

ACES MICROWAVE LINK DATA ANALYSIS : STATUS UPDATE

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ABSTRACT. The Atomic Clocks Ensemble in Space (ACES-PHARAO mission [1]), which will be installed on board the International Space Station in 2016, will realize in space a time scale of very high stability and accuracy. This time scale will be compared to a ground clock network thanks to a dedicated two-way MicroWave Link (MWL). For that purpose our team is developing advanced time and frequency transfer algorithms.

The altitude difference between the ACES-PHARAO clock and ground clocks will allow to measure the gravitational redshift with unprecedented accuracy, as well as looking for a violation of Lorentz local invariance. Several ground clocks based on different atomic transitions will be compared to look for a drift of fundamental constants. Moreover, the mission will pave the way to a new type of geodetic measurement: the gravitational redshift will be used to measure gravitational potential differences between distant clocks, with an accuracy around 10 cm.

1. THE ACES MISSION AND ITS MICROWAVE LINK

The ACES payload includes : a cesium atomic clock (PHARAO), an active hydrogen maser (SHM), a GNSS receiver for precise orbit determination, a Frequency Comparison and Distribution Package (FCDP) for local comparison of the onboard clocks and generation of the onboard timescale, a MicroWave Link (MWL) using both code-phase and carrier-phase measurement.

The MicroWave Link (MWL) will be used for space-ground time and frequency transfer. A time transfer is the ability to synchronize distant clocks, i.e. determine the difference of their displayed time for a given coordinate time. The choice of time coordinate defines the notion of simultaneity, which is only conventional. A frequency transfer is the ability to syntonize distant clocks, i.e. determine the difference of clock frequencies for a given coordinate time.

2. TWO-WAY MEASUREMENT PRINCIPLE

The MicroWave Link is composed of three signals of different frequencies: one uplink at frequency $f_1 \simeq 13.5$ GHz, and two downlinks at $f_2 \simeq 14.7$ GHz and $f_3 = 2.2$ GHz. Measurements are done on the carrier itself and on a code which modulates the carrier. The link is asynchronous : a configuration can be chosen by interpolating observables. The so-called Λ -configuration minimizes the impact of the space clock orbit error on the determination of the desynchronisation [2].

We define the observables used by the Syrte Team (ST observables) by $\Delta\tau(\tau_e) = \tau_e - \tau_r$, where τ_e is the local time of emission of the signal and τ_r the local time of reception. It can be linked to desynchronisation :

$$\text{desynchronisation}(t_2) \equiv \tau^s(t_2) - \tau^g(t_2) = \frac{1}{2} (\Delta\tau_{\text{mo}}^g(\tau^g(t_4^0)) - \Delta\tau_{\text{mo}}^s(\tau^s(t_2^0)) + [T_{34} - T_{12}]^g) \quad (1)$$

where t is coordinate time, $\Delta\tau_{\text{mo}}$ are the ST observables corrected for the delays in the cable between the clock and the antenna at transmission and at reception, s and g stand for *space* and *ground* respectively, $T_{ij} = t_j - t_i$ and $[\cdot]^g$ is the coordinate time to the ground clock proper time transformation.

The time-of-flights T_{34} and T_{12} can be calculated from the known orbits of the clocks, accounting for the tropospheric, ionospheric and Shapiro delays.

The observables from the two downlinks can be used to determine the Total Electronic Content (TEC) of the atmosphere along the line-of-sight, in order to correct for the ionospheric delay. The two-way configuration cancels the tropospheric delay, which does not depend on the signal frequency at this level of accuracy.

3. DATA PROCESSING SOFTWARE

Our team is currently developing a prototype of the data processing software. It will be used as a guideline for Astrium who will implement the industrial-grade data processing in the ACES ground segment and also by our team, to achieve the highest possible accuracy in post-processing. The core algorithm has been largely inspired by Loïc Duchayne's PhD thesis [3].

4. SIMULATION AND ANALYSIS: FIRST RESULTS

The basic observables of the modem developed by TimeTech (TT observables) are different from the observables used by the Syrte Team (ST observables). The link between TT and ST observables is detailed in [4]. In order to test the data processing software, we wrote a simulation that generates TT observables as well as ST observables. The simulation is as much as possible independent from the data processing software.

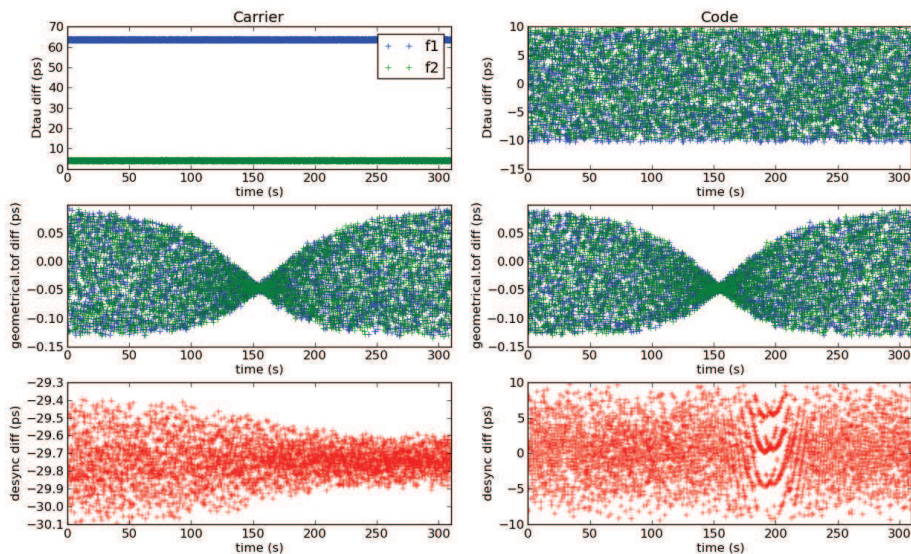


Figure 1: Here we plot the differences between simulated input quantities and quantities recovered by the data analysis software for: the ST observables recovered from the TT observables (Dtau diff), the time-of-flights and the desynchronisation, which is the final scientific product (see eq.(1)). Atmospheric delays and the lambda configuration are not yet implemented.

5. REFERENCES

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