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Overview

The term “satellite navigation” is a short version of Radio Navigation Satellite Service (RNSS). The service that obtains the position vector $\overrightarrow{R} = (X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}, T)$ under the fixing time of the Earth coordinate system by determining the traveling distance and rate of distance change of the radio signal transmitted by satellite is called the “RNSS,” where (X, Y, Z) is the user’s coordinate in the Earth-fixed coordinate system; $(\dot{X}, \dot{Y}, \dot{Z})$ is the user’s velocity component; and T is the moment when the user is located at the coordinate (X, Y, Z). The satellite navigation system consists of the satellite that realizes the radio navigation target, the ground operation control system, and the application terminal.

Transit and цикаdа, built by USA and the Soviet Union successively in the 1960s, can only obtain the position coordinate (X, Y, Z) of the user under static state conditions. Movement velocity of the ship must be given to obtain the position coordinates in motion. The second generation of satellite navigation positioning systems, Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS), built by the USA and Russia, respectively, can realize high-accuracy timing, spatial 3D positioning, and measurement of kinematic velocity for aerospace, aviation, navigation, and ground users at any point on Earth or in terrestrial space. Compared with the first generation of satellite navigation systems, the difference is significant in terms of the name of the system, positioning principle, positioning method, and so on. The first generation of Chinese satellite navigation positioning system utilized a positioning principle totally different from the one mentioned here. The confirmation of radio navigation parameter and position calculation required by user positioning is accomplished by ground control center other than the user, in fact, both positioning of the user terminal and positioning report from the user terminal to ground control center are completed, therefore it is called the Radio Determination Satellite Service (RDSS). RNSS is a subset of RDSS. China Compass is a multi-functional aerospace application system integrating satellite radio positioning, navigation, communication, location reporting, and identification.

In the corresponding chapters of this book, the system that can only confirm the position coordinate of the user is called the satellite positioning system, and the system that can completely confirm position vector of the user is called the satellite navigation system. However, RDSS is a complete system that accomplishes navigation, positioning, location reporting, and short message communication. This system was created originally by China Compass. Its function of location reporting has the features of lower

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systematic complexity and cost as well as shorter responding time of positioning reporting and higher security than RNSS positioning, which are the advantages of Compass and also the future directions for GLONASS development.

1.1 Origin of GLONASS

GLONASS, which originated from satellite positioning, has been through the development of satellite navigation. On December 27, 2012 regional deployment of Compass Satellite Navigation System positioning was accomplished; and the system integrating satellite navigation and positioning reporting pushed the GLONASS to its zenith. The development process can be divided into the three stages that follow.

1.1.1 Stage 1: Satellite Radio Positioning

This originated in the 1960s. Typical systems were the Transit (the US Navy Satellite Navigation System) and Russian цикаuа. Their principles originated from Professor Shekbusavidge's team of former Soviet Union Leningrad Marjongski Airforce Engineering Academy of Science and Frank T. McClure, George C. Wesabah, and William H. Jill of the Institute of Applied Physics at Johns Hopkins University, USA. In principle, the space-borne transmitting signal is the navigation signal and the receiver of the Earth station receives the satellite signal. Through measurement of the Doppler frequency of electricity generated by satellite signal under relative movement, as well as the orbital parameter given by the satellite navigation signal, the location of the receiver, the user's positioning can be confirmed and accomplished. Determination of orbital parameters is realized through the reverse operation of the Doppler measurement after the satellite navigation signal is received by the fixed station on the Earth. This kind of system can only achieve the user's point positioning. Continuous navigation requires phase assistance. Therefore, the early stages of satellite navigation development only accomplished positioning.

1.1.2 Stage 2: RNSS

The RNSS originated in the 1970s. Typical systems are the US GPS and the Russian GLONASS. The principle roots can be found in the US Navy Research Council's (NRC) "Timation," the EZIB Program by the Air Force's SAMSO Organization, and the former Soviet Union's research program. The fundamental principle is that the user uses the radio signal transmitted by satellite to determine the position vector $R = (X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}, T)$ under the Earth's fixed time coordinate system through measurement of the distance and rate of distance change: this is referred to as the RNSS, where (X, Y, Z) is the position coordinate of the Earth-fixed coordinate system of the user; $(\dot{X}, \dot{Y}, \dot{Z})$ is the velocity component of the user; and T is the moment when the user is located at coordinate (X, Y, Z). RNSS is the English terminology.

The satellite navigation system consists of the satellite that realizes the radio navigation target, the ground operation control system, and the application terminal. The application terminal provides not only the user's location but also the velocity, heading, distance to the destination, and trip time of the user. Therefore, the system that provides the RNSS signal service is also called the satellite navigation system. It can continuously provide the positioning velocity determination parameter.

1.1.3 Stage 3: Satellite Navigation Positioning Reporting

This originated in the 1990s. A typical system is China Compass Satellite Navigation Positioning System. As the information era progresses, the user not only needs to know his own location, velocity, and time, but also needs to share location, velocity, and duration of voyage with other users. In 1994, a Compass testing system was started to realize positioning, location reporting, and short message communication. In 1994, the "Double Satellite Navigation Positioning System" was approved. By taking two satellites as the space segment and taking the ground user electron height as the third material, it constitutes two spherical surfaces with the two satellites as the center of sphere and distance of the user as the radius, and the third spherical surface where the Earth's core is the center of sphere and the user's distance from surface of referenced ellipse sphere to the Earth's core plus height is the radius. The cross point of the three spherical surfaces is the location of the user; therefore, its principle is similar to the three-sphere positioning principle. The location reporting to the central control system is accomplished during the positioning of the user and it can realize short message communication between users. Compass provides the complete RNSS service at the same time; it is an integrated GLONASS system integrating navigation, positioning, location reporting, and short message communication. It has a greater number of outstanding advantages in achieving double satellite positioning reporting and triple satellite positioning reporting so as to avoid positioning reporting failure caused by conditions where four positioning satellites cannot be received, such as in the city among high-rise buildings and in cliff/remote gorge environments.

1.2 Development and Future Plans for the GPS System

In 1973, the United States Department of Defense approved the proposal of GPS and named it the NAVSTAR Global Positioning System, [1] which aimed to (1) deliver weapons accurately and (2) provide uniform navigation positioning to reverse the booming kinds of military navigation. The proposed constellation was a total of 24 satellites distributed on three circular orbital planes, with eight satellites on each orbital plane with a dip angle of 63°. The orbital planes were distributed with uniform space along the equator with an orbit height of 10,980 sea miles. Such an orbit height was a semi synchronous orbit, which was able to produce the repeated ground track. The large-scale antenna with an uplink injection station set in the mainland of the USA could accomplish the injection to the satellite according to the plan orientation safely and reliably. This selection of the three orbital planes not only features in good coverage but also facilitates backup satellite distribution with one backup satellite on each orbital plane and accomplishes the backup of the failure satellite. This constellation allows users to observe 6–11 satellites anytime in any place.

Two L-frequency band radio navigation signals are transmitted by each satellite, with L1 of 1575.42MHz and L2 of 1227.6MHz. L1 modulates two orthorhombic spreading code signals. I-subcircuit is a C/A code, named the coarse code or acquisition code with a code rate of 1.023 Mbps and used for civilian navigation; the Q-subcircuit is a precise distance measurement code, also called the P code with a code rate of 10.23 Mbps and used for authorized users. L2 only modulates P code, and is only used for authorized users. During the implementation of the engineering, due to concern about the prospect of GPS, financial expenditure is a constraint. In order to guarantee the effective experiment set up in Yuma Proving Grounds, three orbital planes were changed to six orbital planes to reflect the limited experimental satellite on the proving ground. There were four satellites on each plane and this had a good effect on the experiment but made the constellation layout difficult. In order to not waste the quantity of satellites or form a blank area in coverage, six orbital planes remain as they currently are. However, the three-orbital-plane scheme is still recommended by the GPS Modernization Plan, and a new civilian navigation signal has been added to L2.

From the proposal approved in 1973, GPS was mainly used for military purposes. Two navigation frequencies can be used for calibrating ionosphere propagation delay. However, there is only one navigation frequency L1 for civilian use. In order to meet civilian needs, calibration parameters of the ionosphere are provided in the L1 navigation message. Under the support of the model, 70% of ionosphere propagation deflection can be calibrated through these ionosphere calibration parameters. Therefore, for civilian users, they can only achieve positioning accuracy to a few tens of meters. Early US government protocols only allowed provision of positioning with an accuracy of 100 m (95%) to the civilian user and added SA measurement that reduced the accuracy on the civilian navigation signal. Due to the increase in civilian demand, various difference navigation positioning technologies have appeared that might improve accuracy to the meter-level. The Wide Area Augmentation System (WAAS) scheme provided by the Federal Aviation Administration (FAA) was typical of this. The US President released the SA Policy of reducing accuracy in 2000, and increased civilian accuracy to 25 m. In order to further expand the civilian market, the civilian navigation frequency was actively advocated and it was decided to modulate the civilian signal on L2 too, in order to carry out the I/Q reused QPSK modulating method. However, as for this proposal, military and civilian users were still on the same frequency for reuse, which brought about difficulties to war navigation implementation. Therefore, the US government took the lead in proposing to use the L5 frequency, that is, 1176.45 MHz, as the working frequency, which was registered in the ITU. At the World Radio Conference in 2000 (WRC-2000), it was proposed that satellite radio navigation frequency should include downlink frequency 1260~1300 MHz, 5010~5030 MHz, and the newly added uplink frequency included 1300~1350 MHz, 5000~5010 MHz, 1164~1215 MHz; downlink navigation frequency lump power flux-density should be no greater than -121.5 dBW/(m^2•MHz). Now, GPS actually occupies three frequency bands; 1575.42±12 MHz, 1227.6±12 MHz, and 1176.45±12 MHz. Although the navigation frequency is so abundant it cannot implement effective war navigation, the increase in military signal in a war zone inevitably affects the civilian one. The interference with the civilian signal will also affect the military one. Therefore, BOC modulation emerges. Reuse of navigation frequency was increased by utilizing space spectrum frequency division. The ideal solution is that military and civilian users, respectively, have two independent navigation frequencies, which is favorable to civilians. However, the current frequency source is limited and it is difficult to find another frequency source on the L-frequency band.

Another technological problem in GPS with any big change is encryption of the military P Code. The initial phase is precise pseudo-code of P code that has a relatively high security property. In order to increase the difficulty of theft, it was changed to a Y Code after adding scrambling code and then M Code.

The latest development in GPS is to continuously improve the navigation performance of GPS on the original track and frequency resource, and the navigation war performance is mainly improved. For instance, a reinforcing measure of the military code war zone is adopted, and control of civilian code is enhanced. The time Keeping System (TKS) and autonomous navigation (Auto-NAV) are added on the BLOCK-IIR satellite. This has autonomous working ability for 180 days without requiring ground system intervention. Autonomous navigation performs distance measurement and information exchange through UHF inter-satellite links, autonomously updating ephemeris on board, and accomplishing the calibration of the satellite clock. The time system is maintained by using a highly stable cesium atomic clock and rubidium atomic clock. It also has the reprogrammable performance of satellite space; namely, that an operative flight program could be completely newly programmed according to ground command. After cold start, the processor will execute the program stored in PROM (Programmable Read-Only Memory), which will maintain the working routine through beam uplink.

The GPS III Program was launched in 2000. Its fundamental target up until 2020 is: (1) to realize the navigation signal's capability of penetrating vegetation; (2) to reach positioning accuracy of 1 m; (3) to realize full ILS capability through a wide area differential; (4) to improve timing accuracy to 1 ns; (5) to possess excellent war navigation performance – in a war zone at least, the navigation signal could be enhanced by 30 db (1000 times); and (6) to fully realize an automatic early warning navigation signal.

1.3 Development and Future Plans for GLONASS

Based on the Soviet Union's successful low orbit system, цикаgа, which began in the 1970s, Russia's GLONASS improved the orbit forecast accuracy and long-term stability of an atomic clock in space and digital signal processing techniques of propagation time delay correction accuracy of the troposphere and ionosphere. The purpose of study was to provide continuous and high-accuracy timing, spatial (three-dimensional) positioning, as well as movement velocity vectors for spaceflight, aviation, and ground users at any point on Earth or in near Earth space. GLONASS also consists of three parts:

1. Satellite system, consisting of 24 satellites on three orbital planes.
2. Monitoring control system, consisting of a ground monitoring station and a control station.
3. User equipment.

Just like as GPS, navigation positioning of GLONASS automatically performs location and velocity calculations through measurement of non-inquiring pseudo-range and the radial pseudo-velocity is finished by user equipment, which is a typical RNSS positioning system. The pre-conditions for this positioning system had been accomplished in ΛBBИA research led by B. C. Sebusa in the period of 1955–1957 before the first man-made Earth satellite was launched.

The rationality and feasibility of a radio navigation system based on the conformance to the requirement of high accuracy for the ground user, offshore user, and air and space user was demonstrated 1 year after the launch into orbit of the first satellite цикаgа used by a non-dynamic user. After the first GLONASS (TLOHACC) satellite, namely

KOCMOC 1413, was launched on October 12, 1982, 65 satellites had been launched up until the middle of 1995. As of December 14, 1995, one rocket with three satellites was successfully launched by Russia that brought the total number of satellites in the GLONASS constellation to over 24. On January 18, 1990, the establishment of GLONASS was announced. The suggestion made in the ICAO 10th Airborne Navigation Conference was approved by the Russian government, which proposed to provide a standard accuracy channel of GLONASS to world aviation users and promised that the positioning accuracy would meet the parameters in Table 1.1. From the successful launch of the first GLONASS satellite to the establishment of the system, 73 GLONASS satellites in total had been launched, 67 of which were successful. Due to the conflict between short lifetime of satellite and long networking period, the satellites had been in orbit for 12 years. GLONASS promises not reduce accuracy.

A GLONASS satellite has a lifetime of at least 3 years. Since the year 2000, satellite lifetime has been anticipated to be 5 years.

GLONASS adopts the frequency division (FDMA) identification system. Each satellite uses a fixed frequency bandwidth. The purpose of the design is to enhance jamming (intentional interference) rejection capability. However, due to the small frequency space of each satellite, which is only 0.5625 MH_2, the resistance ability to modern bandwidth disturbance is very limited, and burdens the design of receivers more to provide a different reference frequency to each satellite. Since L_1 frequency of GLONASS uses the radio astronomy operating frequency band, it has been suggested by the World Radio Conference this must change, which also makes the design of GLONASS satellite frequency more difficult. The only solution is sharing one frequency between two satellites corresponding to Earth, which undoubtedly will cause difficulty in the identification of low elevation of satellites. Is FDMA suitable for the navigation system? Many people disagree with this viewpoint. The Galileo System in Europe is still using a CDMA system. GLONASS frequency assignment is listed in Table 1.2.

It was decided in WRC-87 in 1987 and WRC-92 in 1992 that 1610–1626 MHz was assigned to the satellite mobile mss ground to spatial service. By 1998, GLONASS had conceded 1610.6–1613.8 MHz to radio astronomy. Therefore, from 1998 to 2005,

Table 1.1 GLONASS accuracy properties.

	Measurement Accuracy	
Parameters	**GPS (P = 0.95)**	**GLONASS (P = 0.997)**
Horizontal Plane, m	100 (72/18) (C/A Code) 300 (P = 0.9999) (C/A Code) 18 (P Code. Y Code.)	60 (CT Code) (39)
Vertical Plane, m	<200 (C/A Code) 20 (P Code. Y Code)	75 (CT Code) (39)
Velocity, cm/s	<200 (C/A Code) 20 (P Code. Y Code)	15 (CT Code)
Accelerated Velocity, cm/s^2	8 (C/A Code) <19 (C/A Code)	–
Time, μs	0.34 (C/A Code) 0.18 (C/A Code)	1 (CT Code)

Table 1.2 GLONASS frequency assignment.

Channel	Frequency (MH$_2$)	
No.	L$_1$	L$_2$
00	1602.0	1246.0
01	1602.5625	1246.4375
02	1603.125	1246.875
03	1603.6825	1247.3125
04	1604.25	1247.75
05	1604.8125	1248.1875
06	1605.325	1248.625
07	1605.9325	1249.0625
08	1606.5	1249.5
09	1607.0625	1249.9375
10	1607.625	1250.375
11	1608.1875	1250.8125
12	1608. 75	1251.25
13	1609.3125	1251.6875
14	1609.875	1252.125
15	1610.4375	1252.5625
16	1611.0	1253.0
17	1614.5625	1253.4375
18	1612.125	1253.875
19	1612.6875	1254.3125
20	1613.25	1254.75
21	1613.8125	1255.1875
22	1614.375	1255.625
23	1614.9375	1256.0625
24	1615.5	1256.5

GLONASS satellites only used Channels 0–12 (1602.0–1608.25, 1246.0–1251.25 MHz). Using Channel 13 is an exception. After the year 2005, GLONASS-M satellite transmitted a channel frequency of K = −7–4, the high-end frequency of which is 1604.25 + 5.11 MHz = 1069.36 MHz. At the same time, the GLONASS-M satellite radiated navigation signals of frequencies L$_1$ and L$_2$ for civilian users, in which radiant power of an L$_2$ civilian user is 12 W. Antenna gain along the direction of axis of a satellite pointing to the ground is 8.8 dB, and corresponding angle of GLONASS relative to this axis is ±15°, 11 dB, ±19°, 9 dB. The civilian ranging code of L2 is the pseudorandom sequence of maximal length the same as L1. The polynomial is $1 + x^5 + x^7$ and the period is 1 m; pseudo-code velocity is 5.11 Mbps. In the message, representation of the difference $\Delta\tau_n$ of L1 and L2 frequencies satellite time delay equipment is added. When L2 signal is lagging behind L1 signal, $\Delta\tau_n>0$. When L1 signal is lagging behind L2 signal, then $\Delta\tau_n<0$, and the deflection $\delta_{\tau_n}<2\times10^{-9}s$.

Besides $\Delta\tau_n$ in the navigation message of GLONASS-M satellite, n parameters for improving the user positioning reliability were introduced.

The difference between representation system master clock time scale transmitted by a GLONASS satellite and time UTC (SU) time scale is τ_c. Satellite ranging code phase position is subject to the system master clock, while UTC (SU) is the Russian time frequency standard, and ephemeris of navigation satellite adopts UTC (SU) for calculation.

In order to fit in the astronomical time, UTC (SU) time scale can be corrected once or twice a year, with 1 s for each correction. The correction can be performed at 00:00 of the night from December 31 to January 1, March 31 to April 1, June 30 to July 1, and September 30 to October 1.

The correction features of UTC (SU) time scale introduced in GLONASS-M satellite navigation message are:

10 – Pending time correction
00 – No correction
01 – Correction with +1 second
11 – Correction with −1 second

Under the condition that UTC (SU) time scale is prepared for correction, this information shall be introduced into the navigation message not less than 2 months before correction.

The features of the satellite remodel are prepared to be introduced into the navigation message:

00 – GLONASS Satellite
01 – GLONASS-M Satellite

In a GLONASS-M satellite, the time scale difference between GPS and GLONSS planned to transmit is $\tau_{GPS-GLN}$. Phase position of the ranging code is subject to the time scale of GPS and GLONASS. The maximum numerical range transmitted by this parameter is $\pm 1.9 \times 10^{-3} s$.

GLONASS will contribute to improve the long-term stability of the satellite clock. The GLONASS-M satellite will be installed with a new type of cesium clock, which will improve maximum day-and-night instability from $5 \times 10^{-13} s$ to 1×10^{-13}. The GLONASS-M satellite will adopt two methods to improve reliability and integrity: Method 1: Autonomous monitoring of basic functions is continuously performed on the satellite. When a phenomenon that affects the quality of navigation quality is found, sign Bn, which automatically connects in the downlink navigation message, means that this satellite cannot be used for navigation. Method 2: Monitoring network is setup by the ground control system to inspect the navigation signal. When the navigation signal is found to possess deviation affecting positioning quality, sign Cn introduced in the navigation message means that this satellite cannot be used for navigation.

1.4 Development and Future of the Chinese Navigation Satellite System

Originating from RDSS, the Chinese satellite navigation system has a weakness in continuous and autonomous navigation, but it was full of advancements – integration of positioning and positioning reporting, which means the integration of navigation and communication was accomplished; and the first generation of the Compass Navigation Positioning System, which was built in 2000. From 2000 to 2004, the three-step development planning of the China Compass was completed. The second generation of the satellite navigation system was launched in 2004. On December 27, 2012, Phase 1 of the Compass Second Generation Project covering China and some regions of Asia-Pacific was formally announced to start running, which completed the creation and perfection of the positioning reporting system of China Compass so as to provide RDSS and RNSS services to the user. The third step of development planning was launched in 2011. It aims to complete the global Compass system around 2020 to provide RDSS and RNSS services to users.

The Compass Navigation System, built in 2012, had navigation signals of three frequencies for the ionospheric calibration and improvement in carrier phase service efficiency. At the same time, it also provides calibration parameters in grid and model representations of ionosphere propagation delay of the user of single frequency, which contains eight model parameters of the ionosphere, α_n and β_n, 8 bits each, 64 bits in total; see to Table 1.3. (Refer to Table 1.4 for the ionosphere grid.)

Table 1.3 Calibration parameters of the ionosphere of the compass system.

Parameter of Ionosphere			
Parameter	**Bit**	**Quantization Unit**	**Unit**
α_0	8	2^{-30}	s
α_1	8	2^{-27}	s/π
α_2	8	2^{-24}	s/π^2
α_3	8	2^{-24}	s/π^3
β_0	8	2^{11}	s
β_1	8	2^{16}	s/π
β_2	8	2^{16}	s/π^2
β_3	8	2^{16}	s/π^3

Note: Parameters marked “1” are the complement of “2.” The most significant bit (MSB) is sign bit.

Table 1.4 Ionosphere parameter error tab information arrangement.

Parameter	IGP	$\Delta\tau_i$	GIVE1
Bit	**8**	**9**	**4**

IGP is the grid point number.

$\Delta\tau_i$ is the vertical delay of ionosphere of grid point.

The system distance is 0.125 m.

GIVE1 is the ionosphere vertical delay correction error tab of this grid point.

Table 1.5 Conversion parameters of compass time and GPS time.

Parameter	Bit	Unit
A_0GPS	14^1	0.1 ns
A_1GPS	16^1	0.1 ns/s

Note: Parameters marked “1” are the complements of “2.” The MSB is sign bit.

Conversion formula:

$t_{GPS} = (t_E - \Delta t_{GPS})$

Wherein $\Delta t_{GPS}=A_{0GPS}+A_{1GPS}\times t_E$

t_E is the BDT of user’s calculation

Table 1.6 Conversion parameters of compass time and Galileo time.

Parameter	Bit	Unit
$A_0Galileo$	14^1	0.1 ns
$A_1Galileo$	16^1	0.1 ns/s

Note: Parameters marked “1” are the “2.” The MSB is a sign bit.

Conversion formula:

$t_{Galileo} = t_E - \Delta t_{Galileo}$

Wherein $\Delta t_{Galileo}=A_{0Galileo}+A_{1Galileo}\times t_E$

t_E is the BDT of user’s calculation

Satellite broadcasts the integrity sign of self-test and the ground test to improve the reliability and integrity of positioning.

In order to meet the needs of multi-system compatibility, it successively broadcasts the time conversion parameters of GPS, GLONASS, Galileo systems (see Table 1.5 and Table 1.6), satellite integrity, and precision positioning clock correction parameter as well as satellite position correction parameters (see Table 1.7).

For time synchronization and satellite orbit determination of Compass Navigation System, the unique method for missions accomplished in the station setup in the home country alone that was mentioned previously is considered, which creates conditions for regional high-accuracy navigational positioning.

The Compass Navigation System is an independent satellite navigation system boasting advantages such as application compatibility with the advanced satellite navigation system, which will become a component of international GLONASS.

1.5 Galileo Navigation Satellite System

The Galileo Satellite Navigation System has been in planning for a long time. From March of 2005, it officially learned to use the (27+3) MEO constellation instead of

Table 1.7 Satellite clock errors, ephemeris correction parameter, and GPS error information.

Parameter	T	PRN	Δx	Δy	Δz	A_0	A_1	$\Delta\dot{x}$	$\Delta\dot{y}$	$\Delta\dot{z}$	EPREI	IOD
Bit	9	6	11	11	11	13	8	8	8	8	4	8

Note: T is the corresponding time of the parameters, expressed with integral minute of the same day in units of 3 min; and PRN is the satellite number of GPS

$\Delta\chi$, Δy, Δz are the correction of broadcast ephemeris of the satellite in unit of 0.25 m.

$\Delta\dot{x}$, $\Delta\dot{y}$, $\Delta\dot{z}$ are the change rates of $\Delta\chi$,Δy,Δz in unit of 0.0025 m/s.

A_0, A_1 are the slow varying correction of satellite clock error. A_0 is the clock offset in unit of 0.5 ns; A_1 is the clock rate in unit of 0.005 ns/s. Clock error correction is relative to the satellite clock error correction in GPS navigation message. Broadcasting value of the navigation message shall be added in user's calculation.

IOD is the date of data issuance. EPREI is the state parameter pointer of equivalent range error of the satellite ephemeris correction. (Omitted).

the GEO satellite constellation. A specific frequency plan was announced officially to the consultative country of the frequency (see Section 9.4.1.) The first navigation experimental satellite, Giove A, was launched on December 28, 2005. Giove B, another experimental satellite, was planned for launch in 2006. Before 2011, another two satellites would be launched adopting at least four work stars to perform the experiment in orbit. And then the remaining 26 satellites would be launched to form the full constellation.

Galileo measurement and control adopts the S frequency band. Uplink injection is L-frequency band of 1300~1350 MHz. Signal monitoring is in the C frequency band of 5000~5010 MHz.

1.6 Indian Navigation Satellite System

The Indian government officially approved implementation of the Indian Regional Navigation Satellite System (IRNSS) on May 9, 2006. A space segment consisted of 7–8 satellites including three GEO satellites and four IGSO satellites with an inclination angle of 29°. It was changed to six IGSO satellites in 2012. Therefore, it consisted of nine satellites in total. In September of 2007, Naill, an official of the Indian Space Research Organization said at an International Spaceflight Conference that 16 billion Rupees would be spent on the setup of the IRNSS system. A navigation satellite would transmit navigation signal of three frequencies. One is BPSK (1) with the center frequency of 1575.42 MHz. The other one is BOC (5, 2) with the center frequency of 1176.45 MHz, and BPSK (1). The third one is the signal of S frequency band with the center frequency of 2491.005 MHz, EIRP = 35.5 dBw. The plan was to finish deployment of seven satellites in 2012 with service regions of 35°E–130°E, 45°S–45°N.

At the same time, India implemented the GPS Aided GEO Augmented Navigation based on the GPS satellite based augment, which is similar to US WAAS. The space segment includes GPS satellites and one GEO (INMARSAT-4F1) satellite. The GEO satellite adopts the C and L bands as the working frequencies. The two L band signals are the same as L1 and L5 of GPS. It is fully compatible with the EU's Galileo and the Japanese GPS Augmented System, MSAS, based on MTSAT.

1.7 Japanese Regional Navigation Satellite System

The Japanese Navigation System serves as a regional navigation satellite system (Quasi Zenith Satellite System) and satellite based augmentation system (multi-function satellite augmentation system). The Multi-Function Satellite Augmentation System is an augmentation system of GPS, which is similar to the US WAAS. Its satellite is the multi-purpose satellite (MTSAT) launched by Japan. Two GEO satellites are located at 140°E and 145°E covering the Asia-Pacific Area. It has possessed the initial service ability since 2007. Ground stations are located in Hawaii, USA; Canberra, Australia, and the Philippines, with the broadcasting signal covering the Asia-Pacific Area.

The QZSS (Quasi Zenith Satellite System) was primarily defined as a multi-mission satellite system providing cell phone communication and broadcasting service with an angle measurement (70°) and positioning service with a rotation angle of 30°. Once the GPS system signal is interrupted, it can still possess reliable navigation positioning and communication capabilities.

The space segment consists of three GEP satellites and four asymmetrical IGSO satellites. At least four satellites at the optimum location within 2500 km around the Japanese archipelago can be observed, among which is at least one has an elevation angle of 70°. This is to improve anti-occluding capability in cities among high rises and mountainous regions to maintain smooth communication, broadcasting, and position reporting.

The navigation signal transmitted by QZSS is completely compatible with GPS, including L1: 1575.42 MHz, L2: 1227.6 MHz, L5: 1176.45 MHz. The broadcasting service signal is 2605 MHz-2630MHz (S frequency band). Low velocity communication service signal frequency is 2170–2200MHz (S frequency band) and the LEX signal with a center frequency of 1278.75 MHz and a modulation system of BPSK (5) is compatible with Galileo E6CS. The minimum received power is −155.7 dBw. Centimeter-level surveying and mapping augmentation information is broadcast at a data rate of 2 kbps through the L-frequency band spiral array antenna with the Reed–Solomon error correcting code (255,233). The broadcasting parameter is ionospheric delay using a ruled surface to match actual measurement at each penetration point, which is vastly superior to the accuracy of Klobuchar model ionospheric correction.