Implementing the Galileo Precise Timing Facility

Renzo Zanello
BUNAV, ThalesAleniaSpace /CTT
Turin, Italy
renzo.zanello@thalesaleniaspace.com

Marco Blanchi
BUNAV, ThalesAleniaSpace /CTT
Turin, Italy
marco.blanchi@thalesaleniaspace.com

Chiara Piras
SOFITER Group /TAS external
Turin, Italy
chiara.piras@external.thalesaleniaspace.com

Edoardo Detoma
R&D, SEPA /CTT
Turin, Italy
edoardo.detoma@sepatorino.it

Paola Capetti
System & SW, SEPA /CTT
Turin, Italy
paola.capetti@sepatorino.it

Angelo Bellotti
Alenia SIA /CTT
Turin, Italy
bellotti@aleniasia.it

Diego Villabruna
Alenia SIA /CTT
Turin, Italy
villabruna@aleniasia.it

***Abstract*— The Precise Timing Facility (PTF) is an Element of the Galileo Mission Segment. It is being developed by the following partners Consorzio Torino Time (CTT): ThalesAleniaSpace Italia, responsible for Management / Technical coordination and overall Design, INRIM (former Istituto Elettrotecnico Nazionale Galileo Ferraris) and Politecnico di Torino for the GST Generation Algorithm, Sistemi Elettronici Per l'Automazione (SEPA) for the Electrical Design and AI&T, Alenia SIA for the implementation of the Control & Algo Software and the Product Assurance, ALTEC for Project Control and Logistics.**

A cooperating is also in place with the Astrogeodynamic Observatory (AOS, Poland) for the implementation of the Time Transfer SW and with SpectraTime (CH) for the Backup AHM Steering Algorithm and the development of the Picostepper.

The PTF is in charge to generate the Galileo System Time (MasterClock), the physical time scale of Galileo.

Following the papers presented at EFTF since 2007 [Ref.1,4] and PTTI 2007 [Ref.3], this paper presents an overview of the PTF, its versioning plan, the current status of development, qualification and delivery.

I. INTRODUCTION

The key aspect of this program is the challenge of passing from the Research level activities conducted at the Time & Frequency Labs into a real industrial product with a high degree of dependability.

In this effort CTT is taking advantage of its experience acquired in GSTB-V1 phase on the Experimental Precise Timing Station at INRIM.

As part of the Galileo Mission Segment (GMS), the PTF will support the Galileo Operations of IOV and FOC phases. It will be hosted at the Galileo Control Centre (GCC).

the Initial Operations Verification phase (IOV) will take place with 4 Satellites in orbit, and then the Final Operational Configuration Phase (FOC) with 30 Satellites

978-1-4244-3510-4/09/$25.00 ©2009 IEEE

II. PTF ARCHITECTURAL DESIGN

The PTF is in charge to generate the physical time scale of Galileo, the Galileo System Time (MasterClock), with two main purposes:

- Metrological Timekeeping: This function is implemented by the PTF with the support of the Time Service Provider (TSP), UTC(k) Labs and BIPM.
- Navigation Timekeeping : This is a critical task for Navigation, needed for orbit determination and prediction, to be ensured even in lack of TSP.

The main functions implemented by the PTF are the GST Generation chain and the Time Transfer.

These functions operate under the PTF monitor & control functions.

The GST Generation chain is based on the Active Hydrogen Masers (AHM) that constitutes the source of the GST signals characterised by a very good short term stability.

The stability on medium and long terms is ensured by a dedicated algorithm mainly based on the local Caesium ensemble and on the TSP data.

A second AHM is present as a backup unit, which output signal is steered to the master one.

The Time Transfer function evaluates time offset of GST(MC) with respect to:

- UTC(k) labs,
- second PTF (PTF1-PTF2 Time Offset)
- GPS/USNO (GPS-Galileo Time Offset, GGTO)

These estimations are made by means of TWSTFT and CV methods, respectively primary and backup methods.

In addition to Time Transfer measurements, the PTF algorithms exploit the measurements of the clocks of the second PTF and the remote clocks (OnBoard and GSS ones) provided by the Galileo OSPF.

The GST(MC) signals are provided as physical reference to the co-located Galileo Sensor Station (not part of the PTF), to provide pseudo-ranging measurements to the GMS Orbit Determination & Time Synchronisation functions.

GST(MC) time codes are also provided to the GMS Elements for segment level synchronization.

The overall scenario and the functional block diagram of the PTF are shown in Figures 1 and 2.

The main external control functions are the GMS Galileo Asset Control Facility (GACF) for configuration aspects and, for performance aspects, by the Time Service Provider (TSP) and by the Monitoring and Uplink Control Facility (MUCF).

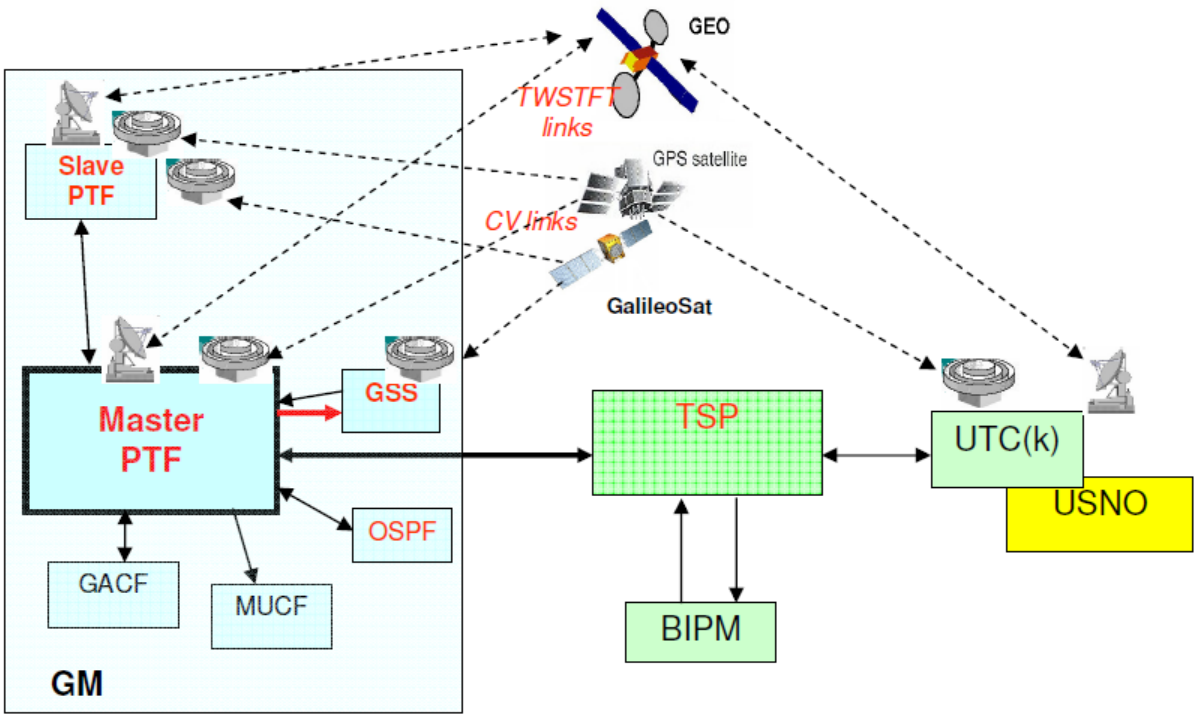

Figure 1. The PTF within the Galileo /GPS scenario

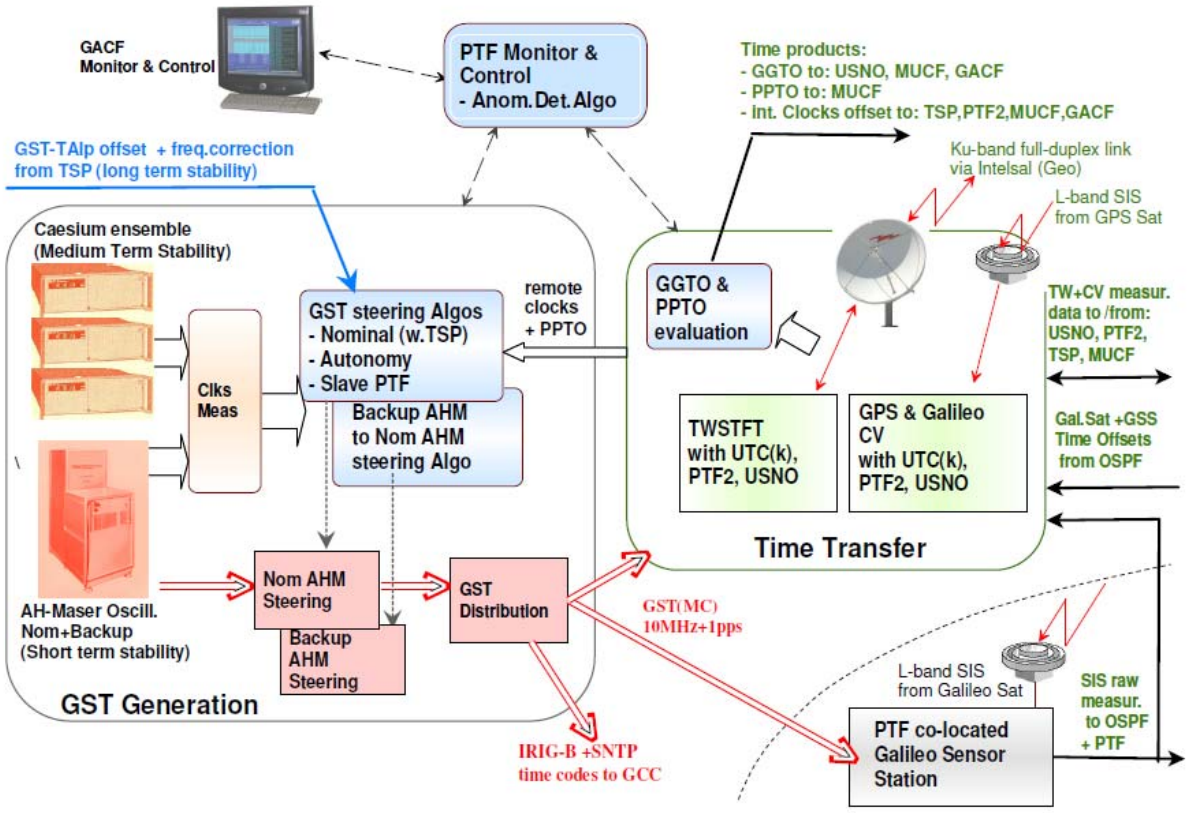

Figure 2. PTF functional block diagram

The PTF Architecture is organized on the following Sub-Systems (S/S):

- Time Generation S/S, including Instruments to generate and distribute GST(MC), i.e. 10 MHz and 1pps, with high dependability, namely the two local Active Hydrogen Masers (4 foreseen in FOC phase) and the 4 local Caesium clocks (upgradable to 12).
- Time Transfer S/S, including TWSTFT Station, GPS CV Rx, OSPF/GSS I/F (to acquire the Galileo on-board and ground "remote" clocks) and the Time Transfer SW to control such high-accuracy synchronization links.
- Measurement and Control S/S, including Control Computers, Data Network and Measurement Instrumentation, namely Time Interval Counter (TIC) and Multi-Channel Phase Comparator (MCPC). The SW includes the Algorithms to control the other S/S's and to monitor the GST performance.

III. PTF PERFORMANCE

The main performance of the GST(MC) is aimed to support the two key purposes of the PTF :

- Metrological Time Keeping performance:
  - Short/Med. term Stability: ADEV@24h $\leq 4.3 \cdot 10^{-15}$
  - Offset to UTC (mod 1s):
    In Autonomy : < 20 ns (2σ) accum. in 10 days
    With TSP support: < 49 ns (2σ) over 1 year, and uncertainty < 28 ns (2σ) (UTC estimate 6 wks ahead)
- Navigation Time Keeping performance:
  - Short term Stability in any Operational Mode:
    - ADEV@1s $< 3.0 \times 10^{-13}$,
    - ADEV@100m $\leq 2.1 \cdot 10^{-15}$
    - ADEV@8 hours $< 2.5 \times 10^{-15}$

Another key performance is aimed to support the interoperability with GPS to allow combined user receivers: the PTF contribution to the uncertainty of the daily prediction of GGTO (Galileo/GPS Time Offset) is < 3.6 ns (2σ).

IV. PTF VERSIONS

At PTF Element level the following versions are foreseen:

- **VER1**, a preliminary version to qualify the external Interfaces.
- **VER2,** "light PTF", finalization of the previous version for the GMS qualification activities conducted at the GIULIA Lab at Pforzheim (Germany)
- **VER3**, recurring of VER2 for AIV, training and maintenance
- **VER4**, the fully operational version, to be installed at Galileo Control Centre of Telespazio, Fucino (I). It will appear something as shown in Fig 3.

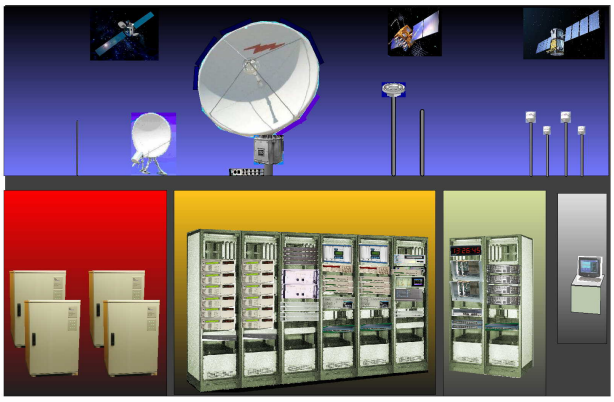

Figure 3. PTF VER4 pictorial view

V. PTF SW DEVELOPMENT

The SW implementation, done in C language, is subject to a rigid process specified by the Galileo SW Standard, aimed to support the certification of the System. The design constraints depend on the criticality of each module, classified in Development Assurance Levels (DAL).

Following the specific lifecycle requested by the Galileo SW Standard, all Algorithms were already passed a prototyping in MATLAB more than one year ago.

Among others, the following simulation results were obtained:

a. Algorithms prototype simulation

The GST Generation Algorithm is provided for GST(MC) steering while in Master Nominal Mode (with TSP support) and in Master Autonomy. In Figure 4 the comparison between PTF in Master/Nominal mode and PTF in Autonomy mode has been depicted. In Autonomy several simulation runs have been executed to obtain a set of realizations for statistical purpose. The bold line represents the PTF in Master/Nominal mode, all the other lines are the different run realizations of PTF in Master/Autonomy Mode. The difference between each run and the Nominal one are less than 10 ns.

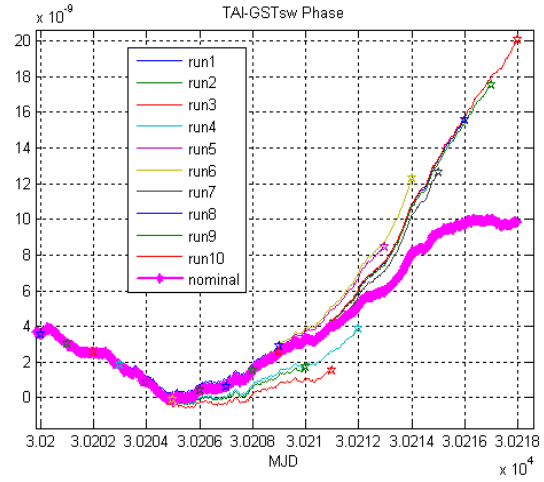

Figure 4. UTC - GST(MC) phase, Master/Auton, zoom

Another key algorithms is the GGTO Evaluation Algorithm that estimates the Time Offset of the Galileo System Time (GST) to the GPS/USNO.

For GGTO computation the Vondrak smoothing is applied; in figure 5 it is shown the resulting curve (in red) compared against the black points curve of time differences without smoothing. The uncertainty requirement of 3.6ns (2σ) is met, and better performance are expected when the actual GST(MC) will be available in place of the PTB historical data used in this simulation.

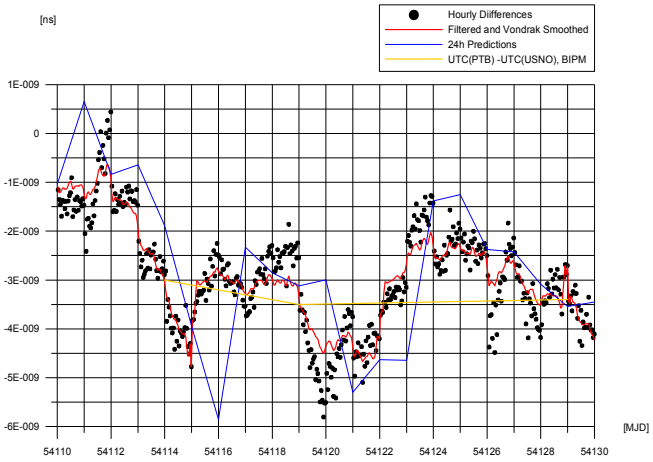

Figure 5. GGTO Simulation using PTB history (with TW)

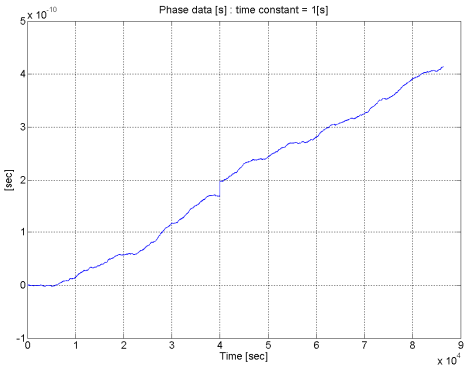

Figure 6. AHM affected by phase jump of 30ps

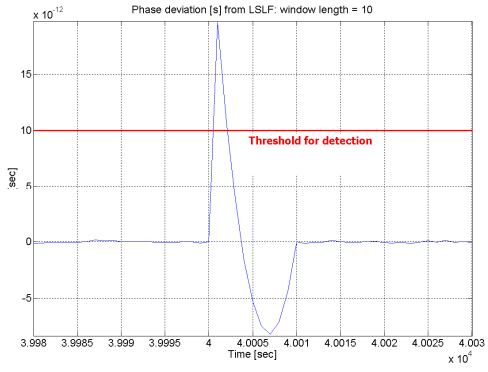

Figure 7. Simulation of Phase jump detection

Several other Algorithms have been developed to identify performance anomalies in GST(MC) and clocks as Phase and Frequency jumps and instabilities. Figures 6 and 7 show the detection of a phase jump introduced in an AHM. When the anomaly occurs, the output of the Algorithm exceeds the threshold and a warning is raised.

b. Operational SW Implementation

The PTF SW is split into the following components :

- PTF Control & Algorithms SW
- Time Transfer SW
- AIV support SW, including local Man Machine I/F

The architecture of the PTF Control & Algorithms SW foresees SW partitions, capable to isolate the modules DAL, and is based on the certifiable Operating System LynxOS-178.

The SW implementation is well advanced.

The Architecture of the VER1 SW, already qualified at PTF Element level and currently under testing on GMS segment level at Pforzheim, is shown in Fig. 8.

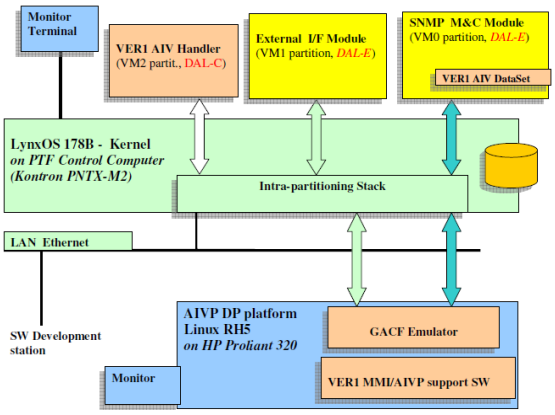

Figure 8. PTF VER1 Control & Algorithms SW Architecture

All PTF SW components will complete their C-coding and SW verification phases in a short time to be downloaded and integrated into the PTF VER4.

VI. PTF HW DEVELOPMENT

This section presents some key equipment developed for the PTF.

A. Active Hydrogen MASER

The Active Hydrogen MASER (AHM) is the source of the time generation chain, ensuring the short term stability to GST(MC). The PTF utilizes the European iMASER™ developed by T4Science (CH), that acquired the technology of the Observatoire de Neauchatel through a joint-venture of international companies (see Fig. 3).
Two AHM units have been developed and tested for the PTF VER4.

B. Automatic Switching Matrix

The Automatic Switching Matrix (ASM) has been designed and developed by SEPA [Ref. 6] (see Figure 9).
The unit is currently under test.
The ASM ensures GST(MC) continuity by switching to Backup AHM in case of Nominal AHM signal loss or out-of-lock, with simultaneous switching of 10 MHz & 1 pps signals in 2/3 hundreds ns from up to 4 AHMs, and adjustment of 10 MHz signal delays down to few ps.

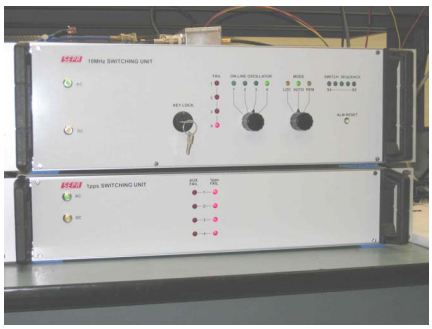

Figure 9. Automatic Switching Matrix under test at SEPA

VII. PTF I&T AND QUALIFICATION

Figure 10. PTF VER1 SW Acceptance in Turin

The different versions listed in section IV are under implementation in parallel.

The VER1 has been already HW-SW accepted in Turin as shown in Fig. 10. Note the 10 MHz signal on the oscilloscope, the first real GST(MC).

It has been shipped to the GIULIA Lab at Pforzheim, where it is currently under integration and test with the other GM S Elements (Fig. 11).

Figure 11. VER1 SW under GMS segment level testing in Pforzheim

Figure 12. PTF VER4 Integration in Turin

The fully operational version, the VER4, is currently under integration phase at SEPA (Fig. 12).

VIII. CONCLUSION

All final PTF Element level versions are in the Integration phase and the first one has been already delivered.

In a short period they will be delivered to their final destination, and in particular the fully operational version to "On-Site" GCC Fucino, where it will take part of the Galileo System integration and verification.

REFERENCES

[1] R.Zanello, M.Mascarello, P.Tavella, L.Galleani, E.Detoma, The Galileo PTF, in press EFTF-2007 Genève-CH, paper id 7336

[2] A.Moudrak, C.Bourga, J.Hahn: "Galileo System Time in Galileo Mission Segment" in press EFTF 2008, Toulouse-F, paper Id 011

[3] R.Zanello, A.Busso, E.Detoma, "Time Transfer with the Galileo PTF" in press PTTI-2007 Long Beach-CA, paper id 038

[4] R.Zanello, C.Piras, A.Samperi, E.Detoma, D.Villabruna "Initial achievements of the Galileo PTF" in press EFTF-2008 Toulouse-F, paper id 064

[5] Q. Wang, P. Rochat: "Backup Hydrogen Maser Steering Algorithm for Galileo PTF", in press EFTF'07 Genève-CH,

[6] B.Bonafede, P.Griseri, E.Detoma, P.Capetti: An Automatic Switching Matrix for the Galileo PTF, in press EFTF 2008, Toulouse-F, paper id 0052