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Positioning Performance Study of the RESSOX System

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ABSTRACT

A positioning performance analysis of the RESSOX synchronization network for the Japanese Quasi-Zenith Satellite System, QZSS, is presented. A hardware-in-the-loop experiment setup has been developed to study concrete effects on positioning when a real space-born OCXO is employed in the atomic clock-less RESSOX software simulator. This study focus on a positioning performance analysis of QZSS used in conjunction with GPS. Particular focus is given to the effects of faulty synchronization on positioning, specifically when, because of unavoidable communication interruptions, the QZSS satellite clock has to function without remote control. Results show that the recently proposed RESSOX phase error compensation method can guarantee enough time accuracy even for communication interruptions of the order of one hour. The relationship between QZSS plus GPS positioning accuracy and QZSS clock quality is discussed.

KEYWORDS: QZSS, GPS, atomic clock, time synchronization.

1. INTRODUCTION

Quasi-Zenith Satellite System (QZSS) is a three satellite system conceived to provide positioning service over a wide mid-latitude region. One of the goals of the QZSS is to improve positioning performances of the present global positioning system (GPS) in urban areas where high buildings could easily reduce the number of visible GPS satellites. Details on QZSS are available from Wu F *et al.* (2004) and Petrovski IG *et al.* (2003).

The AIST space research group (AIST labs) together with the SNAP group at the UNSW (SNAP group) have been studying the feasibility of a novel remote synchronization system named RESSOX for QZSS where no on-board atomic clock is employed, details are available from Iwata T. *et al.* (2003) and Tappero F *et al.* (2006/1). RESSOX is based on the idea that if a good location for the control master station is chosen, each QZS could be visible/ controllable during its whole orbital period (24 hours). Therefore, an all-time synchronization communication framework could hypothetically guarantee the accurate synchronization of the on-board QZSS satellite clock with the master station (master clock). A practical implementation of the RESSOX concept is now under study. By means of a feedback/feed-forward control loop, RESSOX keeps a lockstep the ground station time reference with the clocks on board each QZSS satellite; The time reference employed in the ground station is a hydrogen maser primary reference, and the time reference employed on board the satellites is an oven controlled crystal oscillators (OCXO). At this stage, two synchronization schematics are under study; details can be found in Iwata *et al.* (2005), Tappero *et al.* (2006/1) and Takahashi Y. *et al.* (2005).

The RESSOX scheme represents a way to synchronize two clocks distant from one an other. it relies on a master/slave clock synchronization architecture, which can guarantee a certain time synchronization quality as long as the master clock (ground station) and the slave clock (satellite) are able to communicate. The main drawback of this technology is the inability to guarantee the desired accuracy when the satellite becomes unavailable to the ground station. In fact, during these periods, the satellite on-board clock cannot be actively steered due to the absence of feedback (Tappero F. *et al.* (2005)) and therefore the global accuracy ends up depending solely on the quality of the satellite on-board clock. It has to be mentioned that QZSS satellite communication interruptions are unavoidable and the condition of having the QZSS satellite operating on its own happens twice a day, when the satellite crosses the equatorial region. Such a condition is necessary for guaranteeing the absence of communication interference with geostationary telecommunication satellites.

Tappero F. *et al.* (2005) presented a study on the performance of the RESSOX system when a constant phase error affects the QZSS on-board clock due to possible problems in the synchronization. Studies of short-term and long-term effects have been presented by employing the RESSOX software simulator. More recently, Tappero F. *et al.* (2006/2) presented some preliminary results on how QZSS positioning quality becomes when the QZSS on-board clock is left in free-run (lacking of control).

Recently, Tappero F. *et al.* (2007) presented a method to reduce the phase error for the on-board QZSS satellite free-run clock by actively steering the OCXO after learning its behavior during the active control periods. This method represent an effective way to reduce the problem of satellite communication unavailability.

In the following study, the space-born oven-controlled crystal oscillator, OCXO, has been integrated in the RESSOX software simulator (hardware-in-the-loop configuration). And the positioning accuracy of the combined system QZSS and GPS when the synchronization system RESSOX is adopted, has been studied with particular focus on the adoption of the phase reduction method presented in Tappero F. *et al.* (2007). In the following sections, the mentioned system will be presented. Some preliminary results of the QZSS&GPS positioning capabilities with the novel phase reduction method for RESSOX will be presented.

2. EXPERIMENTAL SETUP

The RESSOX software simulator employed for the study presented in Tappero F. *et al.* (2005) has been modified to accommodate the integration of a space-born OCXO throughout an hardware-in-the-loop configuration. The OCXO employed for this set of experiments is the OCXO 8607-BM from Oscilloquarz. Specifications can be found in Table I. An accurate atomic reference is employed in the ground station. Two different controllers, the open-lop controller and the closed-loop controller are both used to first achieve synchronization and secondly to “control” the OCXO when the atomic reference is not available. Details on both controllers can be found in Tappero F. *et al.* (2007).

Fig. 1 shows the software simulator for RESSOX and the clock hardware implementation connected to it. The objective of this tool is to calculate the user position (NMEA file and Earth fixed-coordinate positioning file) for different scenarios where GPS is combined with QZSS. The simulator can also simulate the RESSOX synchronization network by which it is possible to independently de-synchronize any of the three QZS clocks and observe the effect on final positioning. The GPS orbit generator itself is not actually implemented in the simulator and thus the GPS RINEX files and the GPS SP3 files need to be provided as input files to the simulator. The QZSS is fully implemented and thus all its orbit parameters are calculated. From a given position (user position input block), the pseudorange (PR) of each QZS is calculated and opportunely modified according to the QZSS clock. The PRs of all QZSs in view and the PRs of the GPS satellites in view are then collected and computed in the receiver block. Before the PR file is computed a cut angle mask is applied for both GPS satellites and QZSs. Ionospheric, tropospheric and relativistic effects are included in the QZSS orbit calculation and in the positioning calculation. The computed position is given in spherical coordinates (NMEA file) and in Earth fixed-coordinates where (0,0) represent the true user position. For these set of experiments, Sydney (lat:26.194 deg. long:127.677 deg) was chosen.

3. FREE-RUN EXPERIMENT

The objective of this set of experiments is to analyze the capability of the Oscilloquarz 8607-BM, on board the satellite QZSS-1, in remaining stable during lack of control. Results are presented in terms of positioning capability, error in northing/easting and height. The scenario under test is depicted in Fig. 2 and the following configuration was chosen:

- System: GPS plus QZSS
- User location: Sydney, Australia (lat:26.1946 deg. long:127.67763 deg).
- Simulation duration: ~ 5 hours.
- Start time: UTC 23:15, December 31st, 2004.
- Sample ratio: 1 seconds.
- Receiver mask angle: 26 deg.

Initially, the OCXO of the satellite QZSS-1 is locked to the atomic standard. Such condition represent the ideal RESSOX scenario. After synchronization is reached the closed-loop condition is intentionally broken and the second control, the closed-loop controller, is used to reduce the OCXO phase. Such condition is applied on on Satellite QZSS-1 (Fig. 2). Positioning is the computed for about 5 hours. The following three different scenarios are considered and the same 5 hour simulation is repeated three times.

OCXO is not controlled. Immediately after closed-loop synchronization, a constant voltage is applied to the OCXO (no phase error compensation). This condition is hold for the whole simulation period of 5 hours. The applied voltage value is calculated as average of the last n voltage samples with n=100.

Compensated OCXO. Immediately after closed-loop synchronization, a variable voltage is applied to the OCXO (phase error compensation). This condition is hold for the whole simulation period of 5 hours. The applied voltage value is calculated accordingly to RESSOX phase error reduction method presented in Tappero F. *et al.* (2007).

Ideal Clock. This is not a realistic scenario. The OCXO is replaced with an ideal clock with a phase error which is virtually zero. This scenario represent the ideal case and is used to evaluate the effectiveness of the OCXO phase error compensation algorithm during the whole 5 hours.

RESULTS AND CONCLUSIONS

Fig. 3 a) shows the phase error when the QZSS-1 OCXO is left in free run (no phase compensation). Fig. 3 b) shows the phase error when the QZSS-1 OCXO phase is contained with the method presented in Tappero F. *et al.* (2007).

Fig. 4, Fig. 5 and Fig. 6 show the relative positioning error of the combined system GPS plus QZSS for the three scenarios under study. The positioning quality degradation caused by the uncompensated drift on the clock of the satellite QZSS-1, refer to Fig. 2, was successfully reduced. The remaining drift of about 4 ns for the compensated OCXO, did not play a appreciable contribution in degrading the quality of the whole augmented system QZSS plus GPS. That proves that the RESSOX architecture would have less stringent timing requirements if applied for QZSS, in fact even a 4 ns drift over 5 hours of one QZSS satellite, does not significantly contribute in degrading positioning, if compared to the ideal case of having an atomic reference on board the same QZSS-1 satellite. The equatorial communication interruption problem does not seem to be a relevant limitation for RESSOX as long as the phase error reduction method presented in Tappero F. *et al.* (2007) is applied.

If the Oscilloquarz 8607-BM, or equivalent, is employed as time reference for QZSS satellites, satellite communication interruptions and therefore free-run OCXO periods of the order of some hours will not create any particular positioning degradation if the considered positioning system is GPS plus QZSS.

Future works will deal with the develop a real time version of RESSOX phase error reduction method which will be then integrated in the RESSOX hardware simulator. The preliminary results presented here will then be confirmed with more depth.

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