0. PROJECT OVERVIEW

The European Space Agency (ESA) is running a project entitled «Improved GNSS-Based Precise Orbit Determination by Using Highly Accurate Clocks». The driving motivation is to take advantage of the high stability of the modern (GNSS and Low Earth Orbit, LEO) satellite clocks by establishing appropriate clock models. Fig. 0.1 illustrates the great improvement in clock stability reached for the latest generation GPS satellites (Block III, RB clocks) and the Galileo IOV satellites (PHM activated) compared to older GPS satellites.

An extensive literature survey was conducted in order to qualify and quantify all effects a clock can be subjected to. They include e.g. relativistic effects, orbit modelling deficiencies (such as solar radiation pressure (SRP), see Fig. 0.2), stability of code and phase observations biases and environmental factors such as temperature variations.

With all potential effects listed, models and concepts shall be developed to represent the apparent clock behavior. Test scenarios were identified to evaluate the proposed models by processing real data.

The following key aspects will be studied in the frame of the project:
- Impact of (station and satellite) clock modelling on GNSS POD and estimated global parameters,
- Impact of clock modelling for absolute and relative LEO POD,
- Impact of clock modelling on the tracking network requirements.

1. GNSS SATELLITE CLOCK MODEL

The IGS final and MGEX satellite clock corrections show a deterministic behavior (in addition to a stochastic component) that can be represented with the following model:

\[ \Delta \text{clock} = a + b \cdot \text{time} + c \cdot \text{time}^2 \]

The 1/rev and 2/rev variations may be caused by radial orbit errors and/or temperature sensitivity of clock frequency and hardware biases.

1.1 Behavior of Galileo satellite clocks

Fig. 1.1 shows the amplitude of 1/rev and 2/rev clock variation from MGEX for Galileo IOV satellites GSAT101 and 102. The 1/rev variations are mainly due to radial orbit errors caused by radiation pressure mismodeling.

1.2 GNSS Clock Modelling Supporting Precise Orbit Determination

Experiment: 16 MGEX stations were used to observe the Galileo IOV satellites. In the POD procedure, the epoch-wise estimated satellite clocks were constrained to a daily linear model (offset+drift). Different clock constraints from 100 ps to 1 ps were tested. The effect on the estimated clocks is illustrated on the left plot of Fig. 1.2. The quality of the different solutions was evaluated in terms of 24 hour orbit prediction accuracy.

Results: The clock constraint at 10 ps level provides best orbit predictions (Fig. 1.2 right).

2. CLOK MODELLING IN LEO KINEMATIC POD

Part of the study will concentrate on the feasibility of modelling the clocks of LEO satellites equipped with GPS receivers. Of special interest are the twin GRACE satellites, since the ultra-stable oscillator on-board used to drive the K-Band instruments is also connected to the GPS receiver.

Fig. 2.1 shows the pre-launch measured stability of the GRACE B satellite together with the ionosphere-free phase observation noise projected onto the receiver clock (Weinbach & Schön, 2013). It indicates that the stability of GRACE clocks is such that clock modelling is feasible over intervals of 40s, or slightly more.

3. CLOCK MODELLING AND RECEIVER-RELATED PARAMETERS

Due to the high correlations between the receiver clock corrections, the height estimates and the troposphere zenith path delay parameters (Rothacher and Beutler, 1998), appropriate modelling the high-performance receiver clocks may play an important role in stabilizing these parameters. As shown in Fig. 3.1, different kinds of atomic clocks are nowadays connected to IGS stations and offer us opportunities to model receiver clocks in network solutions. In this study, only H-Masers are considered for the receiver clock modelling in phase-based solutions.

The receiver clock model consists of a deterministic part, i.e., a low-order polynomial and a stochastic part, i.e., relative constraints with appropriate weights. Apart from that, the influences of temperature on the hardware delays are also considered in the clock modelling. Based on the model introduced by Weinbach (2013), it is possible to observe unignorable temperature influences on the receiver clock estimates, as shown on Fig 3.2.

4. OUTLOOK

During the initial phase of the study, concepts and models for clock modelling have been identified. The next phase of the project will be dedicated to the implementation of these models and their evaluation and fine-tuning by processing real data from GPS and Galileo over selected periods.