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Galileo on board International Space Station and synergy with the ACES clock ensemble

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In the first part of this contribution we present a proposal submitted to the ESA Announcement of Opportunity 2004 in support of the orbit determination for the ACES mission (Atomic Clock Ensemble in Space) on the International Space Station (ISS) and the clock comparison using a spaceborne GPS/Galileo receiver. The idea is to install a GPS/Galileo receiver, driven by the external frequency of the ACES clock ensemble, onboard the ISS and a set of 1-3 GPS/Galileo antennas in order to: 1) establish a highly accurate positioning facility for the ISS and its local environment; 2) perform precise orbit determination of the ISS based on kinematic and reduced-dynamic algorithms with an accuracy of a few cm and to provide ISS positions, velocities and total accelerations. It will be a challenge to monitor the ISS dynamics purely geometrically and to provide non-gravitational accelerations (micro-gravity environment) for any ISS payload; 3) compute the relative positions between the three antennas on the mm-level forming an ISS reference frame. This frame will allow 1-mm relative positioning of other low-cost GPS/Galileo receivers in the vicinity or on the ISS (e.g. "Canadian arm" or the Space Shuttle docking) and derivation of high-precision attitude information. With more than three antennas it will be possible to measure the deformation of the ISS platform; 4) use the ISS dynamics as a sensor to retrieve atmosphere density and to estimate free electron content above the ISS by studying delays in the signal from GPS/Galileo satellites; 5) make available GPS/Galileo measurements to the scientific community in order to perform additional experiments (e.g. radio-occultation);

6) use the Galileo/GPS measurements as a tool for precise clock comparison by connecting the Galileo/GPS receiver to the ACES clock ensemble.

In the second part we present a method to compare the ACES clock ensemble with ground clocks using GPS/Galileo phase measurements combined with the two-way ACES MW-link measurements. The method using "phase clocks" is originally developed and tested for the orbit determination of the CHAMP and GRACE satellites in the LEO orbit. The advantage of this method is that it is solely based on the GPS carrier-phase measurements and all GPS receiver clocks are compared at the same time and estimated together with the clocks of the GPS satellites. Since only GPS carrier-phase measurements are used, an overall phase ambiguity over all stations has to be estimated using smoothed P-code measurements from just one ground or space clock taken as a reference. In this way, any inconsistency between code and carrier-phase measurements does not affect clock comparison or precise-point positioning. The novelty is the combination of the highly accurate dedicated ACES MW-link measurements (0.3 ps/300s, 20 ps/day) with the GPS/Galileo phase measurements stemming from 30-40 ground IGS stations and GPS/Galileo receiver from the ISS. The advantage of the carrier-phase GPS/Galileo measurements is that they are continuous and that very long uninterrupted time series can be obtained, compared to the ACES MW-link measurements limited by the short tracking passes to the ISS. Time transfer using GPS is limited by the accuracy of the code GPS measurements, but combination of carrier-phase GPS/Galileo measurements with the MW-link measurements may solve this problem. Using simulated GPS/Galileo carrier-phase measurements from 30-40 IGS stations and MW-link measurements from ca. 10 ground stations, highly accurate, calibrated "phase clocks" will be estimated for the GPS and Galileo satellites together with all ground clocks. This second part will show the benefits of a combined processing of GPS/Galileo phase measurements and MW-link measurements for the realization of the time scale for the Galileo and GPS navigation systems and demonstrate highly accurate time and frequency transfer using calibrated "phase clocks".