SBAS satellites, uplink of MTSAT is Ku-band (13GHz) due to results of frequency coordination. MTSAT satellites also have downlink channel in Ku-band because they need power control of uplink signal because of rain attenuation in Ku-band. Figure 2 shows the image of MTSAT-1R on the orbit. It is the 3-axis stabilized spacecraft with the standard bus system, but has a solar panel at the single side due to installation of equipment for the weather mission.

MSAS ground facilities include 2 MCS (Master Control Station), 4 GMS (Ground Monitor Station), and 2 MRS (Monitor and Ranging Station). MCS are located in the eastern and western parts of Japan to improve redundancy. The western station, KASC (Kobe Aeronautical Satellite Center, Figure 3) normally operates MTSAT-1R with PRN 129, while the eastern station, HASC (Hitachi-Ota Aeronautical Satellite Center), operates MTSAT-2 with PRN 137. In fact, due to the great earthquake in 2011, the eastern station HASC stopped its operation for a few weeks, but the other station continued MSAS mission.

4 GMS are distributed at Sapporo, Tokyo, Fukuoka, and Naha, and all equipment are installed in the ACC (Area

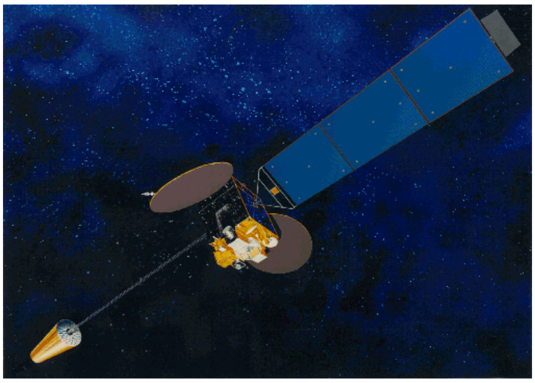


Figure 2. MTSAT-1R spacecraft.

Figure 3. Kobe Aeronautical Satellite Center.

Control Center). Each GMS has 3 sets of choke-ring antenna and NovAtel G-II receiver. Totally MSAS has 6 domestic monitor stations because MCS also has GMS functionality. MRS in Hawaii and Australia are basically equipped with the same as GMS and working to improve the performance of orbit determination with long baselines.

A unique function of MSAS might be the dual PRN operation mode. MSAS has 3 configurations: (Configuration-A) Normal operation: KASC transmits uplink to MTSAT-1R with PRN 129 while HASC operates MTSAT-2 with PRN 137; (Configuration-B) MTSAT-1R out condition: Both MCS transmit uplink to MTSAT-2 and MTSAT-2 broadcasts both PRN 129 and PRN 137; (Configuration-C) MTSAT-2 out condition: Both MCS transmit uplink to MTSAT-1R and MTSAT-1R broadcasts both PRN 129 and PRN 137. Change of configuration was, by 2015, performed in the emergency condition as well as for maintenance purposes.

III. Current Status

As explained above, MTSAT-1R has run out of its life time in December 2015. Since then, currently MSAS has continued the operation in the dual PRN mode (Configuration-B); KASC transmits the PRN 129 signal while HASC also transmits the PRN 137 signal, both via MTSAT-2.

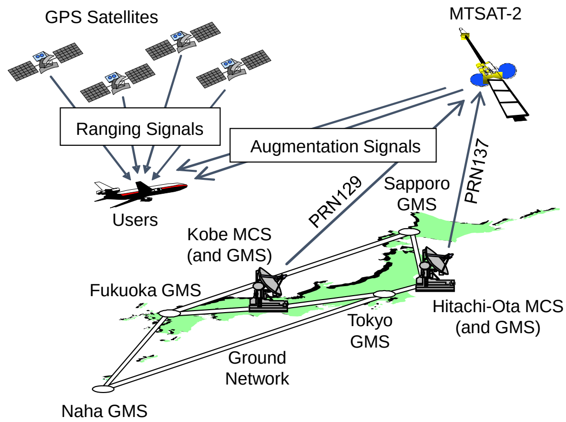


Figure 4. The current configuration of MSAS.

Further, in February 2016, two MRS sites were removed from the MSAS system. As a result, the current MSAS has the configuration shown in Figure 4.

Figure 5 shows the typical performance of MSAS in terms of accuracy at Takayama near the center of Japanese landmass. Thanks to differential corrections, the RMS of horizontal error is typically about 0.7m to 0.8m at this location. For vertical direction, the accuracy is degraded but the RMS of vertical error is typically less than 1m.

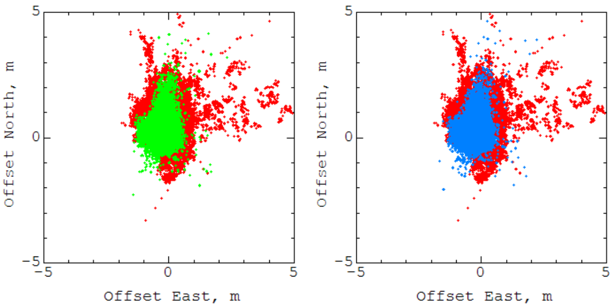
In civil aviation use, the protection level is the important factor which dominates the availability of the system. Protection levels mean the confidence limit at 99.99999% confidential level. Figure 6 shows example of comparison between horizontal protection level (HPL) and the actual error for a day derived by MSAS PRN 137. In this chart, so-called triangle chart, unsafe condition exists if there are plots at the right of the diagonal line; Such a condition does not exist in this case. And, the system is available if protection level is less than the alert limit associate with the flight mode in operation. In this case, the availability of MSAS for Enroute to NPA flight modes is completely 100%.

IV. Improvement Plan

A. Replacement of Geostationary Satellites and Ground Facilities

After 10-year operation from the launch, recently MSAS needs to replace its geostationary satellites. The first satellite for MSAS, MTSAT-1R, launched in 2005 terminated its operation and was already decommissioned in December 2015. The other satellite, MTSAT-2, launched in 2006 is still operational, but its operation will terminate by 2020. It is also necessary to update ground facilities for MSAS because some equipment inside the current facilities are no longer available.

Recently the Japanese government has decided to replace geostationary satellites for MSAS service as a part of the QZSS regional satellite navigation program. A geostationary satellite of QZSS (QZS-3) will have an additional L1 transmitter for the SBAS signal. The ground facilities will be completely replaced



(a) PRN 129 (b) PRN 137

Figure 5. Horizontal error example for 5 days.

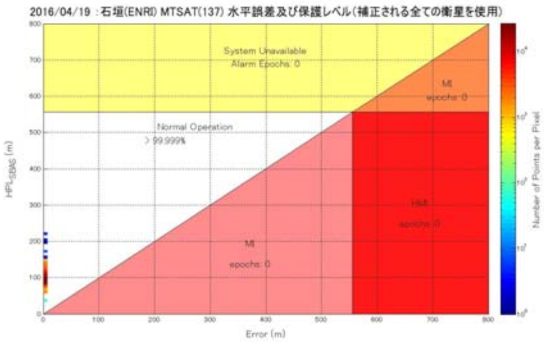


Figure 6. Comparison between HPL and HPE at the southwestern island of Japan.

by the new system with increased number of GMS: 13 stations in Japanese territory. Note that the QZS-3 L1 transmitter for MSAS service has 24MHz bandwidth and works with an onboard atomic clock, which is not a bent-pipe transponder employed by all other SBAS systems.

The transition to the new geostationary satellite and new system will occur in 2020. The MSAS will continue the service by a geostationary satellite and have the second geostationary satellite in accordance with the expansion of the QZSS constellation with 7-satellite tentatively planned in 2023.

B. *Vertical Guidance Capability*

MSAS has provided horizontal navigation only for Enroute to NPA operations since the beginning; No vertical guidance so far. The major concern for providing vertical guidance is due to the ionosphere condition. The magnetic latitude of the service area of MSAS is relatively low in comparison with WAAS and EGNOS. The current system cannot achieve enough availability of vertical guidance, for example LPV operation, especially at the southwestern islands.

However, the demand for vertical guidance is clear to expand the use of MSAS. Once the research activities for vertical guidance were conducted but they could not gain the budget for the upgrade at that time unfortunately.

Recently the research for vertical guidance is conducted again with the assumption of 13 domestic ground monitor stations for MSAS in 2020 and later. This time it is tentatively planned to upgrade the ground facilities to support LPV

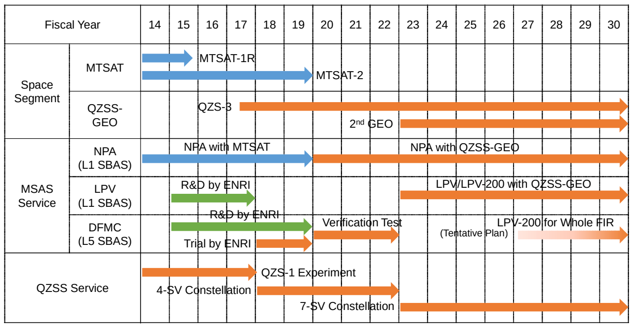


Figure 7. The MSAS evolution plan.

operation in accordance with 2-GEO MSAS configuration planned in 2023. The upgrade version of MSAS will provide LPV operation at the most airports in Japan and LPV-200 at some major airports.

The complete solution for ionosphere is usage of dual frequency. Thanks to dual-frequency signals, it is expected that the effects of the ionosphere are greatly eliminated and the vertical navigation is enabled even in the equatorial regions. Usage of multi-constellation also improves availability of navigation. The specification of DFMC (dual-frequency multi-constellation) L5 SBAS has been discussed by the SBAS IWG (Interoperability Working Group) and the ICAO is willing to issue the international standard around 2023. The QZSS L5 signal will work as the DFMC SBAS and support LPV-200 operation in the whole Japanese territory.

C. *Dual-Frequency Trial*

It is planned to conduct a trial of DFMC SBAS with the L5 SBAS signal on QZSS satellites to be launched in 2017 and later. The Electronic Navigation Research Institute (ENRI), National Research Institute of the Maritime, Port and Aviation Technology is responsible of this trial. We are preparing the prototype L5 SBAS ground facilities for the trial based on the draft specification of L5 SBAS discussed at the SBAS IWG. The coordination on the interface between the QZSS MCS and ENRI is ongoing.

It should be noted that the draft specification of L5 SBAS so far allows to transmit L5 SBAS signal from the non-GEO orbit. In our trial, both GEO and non-GEO satellites will be used for transmission of L5 SBAS signals.

The first L5 SBAS experiment with the real signal from the space is planned in 2018 and many participations from East-Asia are greatly expected.

D. *Summary*

Figure 7 summarizes the recent events and the evolution plan of the MSAS program based on the latest information. Note that this Figure contains tentative information and some uncertainties such as a satellite launch failure and delay of standardization activities.

V. CONCLUDING REMARKS

Japanese SBAS service called MSAS has been operational continuously since September 2007. It will be replaced to a new version in 2020 with a new GEO in the QZSS constellation and also have LPV capability with two GEOs in 2023. The ENRI will begin the dual-frequency SBAS trial in 2018 using QZSS L5 signal with both GEO and non-GEO satellites.

REFERENCES

[1] D. Lawrence, Global SBAS Status, Proc. 24th Int'l Tech. Meeting of the Satellite Division of the Institute of Navigation, pp. 1574-1602, Portland, OR, Sept. 2011.

[2] SBASs: Striving towards seamless satellite navigation, Coordinates, March 2014.

[3] International Standards and Recommended Practices, Aeronautical Telecommunications, Annex 10 to the Convention on Int'l Civil Aviation, vol. I, 6th Ed., ICAO, July 2006.

[4] D. Bunce, Wide Area Augmentation System (WAAS) - Program Update, Proc. 26th Int'l Tech. Meeting of the Satellite Division of the Institute of Navigation, pp. 2299-2326, Nashville, TN, Sept. 2013.

[5] J. Imamura, MSAS Program and Overview, Proc. 4th CGSIC IISC Asia Pacific Rim Meeting, 2003 Joint Int'l Conference on GPS/GNSS, Tokyo, Nov. 2003.

[6] H. Manabe, MTSAT Satellite-based Augmentation System (MSAS), Proc. 21st Int'l Tech. Meeting of the Satellite Division of the Institute of Navigation, pp. 1032-1059, Savannah, GA, Sept. 2008.

[7] T. Sakai and H. Tashiro, MSAS Status, Proc. 26th Int'l Tech. Meeting of the Satellite Division of the Institute of Navigation, pp. 2343-2360, Nashville, TN, Sept. 2013.