Development of the Quasi-Zenith Satellite System and High-Accuracy Positioning Experiment System Flight Model

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Abstract

The Quasi-Zenith Satellite System (QZSS) is a positioning/navigation/timing (PNT) system for the Eastern Asia and Oceania regions. It is used to supplement and enhance the updating of the Global Positioning System GPS [1)] . It consist of three satellites, QZSS improves the visibility of the satellite for terrestrial users in the low and medium altitude areas. The first satellite of QZSS was developed by the governmental sector composed of four ministries/agencies, research institutions and JAXA (Japan Aerospace Exploration Agency). NEC was in charge of fabrication of the Navigation Payload (NP) and the entire High-Accuracy Positioning Experiment System (HIAPEX) [2)] carried by the satellite. Navigation Payload (NP) has already completed the satellite system testing and it was launched at the Tanegashima Space Center in September, 2010. This paper describes the results of the protoflight test (PT) of Navigation Payload (NP) and the navigation system test (NST) of the terrestrial system equipment at the master control station (MCS) and monitoring station (MS).

Keywords

satellite positioning system, Quasi-Zenith Satellite System (QZSS)
Navigation Payload (NP), Protoflight test (PFT)

1. Introduction

The Quasi-Zenith Satellite System (QZSS) is the first satellite positioning system of Japan and it is composed of space-based and ground-based modules. **Fig. 1** shows the system configuration of QZSS. The space segment consists of three Quasi-Zenith Satellites (QZS) and at least one of these is always located on the zenith above Japan.

Since QZSS utilizes the QZS at a high elevation angle, a seamless positioning service is possible by improving the positioning availability in urban canyons and intermountain areas. **Fig. 2** and **Fig. 3** show the orbits and terrestrial trajectories of the QZSS satellites.

The first QZS (QZS-1) has the appearance as shown in **Fig. 4** . Its attitude is controlled so that the L-band antenna points towards the center of the earth. **Fig. 5** shows the positions of the tracking and communication stations (TCS) and **Fig. 6** shows that of the monitoring stations.

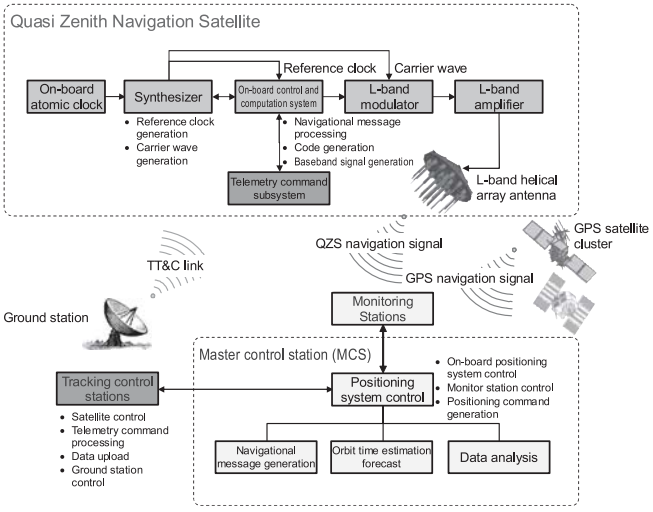

Fig. 1 System configuration of QZSS.

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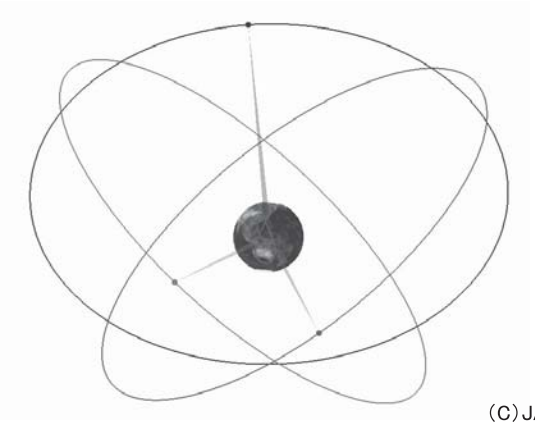

Fig. 2 Orbits of QZSS.

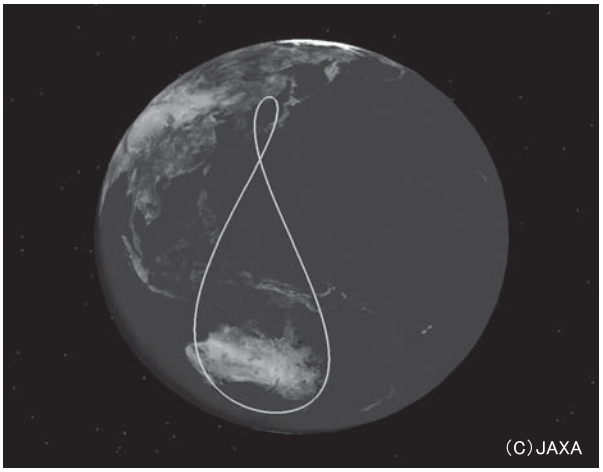

Fig. 3 Terrestrial trajectory of QZSS.

Fig. 4 External view of QZS-1.

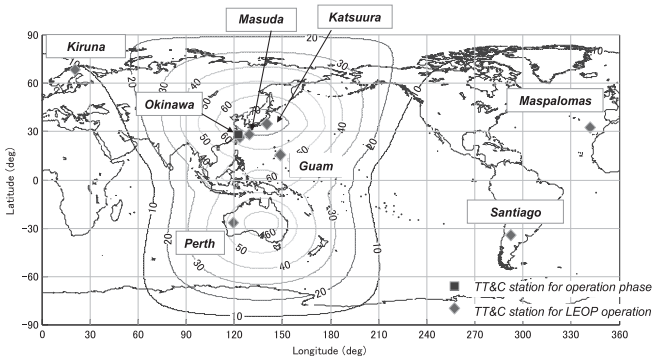

Fig. 5 Tracking and Communication Stations (TCS).

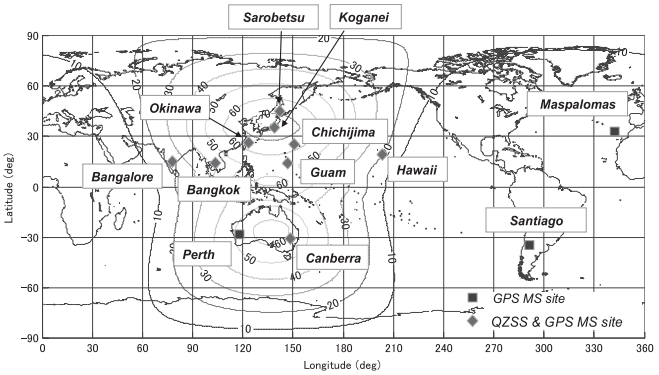

Fig. 6 Monitoring Stations (MS).

2. Navigation Payload (NP)

Fig. 7 shows a block diagram of the Navigation Payload (NP) of the satellite. NP has the function of transmitting six QZS signals (L1-C/A, L1C, L2C, L5, LEX and L1-SAIF) and adopts complete redundancy. **Table 1** shows the specifications of the QZS signals.

The satellite reference clock is generated by the time keeping system (TKS) which is composed of the rubidium atomic frequency standard (RAFS), time keeping circuit (TKC), synthesizer (SYNTH) and navigation on-board computer (NOC). Each TKC unit incorporates an oven voltage controlled crystal oscillator (OVCXO) with excellent phase noise characteristics. OVCXO controls the oscillation frequency according to the signal from NOC so that the frequency tracks the RAFS with good long term stability. SYNTH outputs the satellite reference clock and L-band carrier waves in synchronism with

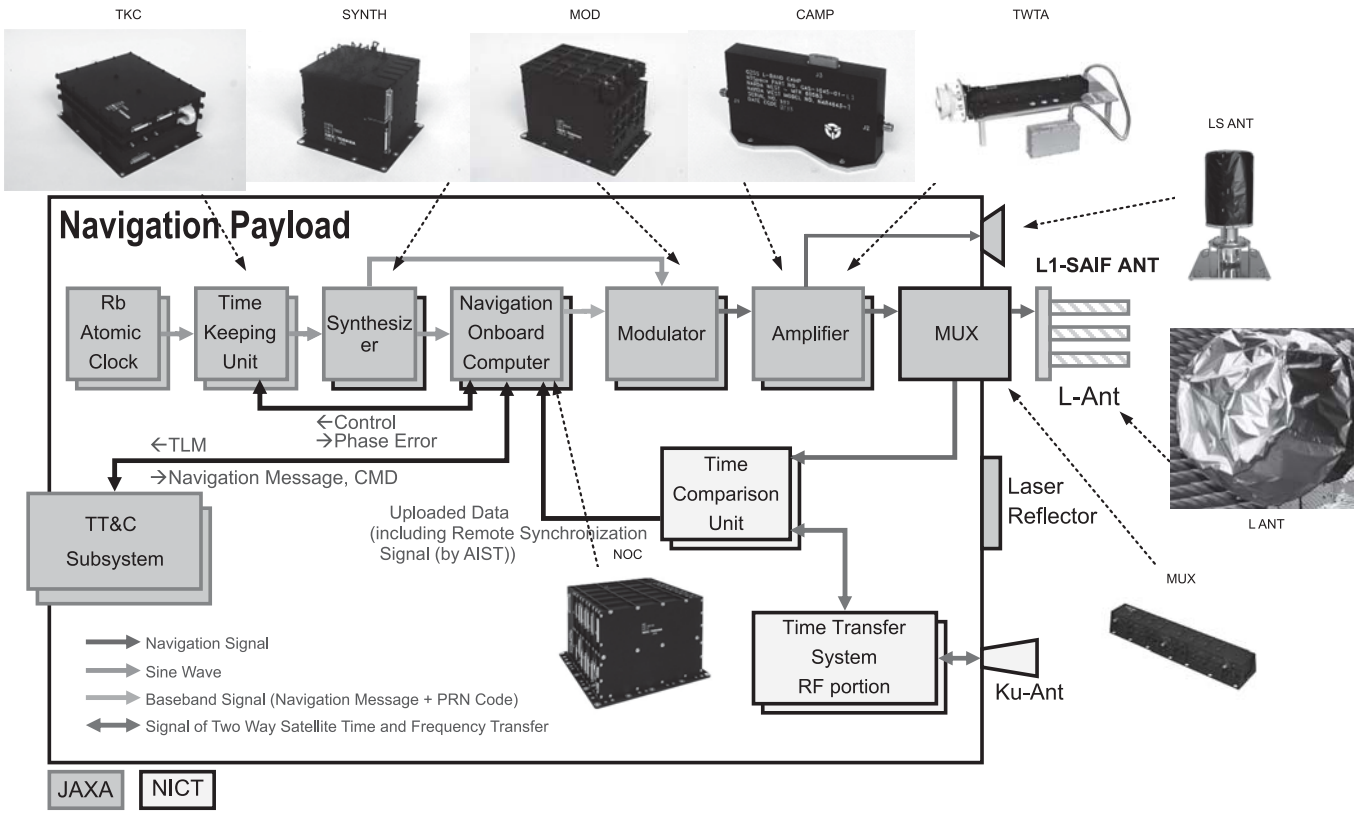

Fig. 7 Block diagram of NP.

Table 1 QZS signal specifications.

Signal	Channel	Center Frequency (MHz)	Modulation Method
L1C	Data Channel (I-Channel)	1575.42	BOC(1,1)
	Pilot Channel (Q-Channel)		
L1-C/A	I-Channel		BPSK(1)
L1-SAIF	-		
L2C	-	1227.6	BPSK(1)
L5	I-Channel	1176.45	QPSK(10)
	Q-Channel		
LEX	-	1278.75	BPSK(5)

the TKC clock, and the modulator (MOD) modulates the L-band carrier waves using the baseband signal containing the navigation message generated by NOC. The modulated signals are amplified by the variable-gain control amplifiers (CAMPs) and traveling-wave tube amplifiers (TWTAs). The positioning signals from the TWTAs are then multiplexed at the multiplexer (MUX). The L1-C/A, L1C, L2C, L5 and LEX signals multiplexed by MUX are radiated from the 19-element helical array antenna, the pattern of which is formed so that the ground reception levels in the service area are uniform. The L1-CSAIF signal is radiated from an L-band horn antenna.

3. Protoflight Test (PFT)

Photo shows the external view of an NP mounted on a dummy plate that simulates the satellite structure. The dummy plate is thermally controlled so that the equipment temperature is within the tolerated temperature range. **Fig. 8** shows the flow of PFT on NP. TVT checks the resistance against the orbit en-

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vironment and EMC checks the electromagnetic compliance in the satellite. After FPT, the navigation system test (NST) is conducted by using the actual MS and TCS in the

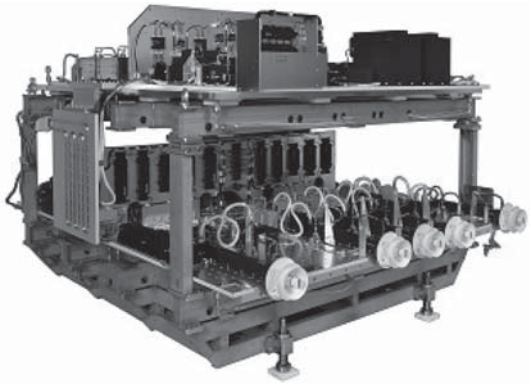

Photo External view of NP.

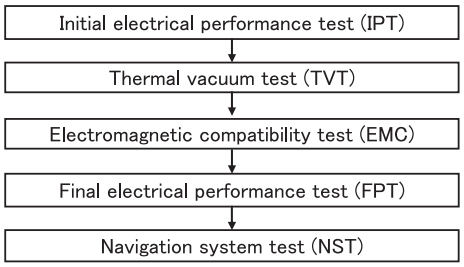

Fig. 8 Test flow.

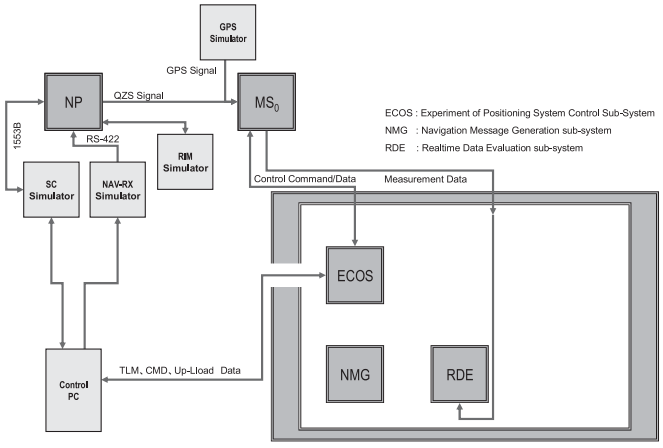

Fig. 9 Configuration of navigation system test.

configuration shown in **Fig. 9** . The devices common to satellites, namely the satellite controller (SC), remote interface module (RIM) and navigation receiver (NAX-RX) are replaced by simulators. By applying the QZS signals generated by NP and QZS signals generated by the GPS simulator to MS and evaluating the data obtained by MS using a real-time data evaluation sub-system (RDE), we were able to confirm that NP has the function and performance required as a navigation system. NP was mounted on the actual satellite after NST.

4. Protoflight Test (PFT) Results

Table 2 shows the results of PFT including the navigation

Table 2 Results of NP protoflight test.

Parameter			Specification	Unit	Data
Spurious Siganal		L1	-60 max	dBc	-68
		L2			-63
		L5			-65
		LEX			-70
		L1-SAIF			-69
Modulation Performance	Amplitude	L1	1.0 max	dB (p-p)	0.1
		L2			0.1
		L5			0.1
		LEX			0.1
		L1-SAIF			0.1
	Phase	L1	+/- 5	deg	-1.4～+1.4
		L2			-0.9～+0.8
		L5			-0.7～+0.8
		LEX			-1.0～+1.1
		L1-SAIF			-0.3～+0.3
Group Delay Response		L1	16 max @21MHz	ns (p-p)	9
			28 max @25MHz		15
		L2	25 max @21MHz		17
			41 max @25MHz		30
		L5	19 max @25MHz		8
		LEX	17 max @25MHz		6
			42 max @42MHz		22
		L1-SAIF	16 max @21MHz		11
			28 max @25MHz		18
Psuedo Range Variation (Ref : L1C/A)		L1CD	100 max	m	-0.08
		L1CP	100 max	m	-0.30
		L2CM	100 max	m	-0.37
		L2CL	100 max	m	-0.19
		L5I	100 max	m	-0.01
		L5Q	100 max	m	0.06
		L1-SAIF	100 max	m	1.80

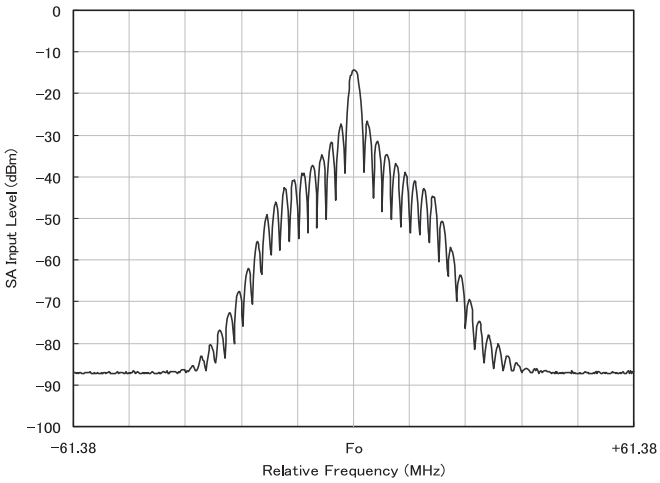

Fig. 10 Modulation spectrum (Representative: L1).

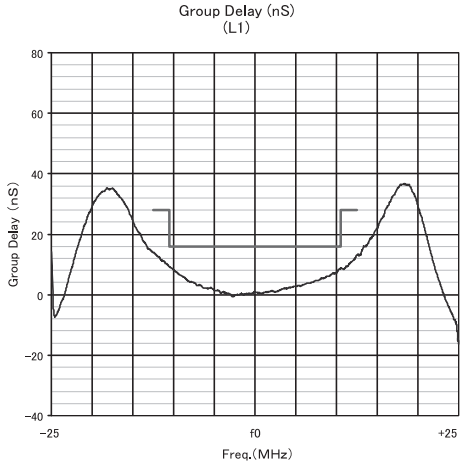

Fig. 11 Group delay time deviation characteristic (Representative: L1).

system test (NST) on the Navigation Payload (NP). With fairly favorable test results, we were able to confirm the required function and performance. We also confirmed that the signals transmitted by NP comply with the QZS interface specifications (ISQZSS) [3] . The modulation spectrum and group delay time deviation characteristic are shown respectively in **Fig. 10** and **Fig. 11** , and the radiation pattern of an L-band antenna is shown in **Fig. 12** .

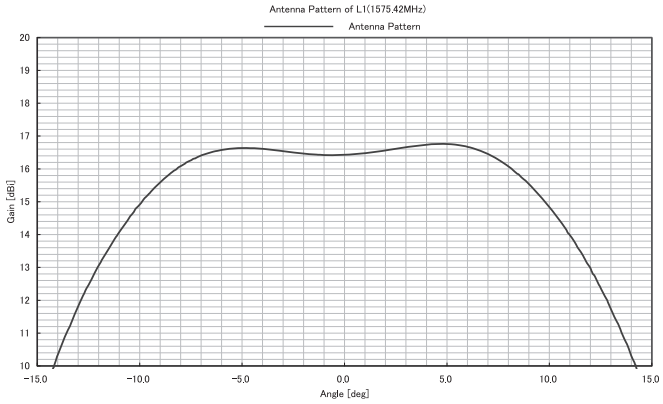

Fig. 12 L-ANT antenna radiation pattern (Representative: L1).

5. Conclusion

We have confirmed that NP meets all of the PFT specifications by including NST.

QZS-1 has already completed the satellite system testing and it was launched from the Tanegashima Space Center in September, 2010 for the in-orbit testing to be performed.

In closing this paper, we would like to express our gratitude to the National Institute of Information and Communications Technology (NIST) and the National Institute of Advanced Industrial Science and Technology (AIST) for their kind guidance throughout this project.

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