Implementation and On-Site activities of Galileo Precise Timing Facility

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ABSTRACT

The Precise Timing Facility (PTF) is an Element of the Galileo Mission Segment. There are two PTF contracts in the Galileo IOV phase. The PTF planned for installation in the Galileo Control Center in Fucino (Italy) and subsequent integration with the IOV GMS, 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.1,5] and PTTI 2007 [Ref.3], this paper presents an overview of the PTF, its versioning plan, the current status of development, qualification and delivery.

1. 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 In-Orbit Validation phase (IOV) and will be upgraded for the Full Operational Capability phase (FOC). It will be hosted at the Galileo Control Centre (GCC) in Fucino (Italy). The IOV will take place with 4 Satellites in orbit, and then the Final Operational Configuration Phase (FOC) with 30 Satellites

2. PTF ARCHITECTURAL DESIGN

The PTF generates 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 functional block diagram of the PTF is shown in Figure 1.

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).

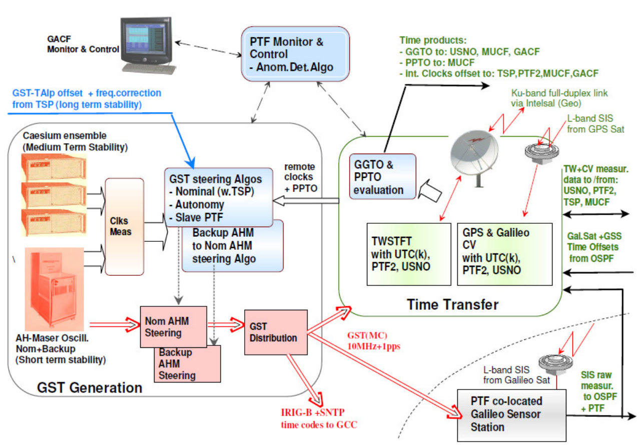


Figure 1. PTF functional block diagram

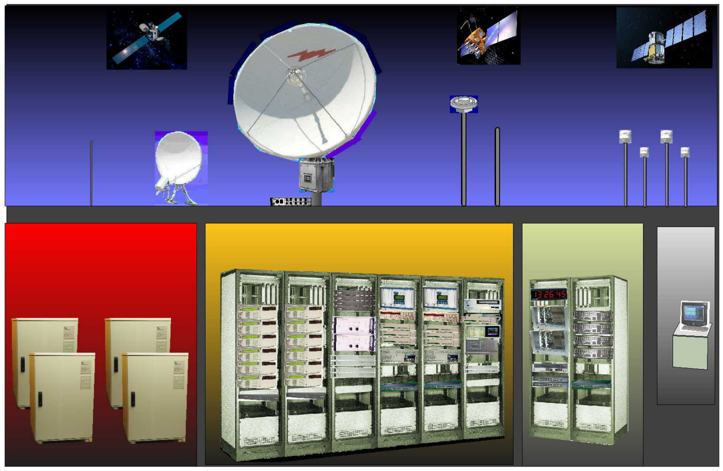


Figure 2. PTF VER4 pictorial view

The pictorial view of PTF configuration for FOC, demonstrating the full clock upgrade capability, is shown in Figure 2.

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.

3. 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 < 3.0×10^{-13},
    - ADEV@100m $\leq 2.1 \cdot 10^{-15}$
    - ADEV@8 hours < 2.5×10^{-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).

4. PTF SW IMPLEMENTATION

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 Galileo. The design constraints depend on the criticality of each module, classified in Development Assurance Levels (DAL).

The final 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 PTF SW is split into the following components :

- PTF Control & Algorithms (C&A) SW
- Time Transfer (TT) SW
- AIV support SW, including local Man Machine I/F

Following the specific lifecycle requested by the Galileo SW Standard, all Algorithms were already passed a prototyping in MATLAB before entering the Operational SW Coding Phase.

The implementation of the Operational SW was conducted directly by CTT for the C&A SW, split apart into two parallel flows respectively for the control functions and the algorithms. In addition AOS implemented the TT SW. The initial SW versions were focused on the M&C and external Interfaces and were delivered to Pforzheim for the integration and verification of PTF SW at GMS level. Then the PTF SW Versions were integrated with the C&A Algorithms and with the TT SW. The following gives some results of the Algorithms Operational SW test campaign.

The GST Generation Algorithm is provided for GST(MC) steering while in Master Nominal Mode (with TSP support) and in Master Autonomous Mode. The Figure 3 shows the simulated GST(MC) to UTC Offset (mod 1s) with an ideal TSP. In particular the steering initialization is reported, followed by the behaviour in Nominal Mode. It clearly appears that the Offset is very lower than the required 49 ns.

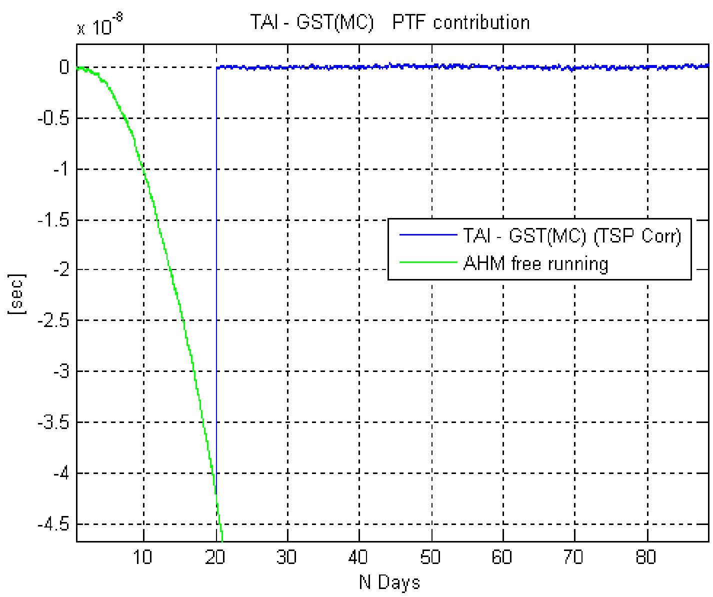


Figure 3. UTC - GST(MC) phase, Master/Auton, zoom

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.

The figures 4a and 4b show the plots of the results of the final Algorithm Operational SW tested with real USNO and PTB historical data, respectively using the GPS CV and TWSTFT methods. The raw differences (red) are compared against the smooth differences (green), and superimposed is the GGTO prediction at 24 H (blue bullets). The respective uncertainty requirements for the two methods are met.

Several Algorithms have been implemented to identify performance anomalies in GST(MC) and clocks as Phase and Frequency jumps and instabilities. Figures 5 a and b 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.

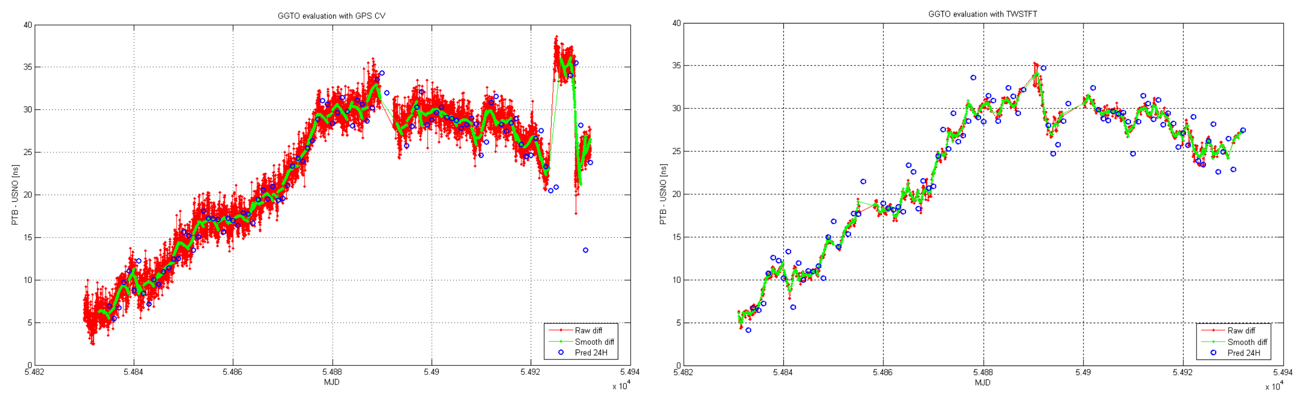


Figure 4. GGTO simulation using USNO+PTB historical data, respectively Fig. a with GPS CV and and Fig. b: TWSTFT

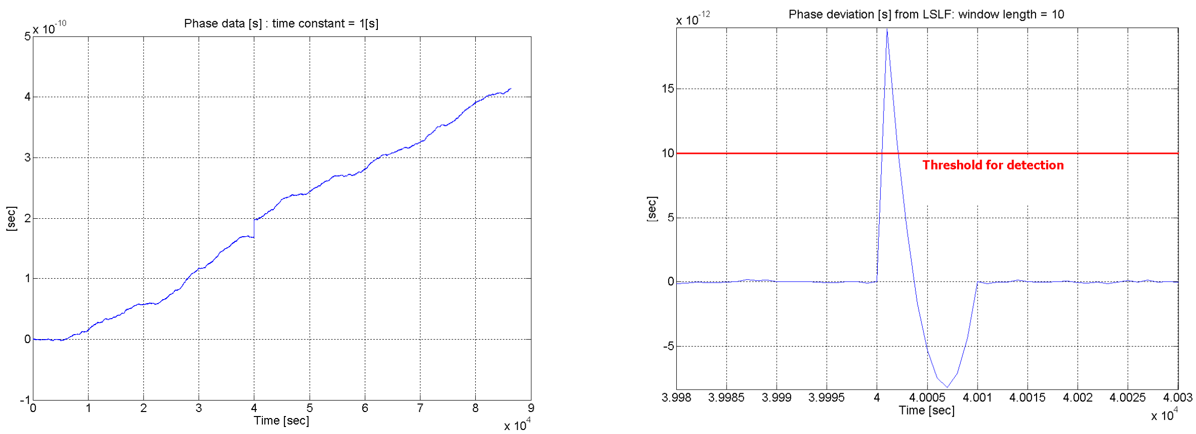


Figure 5. a: AHM affected by phase jump of 30ps b: Simulation of Phase jump detection

5. PTF HW DEVELOPMENT

This section presents some key equipment implemented for the PTF.

5.1. 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 Neuchatel through a joint-venture of international companies. Two iMASER™ units have been developed and accepted for the PTF VER4 (see Figure 6). Note the good stability performance achieved despite the environment was not meeting the 0.1°C temperature range required to the AHM operational environment.

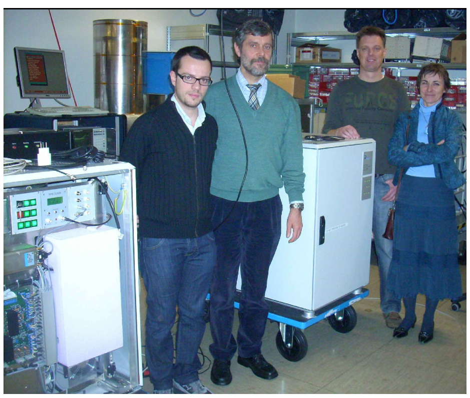
These units will be installed at GCC Fucino next May as part of the VER4.

5.2. Picostepper

To Picostepper has been implemented and tested by SpectraTime (Switzerland) with the purpose to steer the AHM (see Figure 7). It affords a phase resolution of 0.1 ps

5.3. Automatic Switching Matrix

The Automatic Switching Matrix (ASM) has been designed and implemented by SEPA to ensure 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 & PPS signals in 200÷300 ns from for 4 AHMs and adjustment of 10 MHz signal delays to few ps (see [6]. and Figure 8).



iMASER48
Stability Test Result:
(ADEV, Drift included)

1s	7.6×10^{-14}
10s	1.4×10^{-14}
100s	2.9×10^{-15}
1,000s	0.9×10^{-15}
10,000s	0.6×10^{-15}
1 day	1.6×10^{-15}

Figure 6. the iMASER48 and iMASER49, Acceptance Review at T4S (Switzerland) with stability results

Figure 7. Picostepper by SpectraTime (Switzerland)

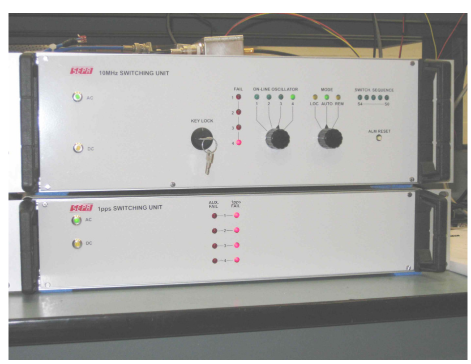


Figure 8. Automatic Switching Matrix by SEPA (Italy)

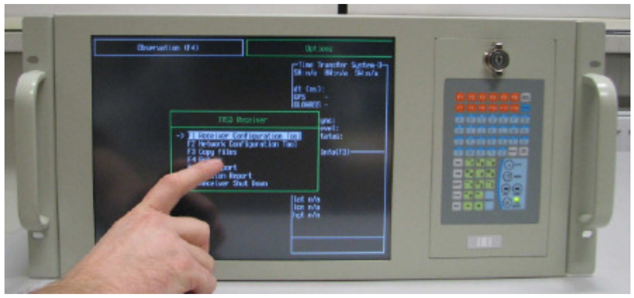


Figure 9. GPS Timing Receiver by AOS/PIK (Poland)

5.4. GPS Timing Receiver

The TTS4 Timing Receiver has been developed and tested by AOS/PIK (Poland) (see Figure 9). Equipped with a Javad receiver it allows reception of GPS, Glonass, GIOVE A-B and is upgradable to receive Galileo C-BOC signals. It generates CGGTTS and RINEX data files (synchronized to an external PPS) and provides the internal PPS sync.

6. PTF VERSIONS

At PTF Element level the following versions are foreseen:

- VER1, VER2 and VER3 “light PTF”, already accepted and integrated at GIULIA Lab (the GMS AIV Factory at Pforzheim) and reusable for training and maintenance (Figures 10 and 11)
- The IOV PTF is under installation in GCC in Fucino (Italy) to support Galileo validation and operations

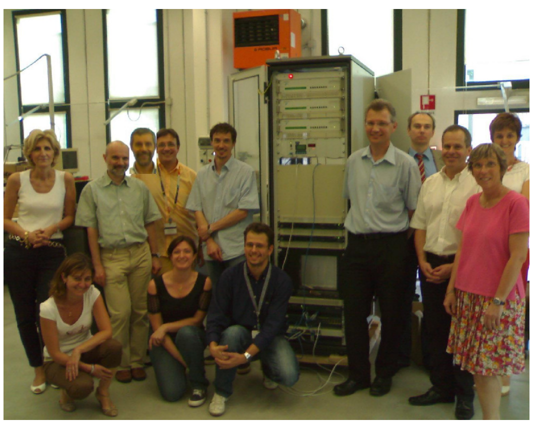


Figure 10. PTF VER2/3 Acceptance in Turin

Figure 11. VER2 under GMS segment level testing in Pforzheim

Figure 12. Roof inspection for Antennas installation at the Galileo Control Centre (Fucino–Italy)

7. CONCLUSION

State-of-the-art Algorithms have been integrated with key timing Instruments like the iMASER, the Picostepper, the Automatic Switching Matrix, etc. being based on the European technology and demonstrating excellent performance.

The PTF Element level versions either have already entered their operational phase or are under installation at the operational Site to undergo the Acceptance campaign and to start supporting the IOV phase .

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