# Measuring Multipath Error of a Pseudo Quasi-Zenith Satellite

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**Abstract**

Japan has been investigating a new satellite based positioning system called Quasi-Zenith Satellite System (QZSS). Since the improvement of positioning availability in urban area is one of the most important advantages of the QZSS, multipath mitigation is a key factor for the QZSS positioning system. Therefore, Japan Aerospace Exploration Agency (JAXA) and GNSS Inc. have commenced the R&D of a pseudolite, which transmits the next-generation signal such as BOC(1,1), in order to evaluate the effect of multipath on the new signal. A prototype BOC pseudolite was developed in 2005, and ground tests showed a capability of generating proper pseudorange. Also, preliminary flight experiments using a pseudo quasi-zenith satellite, a helicopter on which the pseudolite is installed, were conducted in early 2006, and the BOC-type correlation function was monitored in real time.

**Keywords:** Pseudolite, BOC, Quasi-Zenith Satellite, Helicopter, Multipath

## 1. Introduction

Japan has been investigating a new satellite based positioning system called Quasi-Zenith Satellite System (QZSS). The service area is limited to Japan and nearby countries since the QZSS consists of Quasi-Zenith satellites and geostationary satellites. The orbit of QZS is designed so that the users in Japan can observe the satellite at nearly zenith angle. Therefore, the QZSS is expected to enhance the availability of positioning in urban/mountainous area (Kawano et al., 2004). The signal design of QZSS is under investigations, however, a compatible signal with GALILEO and modernized GPS would be most appropriate. The purpose of this research is to develop a pseudolite which transmits the next-generation signal, such as BOC(1,1), and to demonstrate the performance of multipath mitigation since the BOC(1,1) is supposed to be less susceptible to multipath effect than BPSK(1). Also, a multipath mitigation technique suitable for the new signal will be investigated.

The aviation group of JAXA and GNSS Technologies Inc. have been conducting the research of aerial pseudolites for the future airship/UAV-based positioning system, and carried out several flight experiments using a helicopter (Petrovski et al., 2001, Tsujii et al., 2002, 2004, 2004). In this research, the helicopter hovering above the users at nearly zenith angle is considered as a Pseudo Quasi-Zenith satellite in the experiments. Figure 1 is the conceptual figure of the flight experiment using the Pseudo-QZS.

In order to use the pseudolite measurements for positioning, the position of the pseudolite antenna underneath the helicopter has to be known. Therefore, a DGPS/INS is installed and the position/attitude information of the helicopter is used to compute the pseudolite antenna position (pseudolite ephemeris). Also, a rubidium clock is installed as a frequency reference.

In fiscal year 2004, a prototype pseudolite was developed and flight experiments were conducted in March 2005 (Tsujii et al., 2005). Although the pseudolite signal was similar to GPS, the data rate was variable up to a thousand bps. As results, the capability of data modulation up to 1000 bps, the pulsing function, and the ranging precision comparable to GPS were demonstrated. In fiscal year 2005, a new pseudolite, which transmits BOC(1,1) signal as well as C/A, was developed, and some preliminary tests to evaluate the multipath effect on BOC and CA code were conducted.

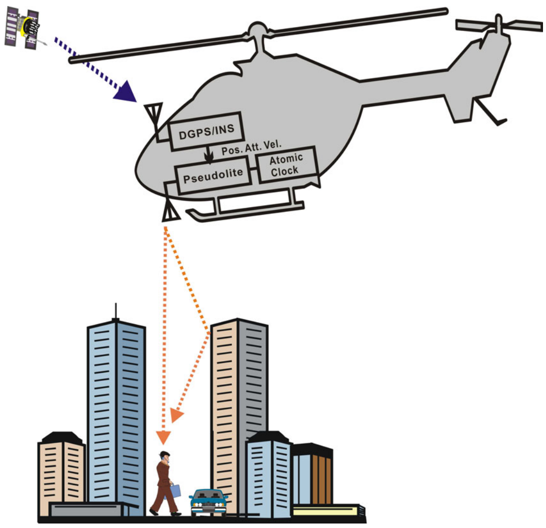


Figure 1 Image of the QZSS flight experiment

## 2. Experimental Systems

### 2.1 BOC/CA Pseudolite

By adding a channel which generates BOC(1,1) code to the existing C/A code pseudolite, a BOC/CA two channel pseudolite was developed. Figure 2 shows the picture of our new pseudolite and Figure 3 shows the concept of pseudolite/receiver system. All functions of the existing pseudolite, such as the pulsing, high data rate modulation, etc., were equipped. Both BOC(1,1) and C/A were generated based on the same rubidium clock and combined before transmitting. Since the BOC and C/A signal propagate in the same path, the multipath error dependent on the spreading code is expected to be seen.

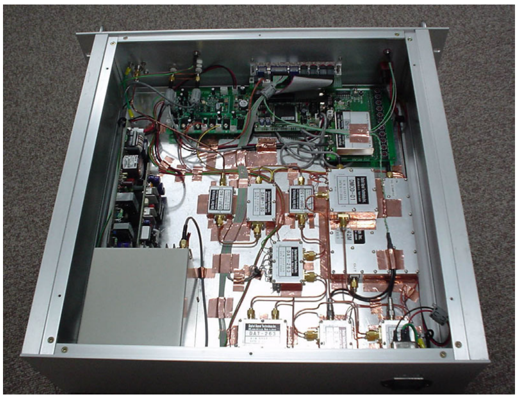

Figure 2 Picture of BOC/CA pseudolite

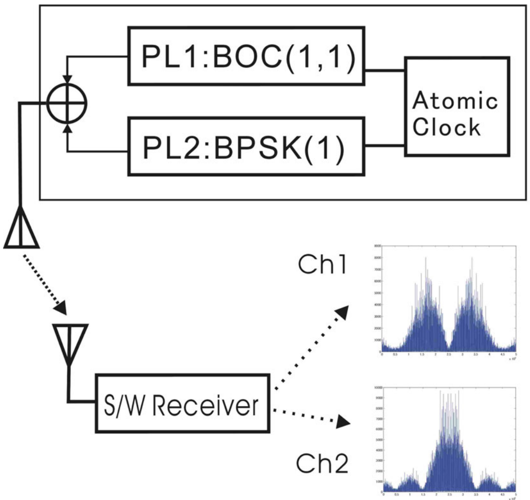


Figure 3 Two channel pseudolite and S/W receiver

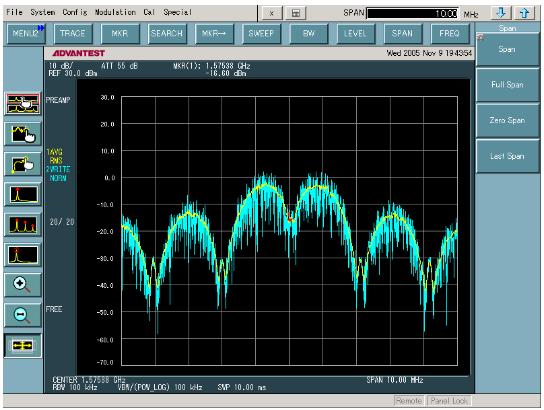


Figure 4 Power spectrum of BOC signal

The power spectrum of BOC signal is shown in Figure 4. Two peaks on either side of the center frequency of L1 are clearly seen. Also, we processed the Intermediate Frequency data by an in-house receiver software. The IF data were collected by using an off-the-shelf software receiver, NordNav R-30. The sampling frequency was 16.3676MHz, and the intermediate frequency was 4.1304 MHz. A result of BOC code and frequency search in acquisition phase is shown in Figure 5. A sharp peak was clearly seen and the acquisition was correctly performed. Figure 6 shows a BOC correlation function in tracking phase. Typical three peaks were seen. Also, output of In-phase and Quadrature channels are shown in Figure 7. The navigation data bits were correctly decoded.

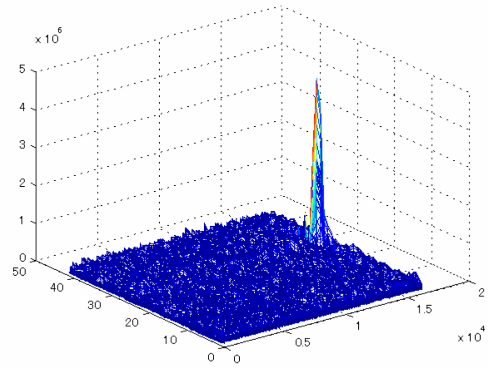


Figure 5 BOC code and frequency search in acquisition

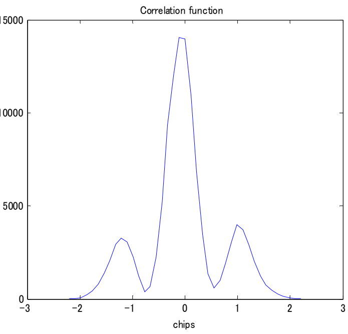


Figure 6 BOC correlation function in tracking

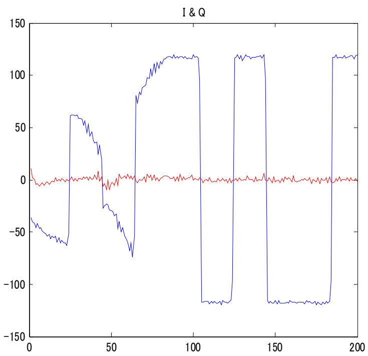


Figure 7 Output of I and Q channel

## 2.2 Airborne System

The pseudolite was installed in a cabin of the JAXA's experimental helicopter MuPAL-e (Mitsubishi MH-2000A) as shown in Figure 8. The pseudolite antenna underneath the helicopter is shown in Figure 9.

A DGPS/INS, which is one of standard equipments of MuPAL-e, was also installed and its data were used to compute the pseudolite ephemeris in the off-line analyses. Before conducting the flight experiments, electromagnetic interference tests were carried out and it was demonstrated that the pseudolite signal did not affect the GPS receiver and other equipments of the MuPAL-e.

Figure 8 JAXA's experimental helicopter MuPAL-e and pseudolite installed in the cabin

Figure 9 Pseudolite antenna underneath the helicopter

## 2.3 Receiver System

Since generic GPS receivers are not able to track the signal of the high data rate pseudolite, NordNav R25/R30 software receivers were used in the experiment. The software of R25/30 receiver was customized to track the pseudolite signal modulated by high data rate navigation message. Figure 10 shows the block diagram of the receiver system. There are two sets of receiver systems, which belong to the reference and rover station, respectively. The GPS/Pseudolite signal received at the antenna is split to the software receiver and the Ashtech ZXtream receiver. The ZXtream receiver records GPS L1/L2 measurements for reference. The GPS/Pseudolite IF signals digitized by the R-25/30 receiver were recorded by PC. Figure 11 and 12 are pictures of the base station and the rover station, respectively.

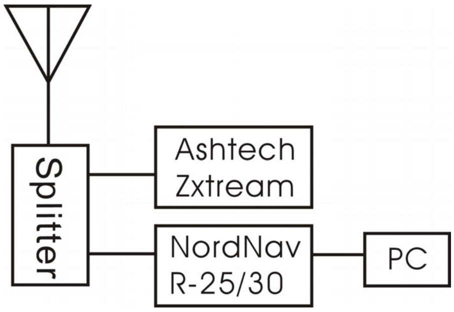


Figure 10 GPS/Pseudolite receiver system

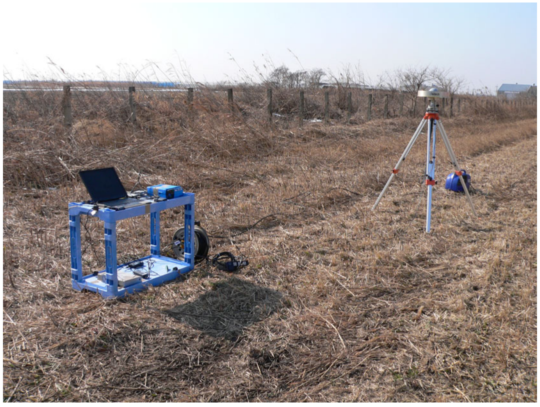

Figure 11 GPS/Pseudolite base station

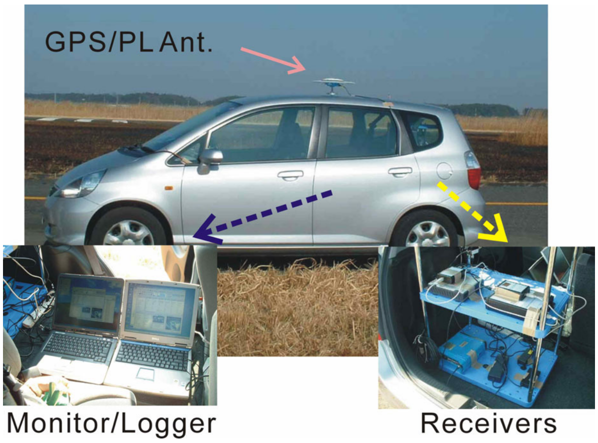


Figure 12 GPS/Pseudolite rover station

## 3. Test results

The flight experiments were conducted at Ryugasaki Airfield, Ibaraki, Japan, in January 2006. The helicopter made hovering at the altitude of 500-1300 ft, as well as circling and level flight as shown in Figure 13. First, Signal acquisition and tracking tests were carried out in both static and kinematic cases. Then, multipath measurement tests were performed in which a station wagon was used as a reflector. The rover antenna was moved from the roof to the bonnet of the rover so as to receive reflected signals. Figure 14 shows the test fields and the setting of multipath measurement.

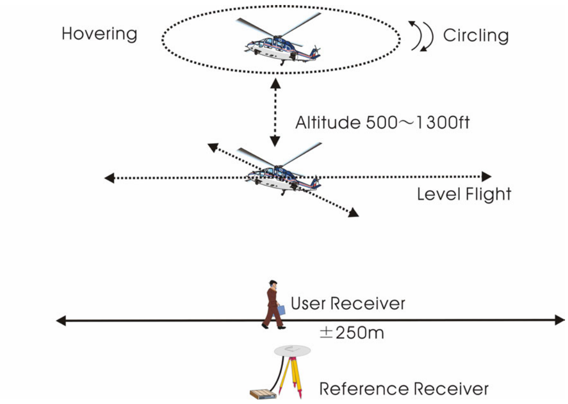


Figure 13 Configuration of flight experiment

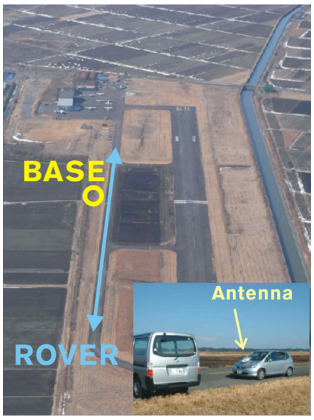


Figure 14 Test field and multipath measurement setting

Before starting IF data logging, the pseudolite signal receiving status were verified by monitoring Nordnav software receiver's output. The measured pseudorange, ADR, C/N$_0$, etc. were shown on the screen of PC. Also, the correlation function of BOC and CA code were seen in real time as shown in Figure 15. PRN 33 and 34 were assigned to BOC and CA channel respectively in these tests. In the multipath measuring tests, we tried to see the deformation of correlation function due to multipath. However, it was difficult since there was no long range multipath in the test environment enough to cause the deformation.

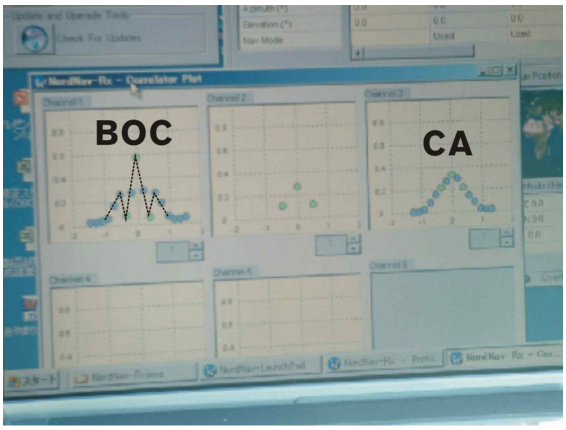


Figure 15 Correlation function monitored by R-30 receiver

In the off-line analysis, the recorded IF data were replayed by the NordNav receiver, and the pseudorange and carrier phase measurements were obtained. The standard correlator with one-chip spacing were used to track both BOC and CA signals. The difference between BOC and CA pseudorange would give the information of multipath since BOC and C/A signal propagated in the same path and other error such as tropospheric error and PL/Receiver clock error cancelled.

Figure 16 gives the variation of helicopter's altitude and the distance of rover from the base station in a multipath measurement test.

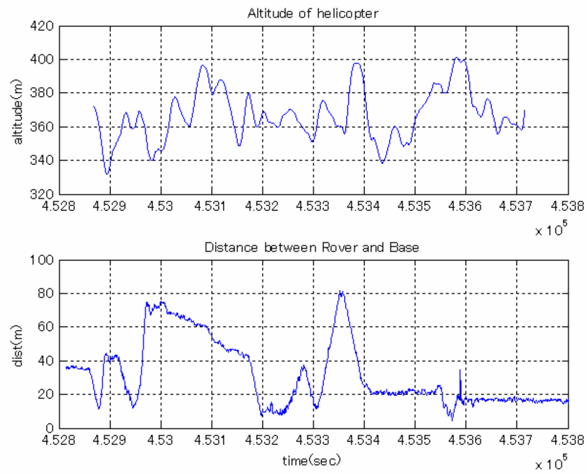


Figure 16 Altitude of helicopter (top) and distance between rover and base station (bottom)

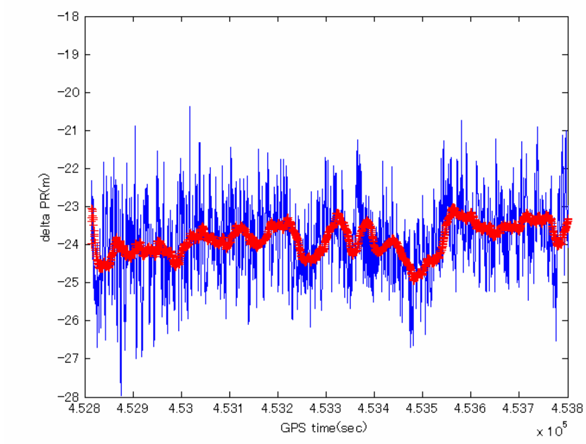


Figure 17 Difference of pseudorange (BASE)

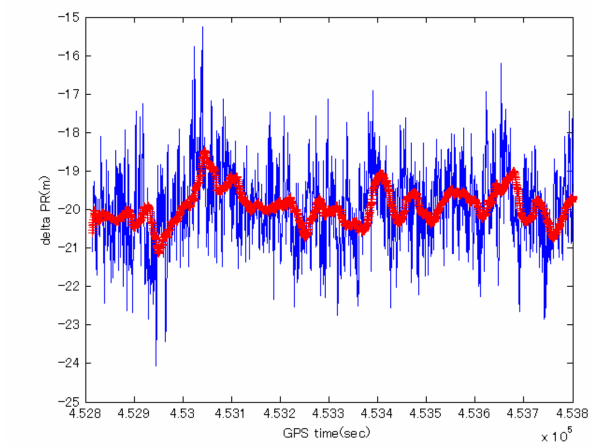


Figure 18 Difference of pseudorange (ROVER)

Figure 17 and 18 show the difference of pseudorange measured at base station and rover, respectively. The thin line shows raw difference, while the bold line shows the moving average computed using the data of 30 seconds. Since a choke ring antenna was used for base station, there seems to be no multipath error in pseudorange, and Figure 17 shows the measurement noise. On the other hand, the pseudorange measured at rover may contain multipath caused by the station wagon. The tendency at around GPS time 453000 in Figure 18 may be due to the multipath. However, there is no significant difference between Figure 17 and 18. Also, there seems no correlation between rover motion and pseudorange difference. The station wagon might be too small to cause multipath error, and no reflected signal was measured at rover station.

## 4. Summary

JAXA and GNSS Inc. have been investigating GPS/Pseudolite applications since 2002, and the R&D project of the Pseudo-QZS was commenced in 2004. The purpose of this project is to evaluate the next-generation GNSS signal in realistic environment using a helicopter-based pseudolite, and to develop a new positioning technology appropriate for the new signal. In succession to the high data rate pseudolite developed in 2004, a BOC/CA two channels pseudolite was developed and preliminary flight tests were conducted. Although some multipath measurement tests were conducted, multipath was not observed clearly. In the future, flight tests in a field with high buildings are planned. Also, a more effective test procedure to evaluate multipath error needs to be developed.

### Acknowledgement

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