ACES-PHARAO : Microwave link data processing

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Abstract

The Atomic Clocks Ensemble in Space (PHARAO-ACES mission), which will be installed on board the international space station , uses a dedicated two-way microwave link in order to compare the timescale generated on board with those provided by many ground stations disseminated on the Earth. Phase accuracy and stability of this long range link will have a key role in the success of the PHARAO-ACES experiment.

The SYRTE is heavily involved in the design and the development of the data processing software : from theoretical modelling and numerical simulations to the development of a software prototype. Our team is working on a wide range of problems that need to be solved in order to achieve high accuracy in (almost) real time.

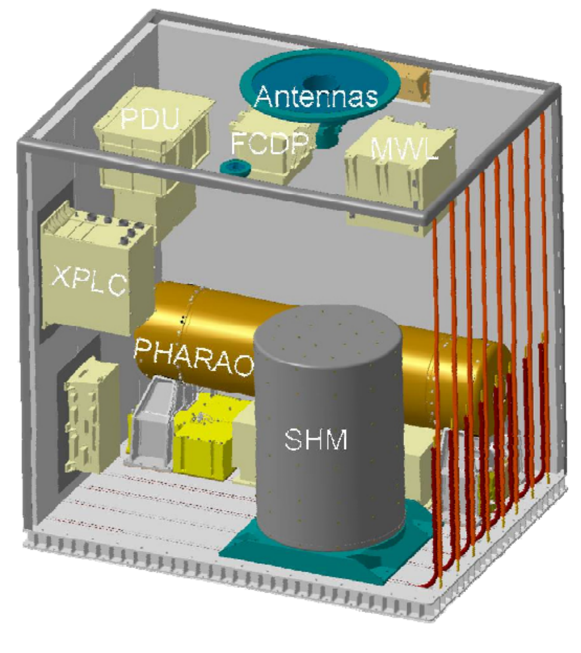
In this poster we present some key aspects of the measurement, as well as the current status of the software's development.

The ACES mission and its microwave link

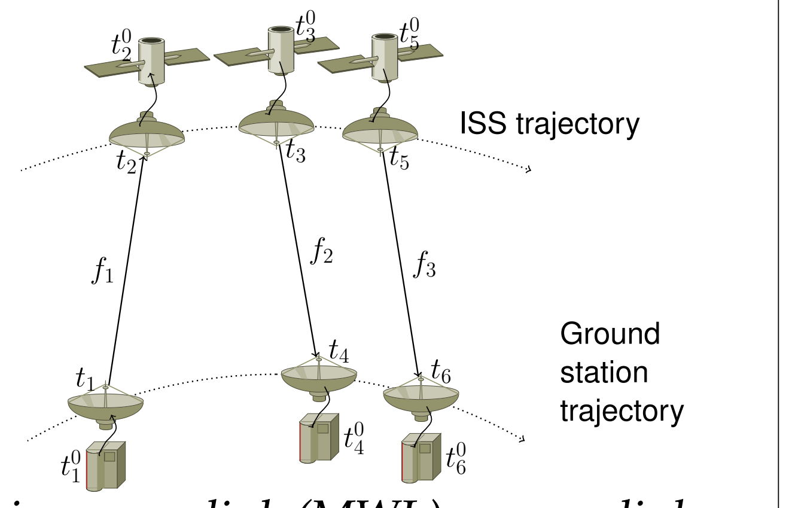
The ACES payload includes :

- a cesium atomic clock (PHARAO)
- an active hydrogen maser (SHM)
- GNSS receiver (for precise orbit determination)
- FCDP (Frequency Comparison and Distribution Package) for local comparison of the onboard clocks and generation of the onboard timescale.
- dedicated microwave link (MWL) using both PRN code-phase and carrier phase measurement.

The primary aim of the microwave link is to compare two clock signals : one is on the ground and the other is provided by the ACES payload on board of the ISS. The method that will be used is an asynchronous two way radio link with an additional downlink (at a different frequency, to infer the ionospheric delay).



The ACES payload



The microwave link (MWL) : one uplink (Ku-Band) and two downlinks (Ku and S-Band). MWL hardware developed by TimeTech GmbH.

Two-way measurement principle

Time transfer with 1 link :

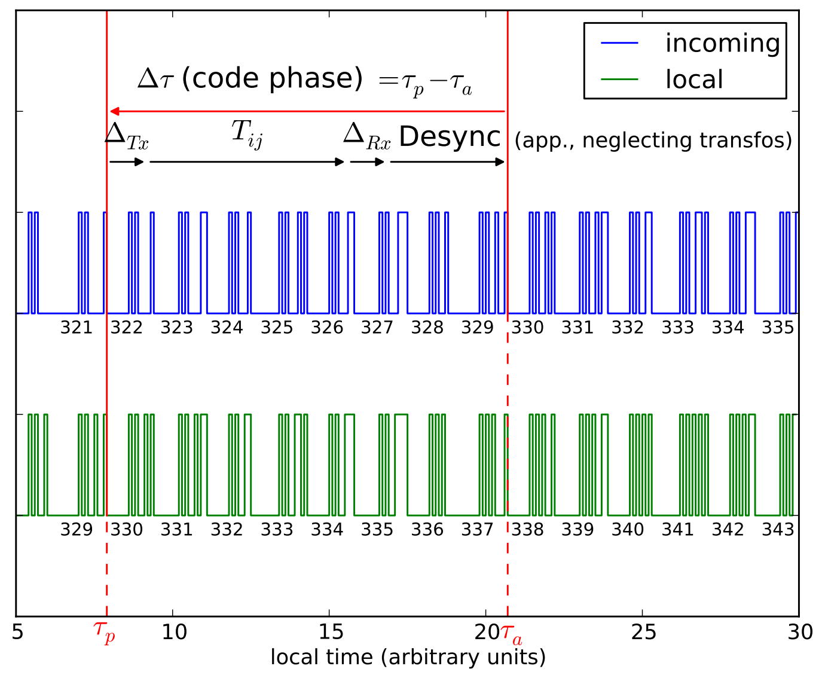
A simple one-way measurement consists in comparing the time displayed by two distant clocks, by measuring the time interval between the reception of a given «tick» and the generation of the same «tick» by the local clock. The result is a time interval $\Delta\tau = \tau_{\text{production}} - \tau_{\text{reception}}$, in the local clock's proper time. In order to recover the clocks desynchronization from this delay, one needs to modelize all other effects that contribute to $\Delta\tau$.

Two-way $\simeq 2\times$ one-way :

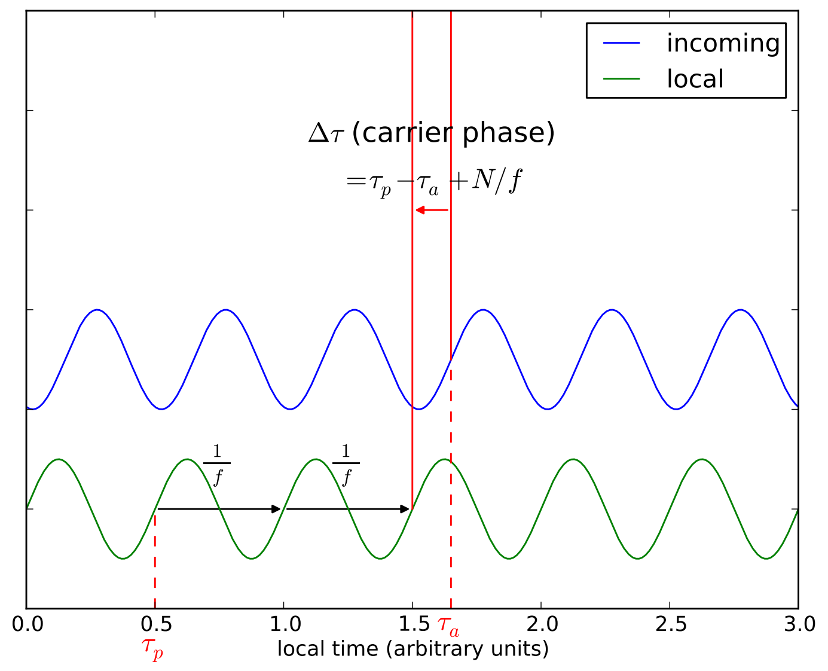
The two-way measurement aims at minimizing uncertainties by performing two symetrical one-way measurements (i.e. one from ground to space, the other from space to ground) : when substracting the $\Delta\tau$ obtained in each case, some major contributions (e.g. the range) cancel out at the first order and the resulting desynchronisation determination is less model-dependant.

Things come in threes :

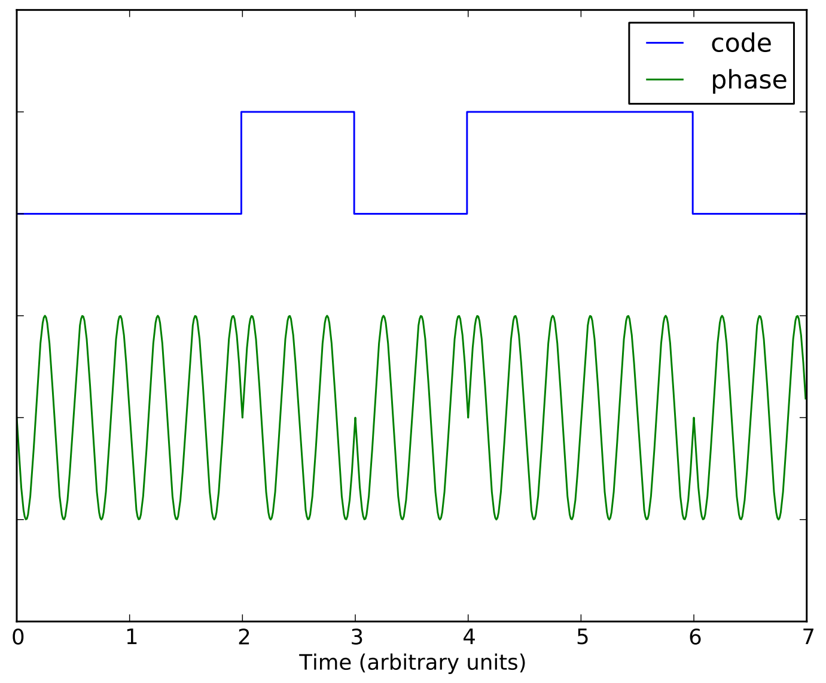
A third (much lower) frequency allows to determine the ionospheric delay (and thus the Total Electron Content).



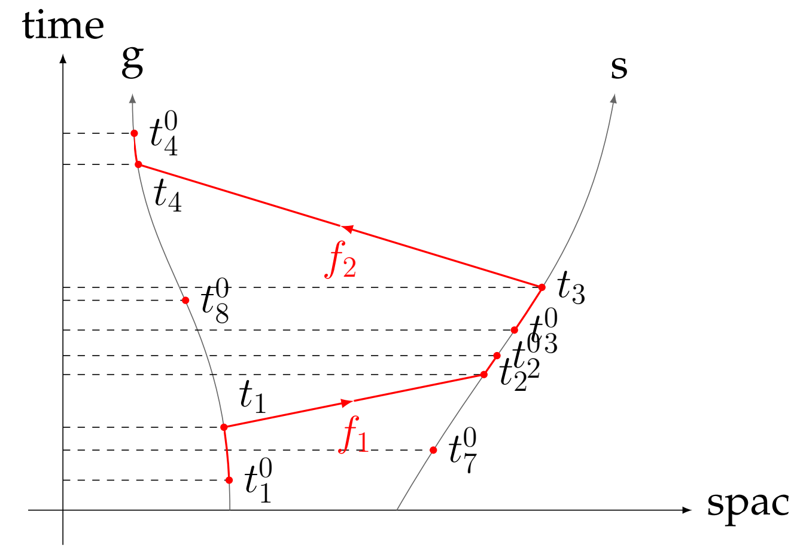
Basic concept of code-phase measurement. For clarity, a simplistic encoding is used here (in reality a PRN code is used).



Basic concept of carrier-phase measurement. Note the phase ambiguity.



Method used for encoding bits on the carrier : π-phase shifts.



Timeline representation of a two-way experiment.

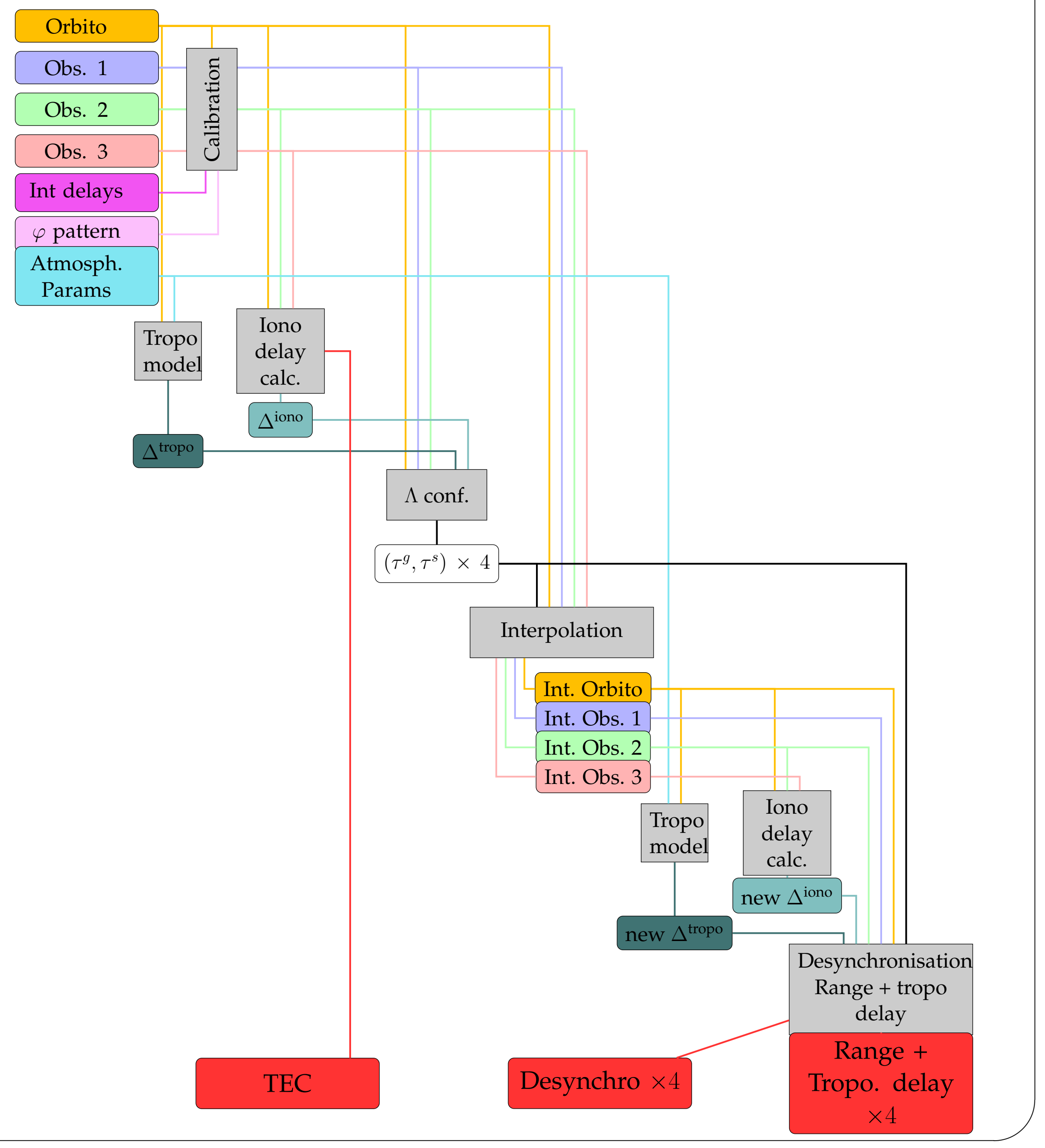
Data processing software

Our team is currently developping 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
- by our team, to achieve the highest possible accuracy in post-processing.

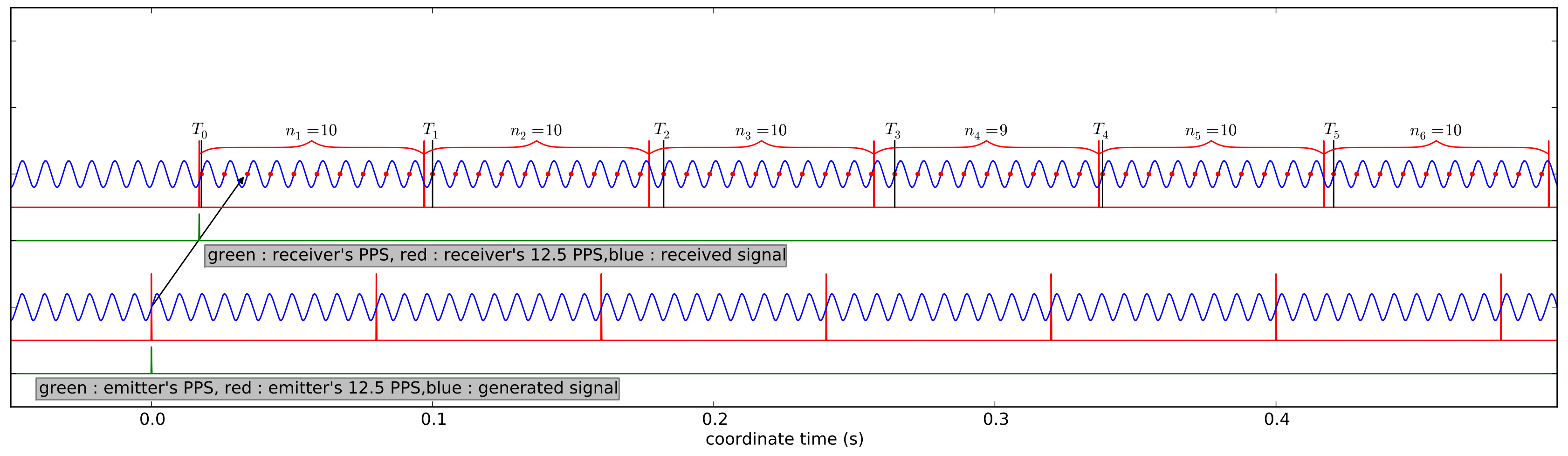
The core algorithm has been largely inspired by Loïc Duchayne's PhD thesis [1].

Right panel : overall flowchart of the data processing software. Inputs are in the top-left corner and scientific products are at the bottom (red squares).



First results

We have designed and implemented the algorithm that recovers $\Delta\tau$ from raw MWL data, i.e. T_i and n_i couples as explained in this figure :



This diagram shows a carrier (in blue) when generated (lower part of the graph) and when it is received (upper part of the graph), with a slight shift and a varying frequency because of doppler effects. Time scales (in red and green) are also different for the emitter and the receiver. Ascending zero-crossings are materialized by a red dot. For each 80 ms interval of the receiver's proper time, we get T (the date of the first zero crossing) and n, the number of zero-crossings in the previous interval.

In such a (simplified) configuration, in the receiver's time frame we get :

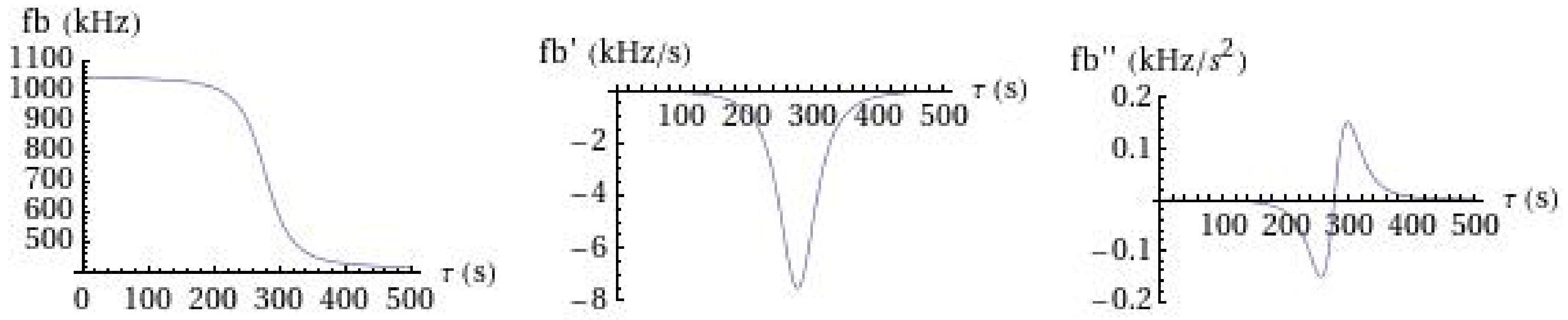
$$\Delta\tau(T_i) = \Delta\tau(T_{i-1}) + \frac{n_i}{f_{\text{Tx}}} - (T_i - T_{i-1})$$

where f_{Tx} is the frequency of the carrier. *Note that, compared to this diagram, the carrier's frequency is much higher, so it is not used directly and we get a beatnote instead : this introduces another term in the equation.*

Simulations

The purpose of simulating data is :

- To generate useful order of magnitudes for the various effects that come into play.
- To test and validate the data processing software. Generating "test cases" and regularly processing it throughout software development ensures there is no code regression.
- To provide reference datasets for use by other processing centers to cross-check their software
- To test our understanding of the various effects, algorithms, data formats (for that purpose the simulation software is developed as independently as possible from the data processing one).



The (simulated) beatnote frequency and its derivatives on board the satellite over a passage of the ISS.

References

[1] L. Duchayne. "Transfert de temps de haute performance : le lien micro-onde de la mission ACES". PhD thesis. France: Observatoire de Paris, 2008. URL: `http://tel.archives-ouvertes.fr/tel-00349882/fr/`.