Development Status and Experimental Plan of Time Management System of Satellite Positioning System using QZSS

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INTRODUCTION

The 1st Quasi Zenith satellites (QZS-1) is planning to launch in summer 2010 at inclined geo-synchronous (Quasi Zenith) orbit for satellite positioning purpose. QZS System (QZSS) is developed as the satellite positioning system using three QZSs by Japanese four ministry and their institutes since 2003. This system uses a complement and an augmentation of the modernized GPS.

In this system, National Institute of Information and Communications Technology (NICT) is mainly in charge of the time management system. The time management system manages all of clocks of this system. We use the two way time and frequency transfer method for these time comparisons.

For the on-board system, we have developed the proto flight model (PFM). The time transfer subsystem (TTS) and the L-band transmission subsystem (LTS) were combined together for Navigation Payload tests, and then have been combined to the satellite bus for system proto flight test (PFT). The PFM of TTS was connected to the ground equipment for tests and the time difference was measured with two-way method to check its performance.

For the ground system, we developed the necessary software and have carried out tests including the interface with a master control station (MCS). The time management stations (TMS) have been built at Koganei, Tokyo, where UTC(NICT) is generated, and at Okinawa. Equiopments using two-way time and frequency transfer via communications satellite (TWSTFT) have been installed at monitoring stations in Hawaii, Sarobetsu, and Chichijima. Hawaii monitoring station will also work as a TWSTFT relay station between United States Naval observatory (USNO) and NICT.

QZSS

The idea for a satellite using quasi-zenith orbit was proposed by NICT in 1972[1]. This is an elliptical orbit with an inclination of about 45 degrees to provide a high elevation to users located in mid-latitude regions like a Japan. The project to study the use of satellite using quasi-zenith orbit has been proposed by the Federation of Economic Organizations.

In the first plan of the QZSS, the Japanese government and a Japanese company began to study the QZSS from FY2003, and was planning to launch three or four QZSs. Fig. 1 shows an example of the footprint of three satellites. In that case, the minimum elevation reaches 78 degrees in Tokyo, for example. It is, therefore, significant merit to both communications and positioning for users located in mid-latitude. The QZSS is developed as an integrated satellite service system for communications, broadcasting, and positioning for mobile users in specified regions of Japan from a high angle of elevation. The purpose of the satellite positioning system using QZS is to complement and augment the GPS. The experiments of the satellite positioning system using QZS will be conducted by the institutes concerned. Fig. 2 is a sample photograph of the orbit of a QZS viewed from the ground in Tokyo. At least one of two or more satellites located within the outer circle of buildings in the figure can service roads to an elevation of 70 degrees or more.

Thereafter, QZSS project was changed at 2006. This project of purpose is only positioning, and It will advance it by two stages. The 1st stage of QZSS is research and verify of technical and utilization by one satellite at 2010. The 2nd stage of QZSS is verify of positioning systems by three satellites.

The main parameter of QZS-1 is shown Table 1 and the image of the QZS-1 is shown in Fig.3 .

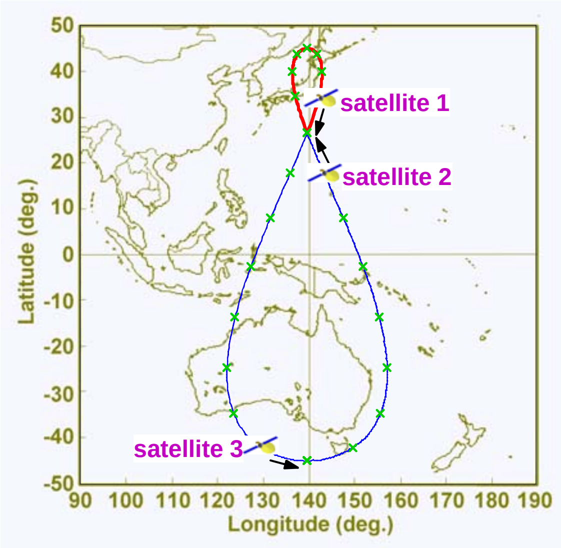

Fig. 1 Example of the footprint of the three QZSs.

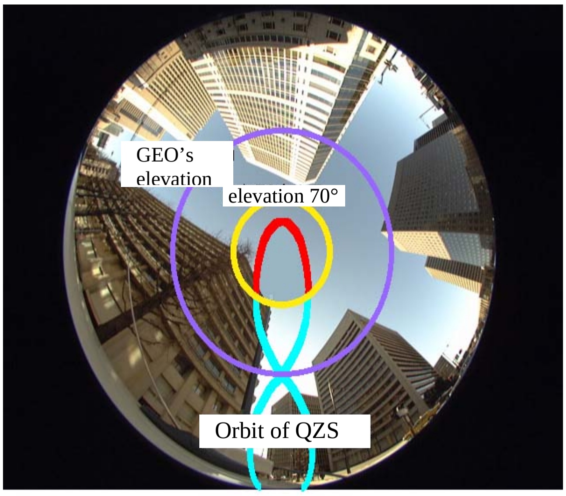

Fig. 2 Sample Photograph of orbit of QZS viewed from ground in Tokyo

Table 1 Main parameter of QZS-1

Mass	**Approx. 1,800kg (dry) (NAV Payload: Approx. 320kg)**
Power	**Approx. 5.3 kW (EOL) (NAV Payload: Approx. 1.9kW)**
Design Life	**10 years**

Fig. 3 Imege of QZS-1

POSITIONING SYSTEM

Fig. 4 is an overview of the positioning system of the QZSS. As the on-board system, The Japan Aerospace Exploration Agency (JAXA) is in charge of manufacturing the bus system and the LTS, and the NICT is in charge of the TTS.

As the ground system, the JAXA is in charge of manufacturing the satellite control station and the MCS and nine monitoring stations, the NICT is in charge of the TMS for the main and sub-stations and three monitoring stations of time management part. Each organization is in charge of other systems as well.

The positioning system of QZSS has transmission bands that shows in the Table 2.

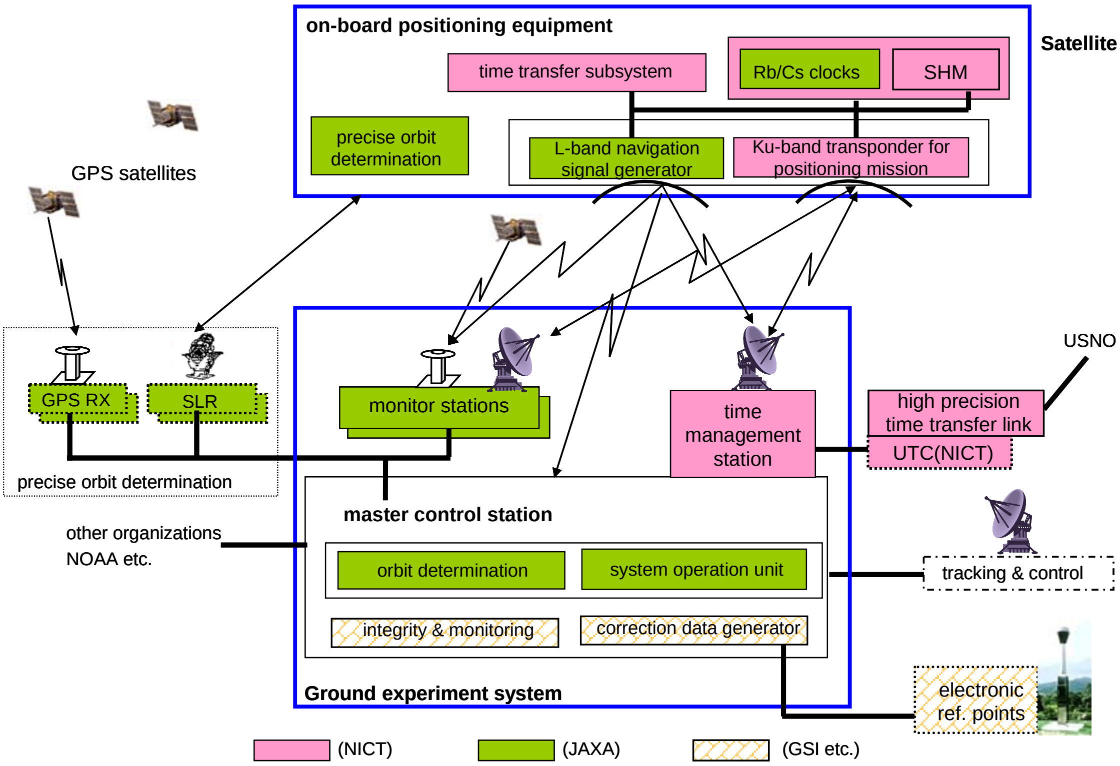

Fig. 4 Overview of positioning system of QZSS

Table 2 Positioning system of QZSS has transmission bands.

Signal Name	*Center Frequency*	*Minimum Signal Strength*	*Notes*
L1C	1575.42MHz	-163.0 dBW (Data) -158.2 dBW (Pilot)	■ GPS interoperable signals ■ Full compatibility and interoperability with existing and future modernized GPS signals ■ These signals include other GNSS systems almanac such as GPS
L1-C/A	1575.42MHz	-158.5 dBW	
L2C	1227.6MHz	-161.0 dBW	
L5	1176.45MHz	-157.9 dBW (I-ch) -157.9 dBW (Q-ch)	
L1-SAIF*	1575.42MHz	-161.0 dBW (Total)	■ Full compatibility with GPS-SBAS ■ Wide Area DGPS, Integrity
LEX	1278.75MHz	-156.0 dBW (Total)	■ Higher data rate (2kbps) ■ Compatibility with Galileo E6

*** L1-SAIF: L1-Submeter-class Augmentation with Integrity Function**

NICT EXPEROMENTAL PLAN

The experimental plan by the NICT as follows ;
- Precise time comparison between the QZS (SV clock) and the TMS (UTC(NICT)). Target accuracy is few ns.
- Measurement characteristics of frequency and frequency stability of on-board atomic clocks. Target accuracy is few ps.
- Time comparison between TMS and monitoring stations by communications satellite and bent pipe of QZS. Target accuracy is few ns@1s.
- Supply of following navigation message source ;
  - GPS to QZSS time offset (GQTO)
  - Difference between UTC(NICT) and QZSS time
- Comparison between on-board atomic clocks. Target accuracy is few ns@1s.
- Precise delay measurement of on-board L-band signal generation and transmitter equipments. Target accuracy is few ns@1s.
- Ranging between QZS and TMS. Target is few 10cm.
- Time dissemination by LEX signal. Target is few 10ns@1s.

BASIC CONCEPT OF QZSS TIME

The QZSS is a complemental system of the GPS. The time offset between QZSS time and GPS time (GQTO) should be monitored precisely, and be broadcasted to users via the navigation message of the QZSS to assure the interoperability between both systems. So, the time bias between both system should be measured precisely. The QZSS time (QZSST) is defined at a particular point in the measurement system of TMS at Koganei and hard-wired to UTC(NICT). The QZSST is planned to be an ensemble time in the future.
How to get time bias or offset? between UTC(NICT) and GPS time as shown in the following and Fig. 5.
① Calculate two data that both time comparison data between UTC(NICT) and UTC(USNO) by using TWSTFT method and observation data of UTC(USNO) – GPS Time . Since there is no common visible GSO satellite between NICT and USNO, a relay station is required to link them.
② Calculate GPS observation data based on UTC (NICT) at the TMS.

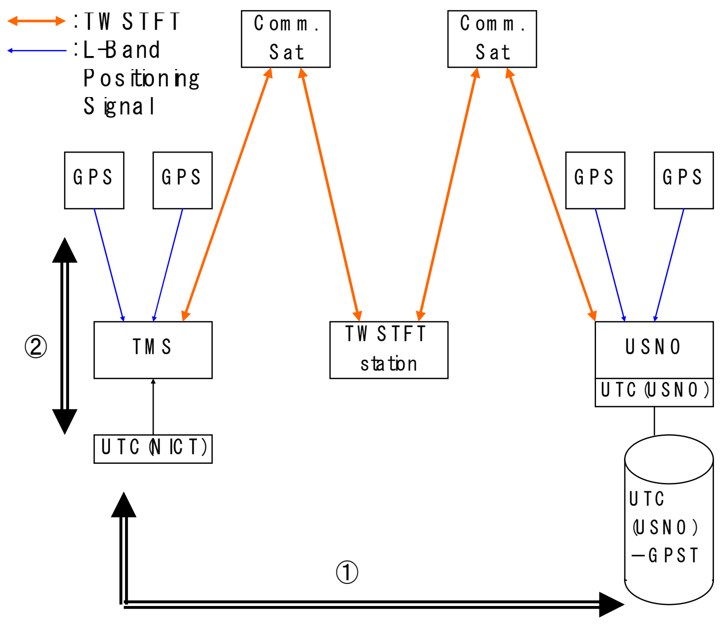

Fig. 5 Overview of how to get time offset between UTC(NICT) and GPS-Time.

DESIGN OF THE TTS

Functions of TTS

The block diagram of the on-board equipment for the positioning mission is shown in Fig. 6. The part surrounded by the red chain line is TTS and therein the green solid line surrounds Time Comparison Unit (TCU).

The receiving part of the Ku-band communication system consists of a Ku-band horn antenna and a low noise converter (LNC), which converts 14.4 GHz RF to 1.42 GHz IF. The transmission part consists of an up converter (U/C), which converts the IF to 12.3 GHz RF, a high power amplifier (HPA), whose maximum output is over 4.5 W, and the antenna. A single antenna of 10 cm diameter is used for both receiving and transmission by making use of a diplexer.

Signals to be compared are input to TCU in IF. Three correlators in TCU compare each signal with the replica to carry out time comparison. In bent pipe experiments, signals to/from the two BPFs are used.

The main functions of TTS are as follows;

(1) to measure the time and frequency comparison between an on-board clock and the atomic clocks of TMS by using two-way technique in Ku-band. This technology applied between a satellite and the ground was first demonstrated in the ETS-VIII experiment from 2008 [2]. Up to four channels are processed for ground-to-satellite time comparison. Typically two channels come from a TMS and one channel from another TMS, and two channels may be used for another experiment.

(2) to superpose data such as telemetry on the Ku-band downlink signal, and to demodulate the uplinked data.

(3) to measure the time difference between on-board clocks (two rubidium frequency standards) and the QZS reference clock (generated from the VCXO).

(4) to carry out TCU instrumental delay calibration.

(5) to measure the delay time between L1 (L1 C/A and L1-SAIF [3]), L2, and L5 signals.

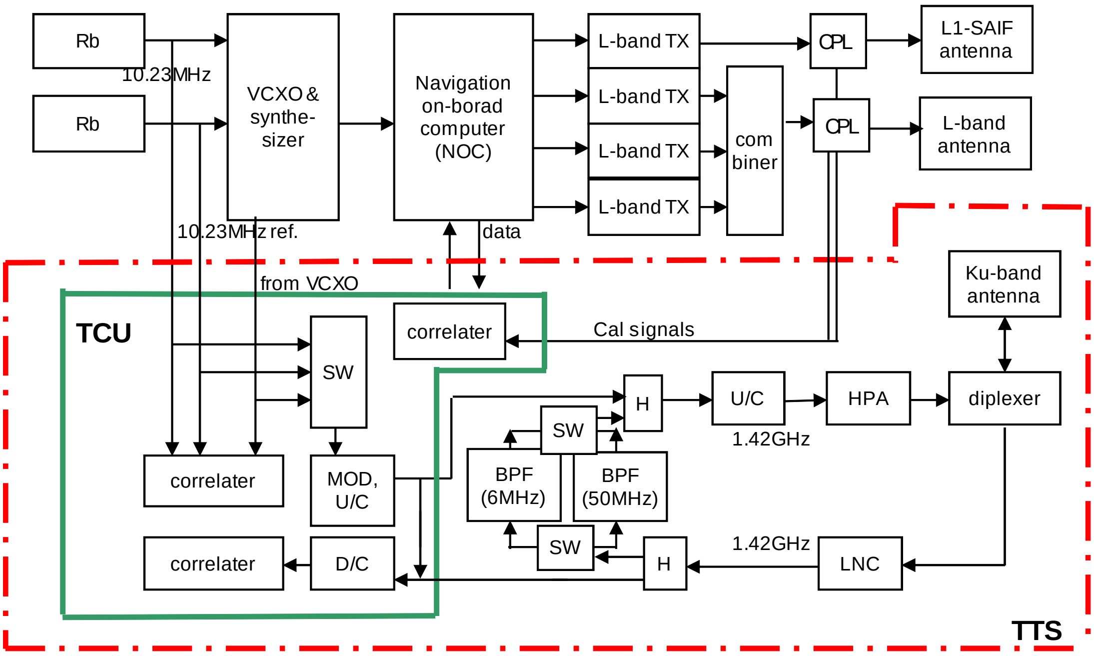

Fig. 6 Block diagram of on-board equipment for positioning system

Performance of the TTS

To attain a QZS-to-TMS two-way time transfer precision for random component of 0.3 ns and bias component of 1.0 ns by using only code phase, we set the pseudo-random noise (PN) code rate as 10.23 Mcps, and the required C/No as 50 dBHz. The correlators used for QZS-TMS time transfer also have ability of carrier phase processing, which is useful for precise frequency comparison.

With regard to the communication system, the G/T is expected to be better than -13dB/K and the maximum equivalent isotropically radiated power (EIRP) is over 12.2 dBW. The Ku-band antenna has a global beam. Based on a budget link assessment, 10 W uplink power is enough for a 1.8 m diameter antenna for a ground station.

Up link and down link data of 2kbps/ch is superposition and modulates the PN code by binary phase shift keying (BPSK).

Bent pipe Function

In TWSTFT, a communications geo-stationary satellite is usually used. But we intend to have an experiment using the QZS's non-GSO, which is inclined around 45 degrees, to extend the possibility of the TWSTFT technology. TTS has two types of bent pipe (through repeater) function as shown in Table 3 for this experiment.

One is the wide-band bent pipe with 50 MHz bandwidth, where the 10.23 Mcps signals are converted for a traditional TWSTFT. It uses the same frequency band as that of the QZS-TMS two-way time transfer.

Another is the narrow-band bent pipe (BP) with double 6 MHz bandwidths separated by 20.46 MHz, where the 2.046 Mcps signals are converted. This is a new method to enable more precise time transfer. In the scheme, it is equivalent for the usage of the wide bandwidth because the group delay is determined by using the double edges separated by 20.46 MHz. The cost of an expensive satellite transponder can be saved without degrading its time comparison precision. While the precision of the conventional method with 2.5 MHz bandwidth and 55 dBHz C/No is estimated as 400 ps, this proposed method achieved the precision of 147 ps with double 3 MHz and 40 dBHz [4]. Since its spectrum peaks is located not to interfere in the regular signal, simultaneous operation of QZS-TMS two-way time transfer experiment and bent pipe experiment is possible (see Fig. 7).

Table 3 Two types of bent pipe function

	wide band BP	narrow band BP
Bandwidth (99% power)	50 MHz	6 MHz x 2 (20.46 MHz separated)
Chip rate	10.23 Mcps	2.046 Mcps x 2 BOC(10,2)
spectrum overlap with regular signal	overlapped	not overlapped
comment	conventional	equivalent to a wideband

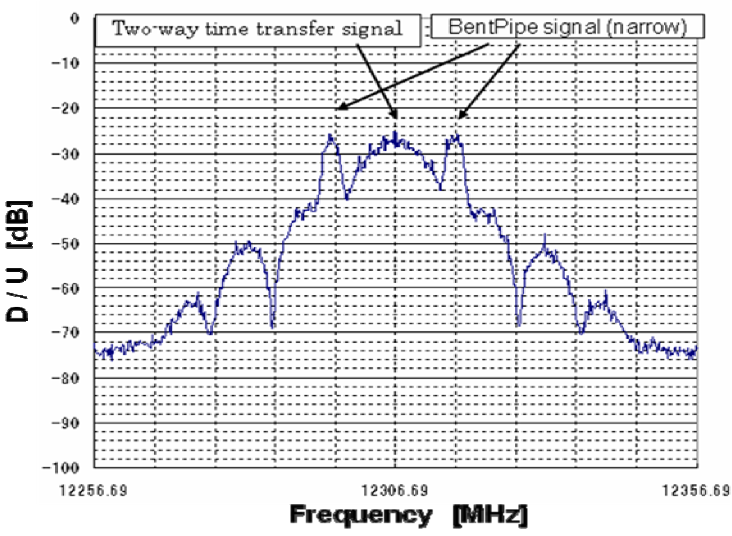

Fig. 7 Spectrum of narrow band BP signals and QZS-TMS two-way time transfer signal.

GROUND FACILITIES

TMS

We will set TMSs at Koganei, Tokyo (N35.5o, E139.5 o) and at Okinawa (N26.5 o, E127.9 o). The QZSS time is managed based on UTC(NICT) which is maintained at Koganei using 18 cesium standards and three H-maser frequency standards. On the other hand, from Okinawa, a QZS is visible above 5 degrees of elevation for 24 hours. TMS Koganei has a 1.8 m antenna and TMS Okinawa has a 3.7 m antenna. Each TMS has a hydrogen maser frequency standard and a modem having almost same function as the on-board TCU. Two-way measurement between a QZS and a TMS is carried out by using this modem. The time of TMS Okinawa will be linked to TMS Koganei by TWSTFT via a commercial Ku-band communication GSO satellite. In each TMS, the indoor equipments are put in a temperature controlled room.

Monitoring stations

Nine monitoring stations are installed in and out of Japan to determine the orbit of a QZS.
NICT will put TWSTFT function on two domestic stations in Sarobetsu, north-most place of Japan, and Chichijima, one of the Bonin Islands. One overseas monitoring station is placed in Hawaii for time link with TMS.
Hawaii monitoring station is installed in Kokee Park Geophysical Observatory (KPGO) on Kauai island. Hawaii is a good place both for well scattered configuration of monitoring stations and for TWSTFT relay station between the USNO and NICT. The USNO and the NICT have begun to install antennas and equipments there.

CURRENT STATUS OF THE TIME MANAGEMENT SYSTEM

On-board equipments

Manufacturing and equipment tests[5] of the TTS were finished. The examination of the TTS installed in the satellite structure were finished, too.Hereafter, the satellite is transported to Tanegashima Space Center that is the launching site and will be examined.

Ground facilities

The installation and the test of equipment were almost completed. The radio licenses for the monitoring stations and the TMSs for communications satellite will be ready soon. It is scheduled to be manufactured in a transportable station for QZS-1 at this fiscal year.

Operation of experiment

The detailed plan and the operation procedure of the NICT experiment will be made. The method of the time dissemination experiment is being examined.

CONCLUSIONS

The time management system of QZSS, the experimental plan, and current status were explained. Now, the preparation for the launch of the QZS-1 is carried forward. It is expected that a good result is achieved in the early stage after the launch.

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