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New satellite navigation systems and moderenization of current systems, why and for whom?

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Abstract
Information about user's position can be obtained from specialized electronic position-fixing systems, in particular, Satellite Navigation Systems (SNS) as GPS and GLONASS, and Satellite Based Augmentation Systems (SBAS) as EGNOS, WAAS, MSAS. All these systems are known also as GNSS (Global Satellite Navigation System). As the number of GPS and GLONASS satellites visible by the user is sometimes in restricted area not sufficient, and these SNS cannot provide information about integrity, there is one service for civil users only etc., new systems, global as well as regional, must be constructed. The last years gave a rise to many important changes in the operational status and practical exploitation of all these systems. New SNS as Galileo in Europe and Compass (Beidou) in China, new SBAS as GAGAN in India and SDCM in Russia, new regional SNS as IRNSS in India and QZSS in Japan are actually under construction. Additionally the new satellite blocks as GPS IIF and III, and GLONASS K1 and K2, the new signals as GPS L5 and L1C, and GLONASS LC3OC and L1OC, the new services and possible applications of the future system Galileo are presented in this paper.

Introduction

Nowadays, information about ship's position is obtained generally from specialized electronic positioning systems, in particular, at present functionally satellite navigation systems (SNS) as the GPS and the GLONASS, and satellite based augmentation systems (SBAS) as EGNOS, WAAS and MSAS [1, 2, 3, 4, 5, 6]. The last years gave a rise to many important changes in the operational status and practical exploitation of these systems. Actually (January 2012) more than 60 operational GPS, GLONASS, EGNOS, MSAS and WAAS satellites are in orbit transmitting a variety of signals on multiple frequencies [7, 8, 9]. As the number of satellites of these systems increases and the new SNS and SBAS are under construction we can suppose that within five years the number of satellites which can be used in user's position computation will reach 90 or more, with even more types of signals broadcast on even more frequencies. All of which represents good news and maybe some not such good news for SNS and SBAS product designers, service providers, and end users [10].

That's why it can put some questions – why new global and regional SNS, new SBAS, new satellites, new signals, new services and for whom?

New satellite navigation systems

As at the time of this writing, January 2012, GPS system fully operational with 31 satellites and GLONASS system with 24 operational satellites, the number of satellites visible by the user is sometimes in restricted area not sufficient, these SNS cannot provide information about integrity, one service for civil users only etc. new systems, global as well as regional, must be constructed [7, 11].

Global systems

Satellite navigation users in Europe today have no alternative other than to take their positions from US GPS or Russian GLONASS satellites. That's why for Europe and China the conclusion was to build own global SNS – Galileo system for civil and Compass system for military and civil users respectively.

Galileo system

Once envisioned to space segment consisting of 30 satellites (27 fully operational and 3 active spares) Galileo has over time been reduced to a planned, though still not space-borne, four initial satellites IOV, plus 14 operational satellites for a total of 18. The European Space Agency confirmed that it plans to declare an Initial Operational Capability (IOC) once a constellation of 18 satellites is achieved in the 2014–2015 time frame [4, 8, 9, 12].

On January 7, 2010, it was announced that the contract to build the first 14 FOC satellites was awarded to OHB System and Surrey Satellite Technology Limited (SSTL). Fourteen satellites will be built at a cost of 566M euros. The first two are expected to be ready in October 2012. At present space segment consists of two test satellites, GIOVE-A since 2005 and GIOVE-B since 2008. Both continue to transmit test signals. These satellites can only transmit two signals at a time; either E1+E5 or E1+E6. The first two in-orbit validation (IOV) satellites, PFM (GSAT0101) and FM2 (GSAT0102), provided by Astrium, were launched on a modified Soyuz rocket from the European Union's spaceport in Kourou, French Guiana in October 20, 2011. The next two IOV satellites are scheduled for launch during the summer 2012 [8, 9].

This was the first launch of Russia's Soyuz rocket from French Guiana, and the first Soyuz launch from a spaceport outside of Baikonour in Kazakhstan or Pletelsk in Russia. French Guiana is much closer to the equator, so each launch will benefit from Earth's spin, increasing the maximum payload into geostationary transfer orbit from 1.3 tonnes to 3 tonnes [8].

The name of this first IOV satellite is Natalia, name of nine-year old Bulgarian girl who won an EC-sponsored drawing contest. All 30 planned satellites will be named after EU children [9].

The Galileo satellites will emit ten navigation signals in the four frequency bands E5a (1176.450 MHz), E5b (1207.140 MHz), E6 (1278.750 MHz) and E1 (1575.420 MHz). Three types of ranging codes are distinguished: the open-access ranging code (signals No. 1, 2, 3, 4, 9 and 10), the ranging codes encrypted with commercial encryption (signals No. 6 and 7) and the ranging codes encrypted with governmental encryption (signals No. 5 and 8). All satellites will use the same carrier frequencies for signal transmission, and will be differentiated as well as in GPS system, by their spread spectrum using the principles of CDMA (Code Division Multiple Access). The Galileo infrastructure will provide five positioning services [12, 13]:

- the Open Service (OS), free of charge and for use by the mass market, a basic level dedicated to consumer applications and general interest navigation, simple timing and positioning down to 1 metre;
- the Commercial Service (CS), encrypted, a restricted access service for commercial and professional applications that require superior performance to generate value-added services, high accuracy to the centimeter, faster data rates, guaranteed service for which service providers will charge fees;
- the Safety of Life Service (SoL), open service, provides integrity data in addition to the OS, a highly stringent service for use in transportation where guaranteed accuracy is essential and passenger safety is critical, integrity messages will warn of errors;
- the Public Regulated Service (PRS) with high continuity characteristics, encrypted, a restricted service for governmental applications as police or customs, provides positioning and timing information, continuous availability even in time of crisis;
- the Search and Rescue service (SAR), support to the international COSPAS–SARSAT, a humanitarian service to accurately pinpoint the location of distress messages from anywhere across the globe, feasible to send feedback, confirming help is on its way.

An initial constellation of 18 satellites and IOC will provide three early services: an initial OS, an initial PRS and an initial SAR [8, 12].

Compass system

Compass is the multistage satellite navigation program designed to provide positioning, fleet-management, and precision-time dissemination to Chinese military and civil users. Long-range plans envision a 35 satellite constellation: five geostationary satellites, 27 in medium Earth orbit (MEO) and three in highly inclined geosynchronous orbits (IGSO). The satellites will transmit signals on the 1195.14–1219.14 MHz, 1256.52–1280.52 MHz, 1559.05–1563.15 MHz, and 1587.69–1591.79 MHz carrier frequencies. Compass satellites have an announced lifespan of eight years.

Compass, sometimes referred to as Beidou-2, is intended to provide service to the Asia-Pacific region sometime in 2012 and to attain global-service levels around 2020. Compass may reach an initially operational capability sooner than Galileo. This is highly probable for coverage in Asia and increasing likely on a global basis. Compass will be a dual-use system. The civilian open service is designed to provide position accuracy of 10 m, velocity accuracy of 0.2 m/s, and timing accuracy of 50 s. No detailed performance parameters have been published for the authorized service [3].

China's State Council Information Office announced at December 27, 2011 the official start of operational positioning, navigation, and timing services of the Beidou / Compass system to China and surrounding areas. The main service area is currently 084°E to 160°E and 55°S to 55°N with horizontal position accuracy of up 25 metres, height to 30 metres, velocity accuracy of 0.4 metres per second, and a timing accuracy of 50 nanosecondes. It is not clear how many satellites are actually providing this initial service. The current operational constellation possibly consists of three GEO satellites and five IGSO satellites. One or two of the IGSO may be considered as in-orbit spares. According to the NASA Forum website, two GEOs and four MEOs are scheduled to be launched in 2012 [8, 9].

Regional satellite navigation system

New regional SNSs as IRNSS (Indian Regional Navigation Satellite System) in India and QZSS (Quasi-Zenith Satellite System), developed in Japan, will provide a regional satellite navigation service, in Asia and Oceania:

IRNSS system. This is an autonomous regional SNS being developed by Indian Space Research Organization which would be under total control of Indian government. The project of this system was approved in May 2006, with the intention of the system to be completed and implemented by 2014. The space segment of this system will consist of seven satellites, three in geostationary orbit (034°E, 083°E, 131.5°E) and four in geosynchronous orbits with an inclination angle 29° with their longitude crossing at 55°E and 111.5°E (two in each plane). All the satellites will be continuously visible in the Indian region for 24 hours a day. IRNSS will provide dual-frequency service using the L-band in coallocation with GPS L5 and Galileo E5a, and the S-frequency band 2483.5 to 2500.0 MHz. This shall enable a position accuracy of 10 m over India and adjacent countries, and 20 m over the Indian Ocean. The system will provide two types of services, a Standard Positioning Service (SPS) and a Restricted Authorized Service (RS). Both of these services will be provided at two frequencies, one in the L5 band and the other in S-band [3, 5, 14].

QZSS system. This system is designed to provide integrity information and position service in urban canyons and mountainous environments in Japan in particular. QZSS will provide three major services, complement GPS by broadcasting navigation signals compatible and interoperable with GPS, augmentation information to correct the GNSS signal for atmospheric effects, orbital and clock errors, broadcasting and communication service in order to enable, similar to the navigation objectives, communication in restricted area. The space segment comprises the quasi-zenith satellites which operate in highly inclined (45°) elliptical orbits (HEO), semimajor axis (average) 42164 km, longitude of ascending node 146.3°E, argument of perigee 270°. Eccentricity (0.099) and inclination of the orbit are chosen in order to provide an elevation of more than 70° over the whole trajectory of the satellites when traveling over Japan. The first QZSS satellite (nicknamed Michibiki) was launched on September 11, 2010. This satellite is the first in history to transmit L1C, new civil signal using PRN code 183, designed to be interoperable among GNSS. The QZSS L1C ranging codes and navigation messages are in accordance to the codes and messages envisioned for the GPS L1C signals. The QZSS L2C will be a replica of GPS L2C and similarly the QZSS L5I and L5Q signals will be a replica of the GPS L5C. The QZSS satellites transmit eight ranging signals. Six of them are referred to as positioning availability enhancement signals since they complement the GPS signals. The two others, L1-SAIF and LEX, provide augmentation information, thus, they are commonly referred to as positioning performance enhancement signals. The QZSS applies for the L1C/A signal the same ranging code modulation as GPS [3, 6]. At the end of 2011 a government ministerial council has taken the decision to expand the QZSS to seven satellites and will seek about $53 million in the fiscal 2012 national budget to start the process. The future constellation could involve a mixture of inclined geosynchronous orbit (IGSO) and GEO satellites [8].

Current satellite navigation systems, theirs new satellites and new signals

As the community of SNS mass market users has increased considerably, and mentioned above the Galileo and Compass programs have become a reality, the need for real improvements in the GPS and GLONASS systems have arisen. First, and most importantly in terms of impact of user's position accuracy, is the need to make two frequencies available for all civil users at least.

GPS system

At present (January 2012) GPS constellation consists of 31 satellites, all operational, 10 satellites block IIA, 12 block IIR, 7 block IIR–M and 2 block

IIF. The newest satellite SVN63/PRN01 block IIF was launched on July 16, 2011, and set usable on October 14, 2011 [8].

The GPS modernization programme involves a series of consecutive satellite acquisitions, including GPS IIF and GPS III. It also involves improvements to the GPS control segment, including the Architecture Evolution Plan (AEP) and Advanced Control Segment (OCX). As at present GPS system provides only one civil frequency, the U.S. government decided to add three new civil signals to new GPS satellites – L2C (1227.60 MHz) to blocks IIR–M, IIF and III, L5 (1175.45 MHz) to block IIF and III, and L1C (1575.42 MHz) to block III. These signals will provide SPS users the ability to correct for ionospheric delays by making dual frequency measurements, thereby significantly increasing civil user accuracy. The additional signals also will increase the receiver's robustness to interference. There are no plans to privatize GPS. U.S. law and policy require the civil GPS service to be provided free of direct user fees. Current and new satellites and theirs capabilities are showed in the table 1, the new signals in the table 2 [15, 16, 17, 18, 19, 20, 21, 22].

The GPS IIF satellites will provide greater navigation accuracy to all users through improvements in atomic clock technology and a more robust signal for commercial aviation and SoL (Safety of Life) applications.

The GPS IIIA satellites (8 planned) will deliver signals three times more accurate than current GPS satellites (blocks IIA, IIR, IIR–M and IIF, and provide three times more power for military users, while also enhancing the satellite's design life and adding a new civil signal (L1C) designed to be interoperable with other global satellite navigation

Table 1. GPS system, current and new satellites and theirs capabilities

Number of satellites, block	Launched	Capabilities
28 block II/IIA 13 block IIR	1989–1997 1997–2004	Basic GPS, initial navigation capabilities: – SPS (single frequency L1, C/A code) – PPS (two frequencies L1 & L2, P(Y) code) – 7.5 year design life
8 block IIR–M	2005–2009	IIA/IIR capabilities and: – second civil signal L2C – earth coverage M code on L1/L2 – L5 demo – anti-jam flex power – 7.5 year design life
12 block IIF	2010 – present	IIR–M capabilities and: – third civil signal L5 – reprogrammable navigation processor – increased accuracy requirement – 12 year design life
32 block III	2014–2024	IIF capabilities and: – block IIIA: increased accuracy (0.63 m), increased Earth coverage power (–151.5 dBW), 15 year design life, fourth civil signal (L1C) – block IIIB (real time communications) – block IIIC (navigation integrity)

Table 2. GPS modernization, new civil signals

New civil signals		
second L2C	third L5	fourth L1C
– designed to meet commercial needs – higher accuracy through ionospheric correction – available since 2005 without data message – satellites IIR-M, IIF and III – full capability, 24 satellites, ~ 2016	– designed to meet demanding requirements for transportation safety-of-life – uses highly protected Aeronautical Radio Navigation Service (ARNS) band – satellites IIF and III – full capability, 24 satellites, ~ 2018	– designed with international partners for interoperability – modernized civil signal at L1 frequency • more robust navigation across a broad range of user applications • improved performance in challenged tracking environments • original signal retained for backward compatibility – specification developed in cooperation with industry recently completed – satellites III – full capability, 24 satellites, ~ 2021

systems, as Galileo (E2–L1–E1) and Compass (B1C, B1A), regional systems, as QZSS (L1C) and all current SBAS as EGNOS, WAAS and MSAS (L1).

The GPS IIIB satellites (8 planned) will deliver real time command and control cross-links, will allow upload of all GPS IIB/IIICs via single contact and improve constellation accuracy.

The GPS IIIC satellites (16 planned) will provide high power spot beam and increased anti-jamming capability for warfighter [18].

The real-world applications of GPS technology can be grouped by [8]:

– survey, construction, and mapping;
– roads, traffic, and freight;
– natural resources, offshore oil platforms, mining;
– defense, security, and first responder;
– disaster management;
– aviation;
– timing, networks, and infrastructure.

GLONASS system

At present (January 2012) GLONASS constellation consists of 31 satellites – 24 satellites operational, 1 in commissioning phase, 2 in maintenance, 3 spares (operation ends); all these 30 satellites are block M. The last satellite block K1 is in test phase 1. The oldest satellite (712) was launched in December 2004. For comparison, the oldest GPS satellite (PRN 32, block IIA) was launched in November 1990. The parameters of satellites of block M, block K1 and the next block K2 are presented in the table 3. Satellite GLONASS K1 is a substantial improvement of previous generation, it is the first unpressurized GLONASS satellite with a much reduced mass; 750 kg versus 1,450 kg of GLONASS M.

On January 26, 2011 Russia launched the first GLONASS K1 satellite into orbit. Since April 2011, this satellite has been transmitting the first code division multiple access (CDMA) signal in L3 band centered at 1202.025 MHz coherently with existing L1 and L2 signals. The K1 satellite inaugurates a new era of radionavigation signal for both Russian system and for international GNSS interoperability [8, 23, 24].

The next generation GLONASS–K2 satellite, with FDMA signals in L1 and L2 band will relocate the L3 signal to 1207.14 MHz and add the CDMA signals located at 1575.42 MHz in the L1 band, and at 1242 MHz in the L2 band. The future generation of satellites, KM, at present at research phase, will probably broadcast additional open and obfuscated CDMA signals in existing L1, L2 and L3 bands and also in L5 (1176.45 MHz) band. The first launch of K2 and KM is planned in 2014 and 2015, respectively. The overall constellation update will be completed in 2021.

Table 3. GLONASS system modernization, the parameters of satellites of block M and new blocks K1 and K2

Parameter	Block M	Block K1	Block K2
launch years	2003–2012	2011	2013–2014
design life [year]	7	10	10
clock stability	$1\cdot10^{-13}$	expected $\sim 10\ldots5\cdot10^{-14}$	expected $\sim 5\cdot10^{-14}$
signals	L1OF, L2OF L1SF, L2SF	GLONASS M + L3OC – test	GLONASS M + L1OC, L3OC, L1SC, L2SC

O – open signal (standard precision), S – obfuscated signal (high precision), F – FDMA, C – CDMA

Since January 2012 GLONASS has a full complement of satellites in orbit providing positioning, navigation, and timing worldwide, the main improvement is a major objective – constellation with 24 satellites fully operational and performance to be comparable with GPS system. GLONASS Programme Updates for 2012–2020 is under development to be adopted in 2012. The Program objective is to make the GLONASS service more available, better accurate, more reliable and more robust in the multi GNSS world [7, 8, 20, 25].

The last proposition of the GLONASS Information Analytical Centre made at a December 27, 2011 meeting on the status and the future of the satellite constellation is 30 satellites using six orbital planes, currently 24 satellite and 3 planes only [8].

Satellite Based Augmentation Systems

Satellite Based Augmentation Systems (SBAS) consist of widely dispersed reference stations that monitor and gather data on GPS satellites at present and perhaps in the future on GLONASS satellites also. These data are forwarded to the SBAS master stations for processing to determine the integrity and differential corrections for each monitored satellite.

The current SBAS format has a limited capability for broadcasting corrections for GPS and GLONASS satellites combined, because there is space for only 51 satellites. Meanwhile, the current total number of satellites of these systems is already greater, at least 56 fully operational satellites (32 GPS and 24 GLONASS). That’s why the studies are looking in attempt to resolve this contradiction [7, 8, 11].

Current systems, modernization processing

At present three SBAS are functional, European Geostationary Navigation Overlay System – the EGNOS within Europe, Wide Area Augmentation System – the WAAS within the United States and Multi-functional Transport Satellite (MTSAT)-based MSAS within Japan and Southeast Asia:

EGNOS system. This SBAS was developed by the European Space Agency (ESA), the European Commission (EC) and Eurocontrol. The space segment consists of three geostationary satellites. The official start of operations, as open and free service, was announced by EC in October 1, 2009. On March 2, 2011 EGNOS Safety of Life (SoL) service, providing the first in history information about SNS integrity (GPS system), was officially made available for the safety-critical task of providing vertical guidance to aircraft on final approach. Two satellites, Inmarsat 3–F2/AOR–E (015.5^{O}W) and Artemis (021.5^{O}E), PRN code 120 and 124, respectively, began this service. The third satellite Inmarsat–4–F2 (025^{O}E), PRN code 126, is transmitting message type 0/2 for industry tests. Reports EGNOS is designed in such a way that the SoL service ensures that the satellite correction error and ionospheric error are bounded with a probability of 99.99999 percent – essentially reflecting the system integrity. On May 10, 2011 Pau Pyrenees in southern France has become Europe's first airport to use the new service, the guide aircraft in four landing using only this highly accurate space navigation signal, according to the ESA. In the next evolution step, the coverage area will be extended to Africa. For the second major evolution step, EGNOS will implement full GPS L5 augmentation service and may also include Galileo and modernized GLONASS augmentation services. The Commercial Service (CS) will be declared later in 2012. The ESA developed the signal in space over Internet (SISNeT) concept to provide EGNOS information also over Internet [3, 8, 9].

WAAS system. This is an air navigation aid developed by the FAA (Federal Aviation Administration) to augment the GPS with the goal of improving its accuracy, integrity and availability. On July 10, 2003 the FAA commissioned the WAAS for aviation use. At present both satellites, Galaxy XV and AnikF1R, contain an L1 and L5 GPS payload. This means they will be usable with L5 GPS signals when this third civil frequency and receivers (L1 & L5) become available. With L5 frequency avionics will be able to use a combination of signals to provide the most accurate service possible, thereby increasing availability of the service. The Galaxy XV(CRW), 133.1^{O}W, PRN code 135, and AnikF1R(CRE), 107.3^{O}W, PRN code 138, payloads, operated by Lockhed Martin for the FAA, are known as LMPRS–1 and LMPRS–2, respectively. The third WAAS geostationary Inmarsat–4–F3 (AMR), 098^{O}W, PRN code 133, began operational service on November 11, 2010, and this satellite is expected to provide non-precision approach ranging service early in 2012. Reports indicate that this service may already be available. FAA announced on March 18, 2011 that Galaxy XV satellite has resumed normal operations and was repositioned to an orbital slot 133.1^{O} W [8, 9, 22, 26].

MSAS system. This Japan's SBAS was commissioned for aviation use on September 27, 2007. At present the space segment consists of two geostationary satellites – MTSAT–1R at 140^{O}E and MTSAT–2 at 145^{O}E. Either satellite can transmit both PRN (129 or 137, respectively) signals if necessary. The coverage area is limited to Japan, since there are no reference stations in other parts of East Asia and Oceania [3, 8, 9].

Systems under construction

New SBAS, as GAGAN (GPS and Geo Augmented Navigation) in India and SDCM (System for Differential Correction and Monitoring) in Russia, will permit to use in the next regions in the world a suite of geostationary satellites and networks of ground relay stations. These systems will offer users (aviation, maritime, road and surveying) more reliability through improved accuracy, availability, integrity and continuity:

GAGAN system. The Indian Space Research Organization in collaboration with the Airports Authority of India implements India's SBAS called GAGAN – GPS And GEO Augmented Navigation. It will include three GEO satellites – GSAT. The goal of this system is to provide navigation system for all phases of flight over the Indian airspace and in adjoining area. Test transmissions using the Inmarsat satellite (064^{O}E) ceased on April 8, 2008. The launch of the first GSAT on April 15, 2010, failed. New satellite, GSAT–8, PRN code 128 was launched on May 21, 2011, its final orbital position is 055^{O}E. Satellite commissioning is under way. Interoperability with GPS is the foundation of the system, but Galileo system is also being considered [3, 5, 8, 9].

SDCM system. GLONASS is being further improved with a new SBAS, called System for Differential Correction and Monitoring or SDCM. This system will use a ground network of monitoring stations and Luch geostationary communication satellites to transmit correction and integrity data using the GPS L1 frequency. The anticipated position accuracy is better than 0.5 m. A high-accuracy service in conjunction with local ground station support may even provide a position accuracy between 0.02 and 0.5 m. SDCM ground segment consists of 14 monitor stations in Russia and two in Antarctica at Russia's, Bellingshausen and Novolazarevskaya (opened in 2010) research stations. Eight more stations will be added in Russia and several more outside Russia. The additional overseas stations may include sites in Latin America (Brasil, Nicaragua) and the Asia-Pacific region (Australia, Indonesia). Taking into account that the SDCM coverage area is Russian territory in the northern hemisphere, the satellite antenna beam will be deviated from the Equator by 7 degrees to the north. Roscosmos, the Russian space agency, has launched the first Luch-5A GEO satellite on December 11, 2011. Its final position will be at 016^{O}W. The transmitted power will be 60 W and will give a signal power level at the Earth's surface roughly equal to that of GLONASS and GPS signals, about –158 dBW. The two next GEO satellites, Luch–5B (the position 095^{O}E) and Luch–4 (167^{O}E) will be launched in 2012 and 2013, respectively [8, 9, 24, 25].

Conclusions

- The goal of each SNS is to provide all-day and all weather PVT (Position, Velocity, Time) services of high accuracy and reliability for users around the world;
- as the current SBAS format has a limited capability for broadcasting corrections, to resolve this problem the three main options can be taken into account: use a dynamic satellite mask, use two CDMA signals, or provide on additional SBAS message;
- new generation of GPS and GLONASS systems, III and KM, respectively, and new system Galileo will provide submeter position accuracy, greater timing accuracy and a system integrity solution, additionally GPS III a high data capacity intersatellite crosslink capability, and a higher signal power to meet military antijam requirements;
- the main task for GLONASS development is an extension of the ensemble of navigation signals. This extension means that new CDMA signals in the L1, L2 and L3 bands will be added to the existing FDMA signals. GLONASS K1 satellite began transmitting its new CDMA signal on April 7, 2011, it means that a new era of GNSS, truly global navigation satellite systems, started;
- in future, augmentation information (integrity and differential corrections) will also be emitted by SBAS geostationary satellites on and for, respectively, the GPS L5C signals and all users;
- the development of Compass (Beidou) is one of China's national strategic objectives. China pays high attention to this system development and navigation industry cultivation.

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