5-3 Quasi-Zenith Satellite System (QZSS) Project

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The first satellite "Michibiki" of the Quasi-Zenith Satellite System (QZSS) was launched on September 11, 2010. This paper introduces the features and the history of the QZSS project and the role of the National Institute of Information and Communications Technology (NICT) in the project. The technical details of the QZSS will be discussed in a different opportunity.

Keywords
Quasi-zenith satellite system, QZSS, Navigation satellite, TWSTFT

1 Introduction

Nowadays, satellite navigation systems are essential not only for everyday applications such as car navigation, but also in numerous fields such as ground surveying and time synchronization at mobile phone base stations. Up to now, satellite navigation has been reliant only upon GPS (Global Positioning System) managed and operated by the United States and upon the Russian GLONASS. However, in order to avoid such reliance on the systems of other countries, the EU, China and India are developing their own independent satellite navigation systems, and Japan has decided to perform research and development on a quasi-zenith satellite system (QZSS) in the initial aim of supplementing and augmenting GPS.

2 The history and inauguration of the Quasi-Zenith Satellite System project

2.1 Investigation of the quasi-zenith orbit

Geostationary satellites can be seen from Tokyo with about 45 degree elevation in south direction. For fixed stations it is sufficient to set up an antenna in locations where satellites are clearly visible, but mobile stations often experience shadowing and multi-passes especially in locations such as urban canyons and mountainous areas. Consequently, satellites should be positioned with a high elevation angle in order to avoid these risks. In 1972, a research paper written by Takahashi from the RRL (Radio Research Laboratory: currently NICT) proposed that the orbit plane of satellites should be inclined so that satellites would move to a high elevation angle periodically[1]. At the time, it was thought that a large amount of fuel was required to maintain this orbit, but as a result of following studies regarding orbit[2], the utilization of the quasi-zenith orbit has become realistic since it was discovered that almost the same amount of fuel as that required in the geostationary orbit could be used in quasi-zenith orbit. Furthermore, at this time, the utilization of the quasi-zenith orbit was mainly considered for mobile communications and broadcasts.

2.2 Trigger for development of satellite navigation systems

While the use of GPS progressed in the 1990's, its precision was forced to be reduced as a result of Selective Availability (SA) (ending in May 2000), and discussions commenced in regard to developing satellite navigation technology or system in Japan without relying solely on the US military GPS (or GLONASS).

In their report "Initiatives for the Development of Satellite Navigation Technology in Japan" released in 1997, the Satellite Navigation Technology Subcommittee of the Space Activities Commission (SAC) reported three essential elements that need to be developed independently in Japan. These were "atomic clocks installed on satellites", "time management technology for satellite cluster" and "highly accurate satellite orbit determination technology". It was also at this time that the Europe finalized their Galileo project for an independent satellite navigation system.

Against this backdrop, momentum for developing the QZSS increased, and in 2002, industry and government joined forces to establish the "Quasi-Zenith Satellite System Development and Utilization Promotion Conference". In December the same year, the Council for Science and Technology Policy determined this to be "research and development of national importance"[3], and based on this evaluation, industry and government jointly commenced the development of the QZSS in fiscal 2003. Consequently, the private sector undertook the communications and broadcasting mission, and at the national government level, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Ministry of Internal Affairs and Communications (MIC), the Ministry of Economy, Trade and Industry (METI), the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and related agencies undertook the navigation mission. Figure 1 shows the structure of the highly accurate navigation system utilizing quasi-zenith satellites (QZS) and the responsibilities taken by each ministry.

As will be discussed below, navigation signals are intended to be interoperable with GPS civil signals. And the characteristic of these signals is that undisclosed services for military purposes similar to GPS are not anticipated, and all content will be publically disclosed.

2.3 Shift to a navigation satellite system

As a result of the rapid spread of mobile phones, and the explosive increase of information flowing throughout networks and reduction of costs, demand for communications and broadcasts utilizing satellites did not increase

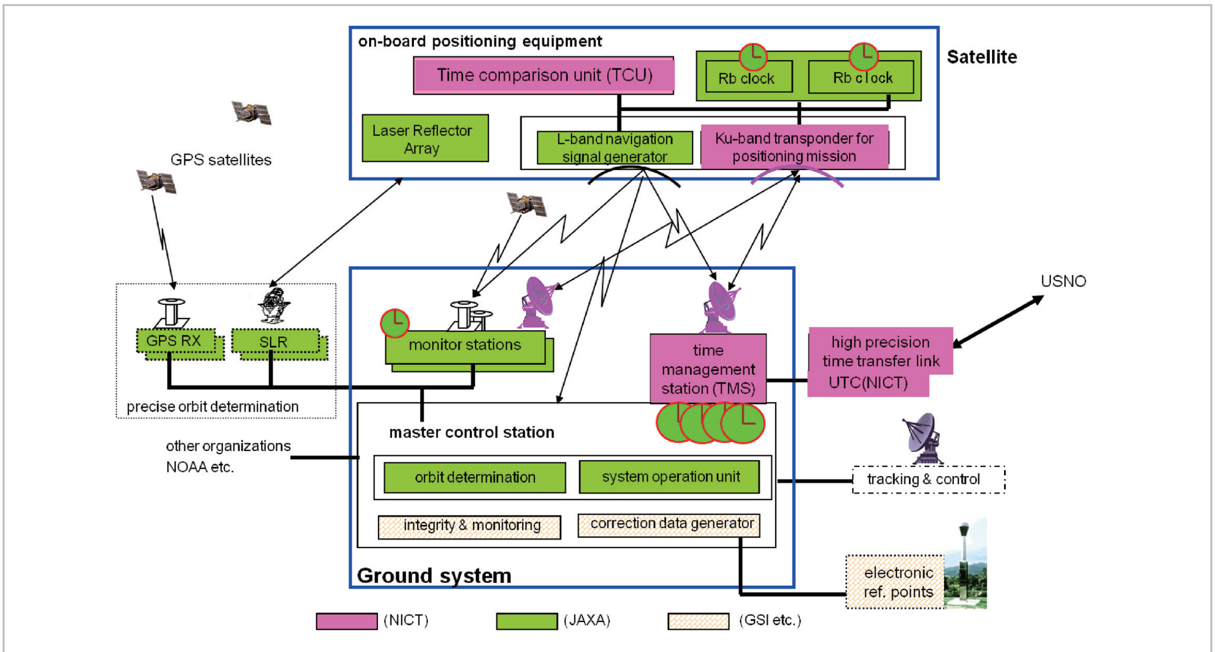

Fig.1 *Structure of the high-accuracy navigation system using the QZSS and the responsibilities of each ministry*

as initially expected. Consequently, the commercial prospects for communications and broadcasting services utilizing three QZSs were put in jeopardy, and the private sector ultimately decided to withdraw from the development of the system in March 2006.

From April 2006, the QZSS became a national project put together by the Japan Aerospace Exploration Agency (JAXA) and the mission was refined to navigation. Based on the Basic Act on the Advancement of Utilizing Geospatial Information (law No. 63 of 2007) implemented in August 2007, the governmental Positioning and Geographical Information System Promotion Conference examined the details, and in April 2008, the “Basic Plan for the Advancement of Utilizing Geospatial Information” was determined. “Part Ⅱ Chapter 3 Policies regarding Satellite Positioning 2. The Advancement, etc., of Research and Development regarding Satellite Positioning (3) The Advancement of the Quasi-Zenith Satellite System” of the plan discusses the following.

“Centered on the national government, one QZS (aimed to be launched in FY2009 by an H-ⅡA rocket) will be launched and the MEXT, the MIC, the METI and the MLIT will conduct a technical validation and the private sector and government agencies, etc., will conduct a utilization validation. <abbreviated>

It is planned that the results will be evaluated after the first stage technical validation and utilization validation, and the national government and private sector will then proceed to the second stage where a system validation will be conducted using the three quasi-zenith satellites (including the initial satellite).

The private sector will progress with the plan after determining its commercial viability based upon the results of the first stage validation and providing the appropriate funds for the business content and scale.”

(However, the specific details of the development for the second stage have not be scheduled at the time of writing this paper in September 2010.)

3 Characteristics of the QZSS

3.1 Characteristics of the QZS orbit

Since a satellite only comes into the quasi-zenith orbit over the sky of Japan for several hours per day, two or more satellites are required in order to be visible for 24 hours 365 days per year. There is a similar United States broadcasting satellite called Sirius. Three Sirius satellites that are positioned in elliptic orbits with a 0.27 eccentricity cover the sky of the United States for a long period of time.

Also in regard to the QZSS, various factors such as the number of satellites (considering response to system failures), orbit inclination angles, and the shape of the elliptic orbit were examined. As a result of placing emphasis on visibility from Japan in all directions, it was determined that three satellites in an asymmetric “figure 8” orbit with a 43 ± 4 degree orbit inclination angle and 0.075 ± 0.015 eccentricity were required. Each satellite would be positioned on an orbit plane 120° apart. The footprint of the QZS is shown in Fig. 2. Consequently, for instance, satellites can be utilized over Tokyo (less than 48° elevation angle for geostationary satellites) with a constant 75° or higher elevation angle, which is particularly effective in the areas between buildings. As shown in Fig. 3, the visibility of geostationary satellites from an urban canyon in Shinjuku

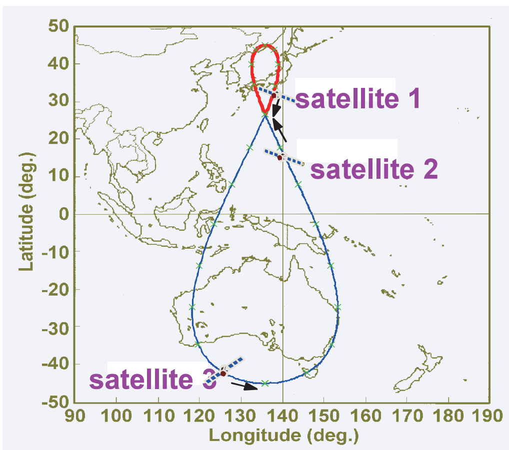

Fig.2 *Orbits of the satellites projected on the ground (asymmetrical figure “8”)*

(actually visible in the south) is poor, but the scope of visibility of the QZS is good.

3.2 The purpose of the navigation mission

The purpose of the QZSS navigation mission is to supplement and augment GPS and the L band signals as shown in Table 1 are broadcast to users. At a minimum, this covers not only all civil signals broadcast by the modernized GPS (GPS-Ⅲ) but experimental LEX signals by JAXA and L1-SAIF signal. The signal details are specified in IS-QZSS[4].

Since one satellite which is interoperable with GPS can be constantly seen with high elevation, the lack of visible GPS satellites will be greatly improved, and there will be more opportunities to acquire better satellite constellation (small DOP). This "supplementary" function is the main purpose of the mission.

In addition, the "augmentation" function improves navigation precision. This broadcasts data such as ionosphere information using L1-SAIF or LEX signal to users via the navigation messages.

Fig.3 *Example for optimal orbit; difference in vision between a geostationary satellite and a QZS from an urban canyon*

4 The time management system developed by NICT

4.1 NICT's mission

Since fiscal 2003, NICT has been consigned research and development from the MIC. This has involved the development of a hydrogen maser, which NICT has technical capabilities for, as an experimental equipment to be installed on a satellite, and the development and experimentation of a precise time management system.

However, since the size and the weight of the hydrogen maser is larger than the GPS onboard rubidium (Rb) atomic clock that was to be used on the QZS, it was determined not to be installed on the QZS. NICT has developed an Engineering Model (EM) in response to the issues which became apparent through the development of a breadboard model and would rise with the installation on the satellite such as lifetime, and vibration/impact resistance[5]. Its en-

Table 1 *Outline of L band signals*

Signal Name	Center Frequency [MHz]	Adovption in GPS	Comments
L1-C/A	1575.42		Most popular civil signal
L1C	1575.42	after 2014	Wider bandwidth than L1-C/A, robust for multipath
L2C	1227.60	from 2006	Second civil signal
L5	1176.45	from 2010	Third civil signal
L1-SAIF	1575.42	—	Supplement signal compatible to SBAS L1, data rate is 250 b/s
LEX	1278.75	—	Experimental signal for QZSS, data rate is 2000 b/s, same frequency as that of GALILEO's E6 signal

durance to the simulated space environment test was validated and the result was reported[6].

4.2 Development of the on-board system

NICT's mission corresponds to the "time management technology for satellite cluster" specified in the report submitted by the Satellite Navigation Technology Subcommittee of the SAC in 1997. In order to acquire the satellite time vis-à-vis the reference station on the ground, NICT conducts two way time and frequency comparisons between the satellite and the ground in the aim of achieving high precision. In addition, the National Institute of Advanced Industrial Science and Technology (AIST) intends to conduct remote synchronization system using an on-board crystal oscillator (RESSOX) experiments[7] in cooperation with NICT on the prerequisite that NICT's on-board and ground equipment be utilized.

The on-board Time Transfer Subsystem (TTS) is made up of Time Comparison Unit (TCU), the main component, and the Ku Band communications device that transmits and receives signal between the satellite and the ground station. The configuration of the TTS is shown in Fig. 4 (not including the redundant system) and its functions are outlined below.

(1) Measuring the time and frequency difference between the on-board atomic clock and TMS atomic clock using Ku band two way time and frequency comparison technology
(2) Measuring the time difference between on-board atomic clocks (two rubidium frequency standards and the satellite reference clock generated from the VCXO)
(3) Measuring the time difference between L1 (L1 C/A and L1-SAIF), L2C and L5 signals
(4) Conducting highly precise time comparison experiments between ground stations utilizing the bent pipe function
(5) Conducting delay calibration within the TCU

In 2007, NICT developed the EM, completed environment tests and evaluations and commenced the development of a Flight Model (PFM). The PFM was transferred to the satellite system in 2009 after conducting tests on each component, conducting TTS tests and conducting tests by combining these with the L band System (LTS) developed by JAXA. After

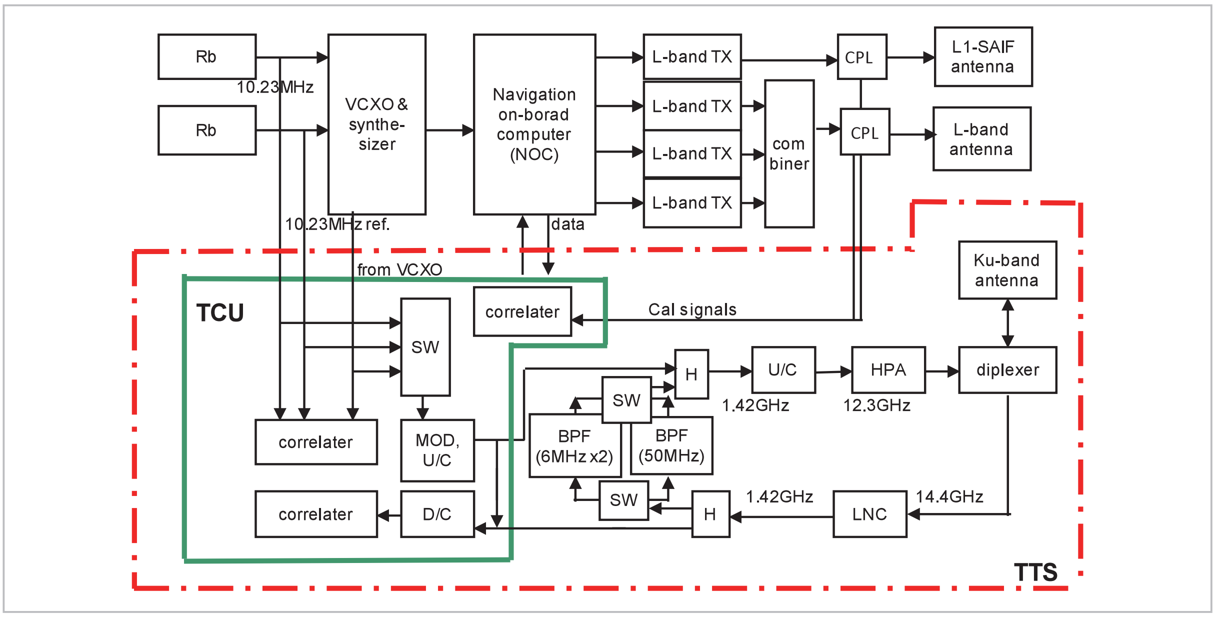

Fig.4 *Configuration of on-board equipments for navigation mission (Not including the redundant system)*

TTS, developed by NICT, is framed by the heavy-dashed-dotted line, and TCU (Time Comparison Unit) by the heavy-solid line.

successfully completing tests in combination with the satellite bus and transporting the satellite to the launch site in Tanegashima in May 2010, the TTS was launched on September 11, 2010.

Approximately three months after the launch, the initial function verification tests for the bus system and mission system are still being conducted (at the time of writing this paper as of September 2010), and the technical validation test are to be performed in cooperation with JAXA and AIST from December.

4.3 Ground segment development

The ground system is made up of a time management experiment station (TMS) used for time comparisons between satellites and the ground, and the time management components established in the monitoring stations. The outline is shown in Fig. 5.

The main TMS was established in NICT headquarters (Koganei-shi, Tokyo) which generates and maintains Japan Standard Time, and a sub-station was established in NICT Okinawa Subtropical Environment Remote-Sensing Center (Onna-son, Okinawa) where QZS is visible 24 hours per day. TMS has a Ku band signal transmission and reception device, a time comparison modem equivalent to the onboard TCU and a group of computors with various softwares. TMS Koganei has a Ku band parabola antenna of 1.8 m diameter and TMS Okinawa has a 3.7 m antenna, both can be driven to point all-sky. Time comparisons are constantly conducted between the two stations by performing two way satellite time and frequency transfer (TWSTFT).

JAXA has established four monitoring stations in Japan and five overseas ones for estimating satellite orbits and time by receiving L band signals. NICT has set up the TWSTFT function at the Sarobetsu station in Hokkaido and the Chichi-jima station in Bonin Islands, Japan and the Kauai station in Hawaii (United States) for time management of monitoring stations,. The two other JAXA monitoring stations in Japan are located in Koganei and Okinawa. Since time comparisons are conducted at these two stations as TMS, the times of five ground stations in total are managed with high precision utilizing two way method. In addition, the Kauai station is set up in NASA's Kokee Park Geophysical Observatory, midway between NICT headquarters and the United States Naval Observatory (USNO) and functions as a TWSTFT relay station between the United States and Japan.

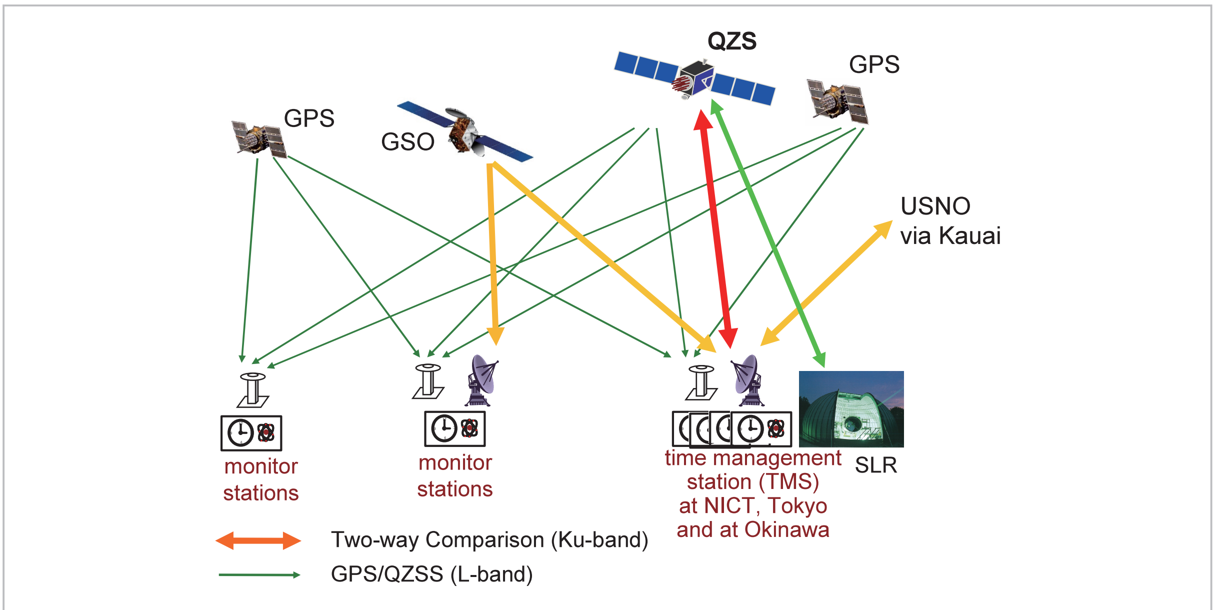

Fig.5 *Configuration of the ground system*

4.4 International relations

In order to coordinate radio interference with GPS, ensure interoperability, and establish overseas monitoring stations, the QZSS has been energetically managing the GPS/QZSS Technical Working Group since 2002 using the framework of the Japan-US GPS Meeting. For time management system, in order to coordinate the relationship between GPS time and QZSS time, the GPS QZSS Time Offset (GQTO) Interface Control Document (ICD)[8] was formulated in 2004 between NICT and USNO.

The International Global Navigation Satellite System Committee (ICG)[9] has been established under the United Nations in order to provide opportunity for coordination between multi-GNSS. In regard to time management, NICT has been participating in the timing task-force established within the working group D "Reference Frames, Timing and Applications (RFTA)" since 2009.

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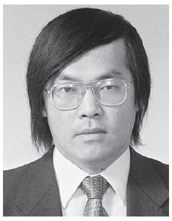

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