Precise Time Technology for Galileo 2006 TIWDC

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Abstract. As part of the European GNSS Galileo project and in particular of the Galileo Mission Segment (GMS), the Precise Timing Facility has started C/D/E1 phase under the conduction of the Consorzio Torino Time (CTT).

The PTF is in charge of the generation of the Galileo System Time with full unmanned operations remotely controlled by the the Galileo Asset Control Facility. It works in cooperation with an entity external to GMS, the Time Service Provider but is capable of full autonomous generation of GST in lack of the TSP.

This paper presents key issues of the PTF technology and performance. It reflect the author's view, without obligation of GMS, GaIn and ESA customers.

1 Introduction

As part of the European GNSS Galileo project and in particular of the Galileo Mission Segment, GaIn has kicked off on December 2005 the C/D/E1 phase for the implementation and initial operations of the Precise Timing Facility, to be conducted by the Consorzio Torino Time (CTT).

CTT has been established in 2004 by local institutions, research laboratories, academic and technology institutions and aerospace industries of the Italian Piedmont region with the aim to foster the activities and knowledge on the navigation/timing matters in the area of Torino, the local chief town.

CTT members are INRIM (former IEN Galileo Ferraris), Politecnico di Torino, Istituto Superiore Mario Boella, AAS-I, ALTEC, SIA and SEPA, further to the Institutional partners FinPiemonte and Fondazione Torino wireless.

During the GMS phase C0 AAS-I, SEPA and INRIM worked together on the Galileo System Test Bed – V1 (GSTB-V1) Experimental Precise Timing Station (E-PTS) [1] and will bring the relevant experience in the PFT project.

This paper presents the PTF technology and performance at the current design status. It includes contributions from the CTT partners and reflects the author's view, without obligation of GMS, GaIn and ESA customers.

2 General Scenario

The PTF is part of the Galileo Mission Segment (GMS), that is in turn part of the overall Galileo scenario as shown in Fig. 1.

In this context the PTF generates the Galileo System Time / Master Clock (GST/MC) that is the physical time scale used as a reference by Galileo.

The PTF is designed with a twofold purpose:

- NAVIGATION TIMEKEEPING:
  Critical task for the Navigation mission, needed for orbit determination / prediction and clock synchronization.
  Fully implemented within the PTF.
  Main performance parameter: GST Frequency Stability.
- METROLOGICAL TIMEKEEPING
  Additional task needed to provide accurate dissemination of the Coordinated Universal Time (UTC).
  Implemented by the PTF with the support of the Time Service Provider (TSP), the National Time Metrology Laboratories and the Bureau International des Poids et Mésures.
  Main performance parameter: GST to UTC offset.

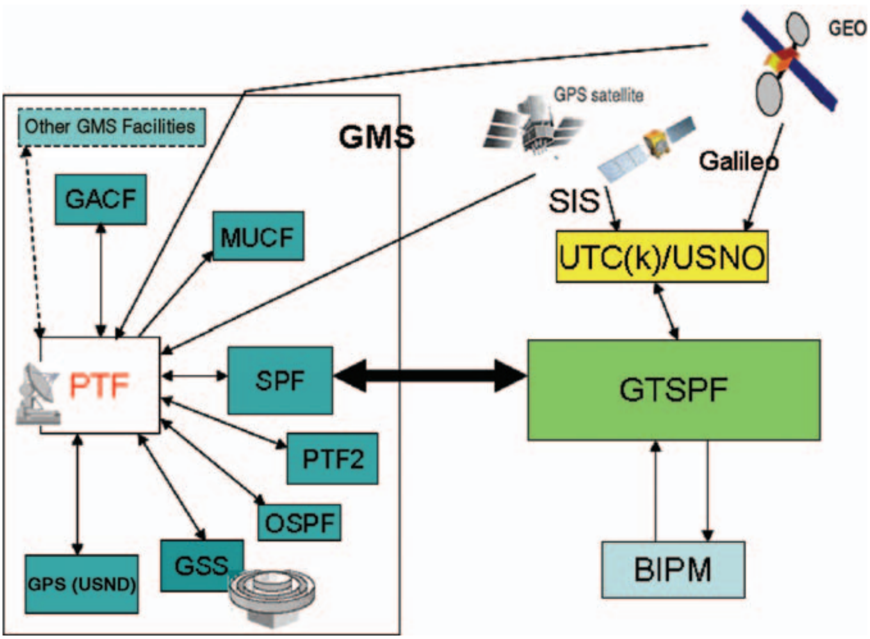

Fig. 1. PFT within Galileo.
GACF: Galileo asset control facility
GSS: Galileo sensor station
USNO: US naval observatory utilized by GPS
GTSPF: Galileo time service prototype facility
BIPM: Bureau international des poids et mésures.

3 PTF Major Design Drivers

The PTF is based on the experience of the Experimental Precise Timing Station. Particularly important with respect to the new PTF targets are the lessons learnt in the field of GST Generation Algorithms, Time generation & measurement performance, Operations & Logistics.

Key functional Req's are the following:

- Generation of the Galileo System Time/MasterClock [GST(MC)]
- Fully unmanned operations under remote Control/Monitor of the Galileo Asset Control Facility (GACF),
- Cooperation for metrological timekeeping with an entity external to GMS, the Time Service Provider (TSP)
- Capability of fully autonomous generation of GST in lack of the TSP.

The PTF Performance Requirements are very challenging; they are dimensioned in front of the results from the research phase conducted by the European Time & Frequency Laboratories, and establish new technology limits for the industrial products (see section 7).

They cover mainly the following parameters:

- GST Time and Frequency Stability
- GST Time and Frequency Offsets wrt. UTC
- GST to PTF2 Time/Frequency Offset and stability
- GST to GPS Time/Frequency Offset and stability Accuracy

Additional requirements are established to ensure that the PTF is a real industrial product; they include Quality, design and environmental req'ts as the following:

- Reliability, Availability and Maintainability
- SW Quality as per the Galileo SW standards
- Electro-Magnetic Compatibility and Interference
- Thermal and Magnetic environments (due to the sensitivity of the instrumentation)

4 CTT PTF Overall Configuration

The PTF configuration is based on the following S/S's (see Fig. 2):

- Measurement / Control S/S including the Data Processing Platforms that run the SW Components, including the main Algorithms, and the Measurement Instrumentation.
- Time Generation S/S including the pure HW items capable to generate and distribute GST with high dependability, namely the short and medium term stability oscillators
- Time Transfer S/S including the Two Way Station, the GPS CV Receiver, the GSS I/F and the relevant Algorithms.

The Fig. 3 shows the PTF from a control view point:

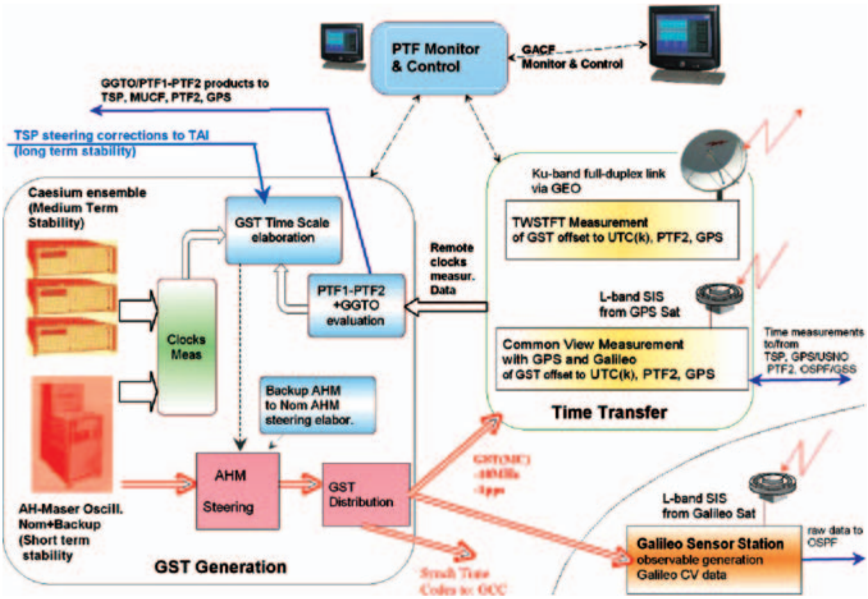

Fig. 2. CTT PTF functional block diagram.

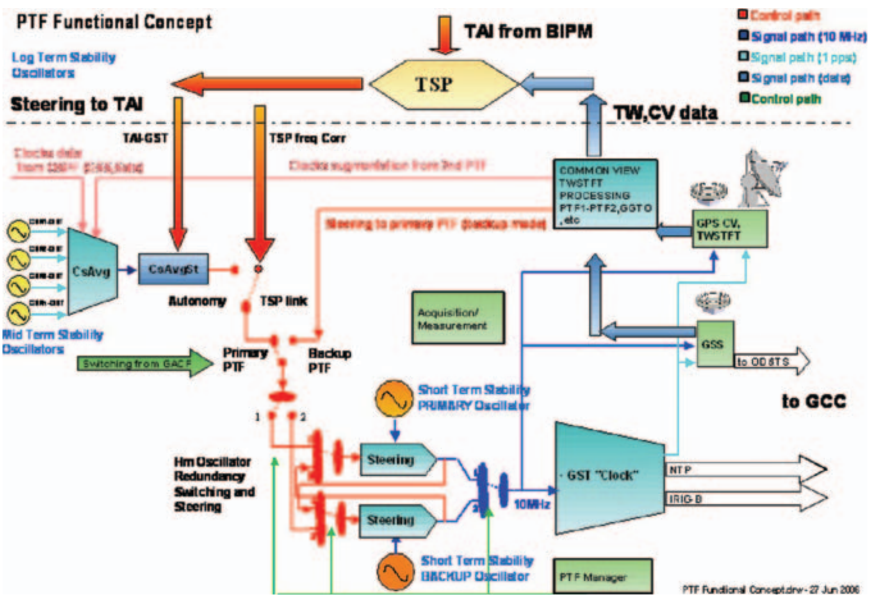

Fig. 3. CTT PTF functional control diagram.

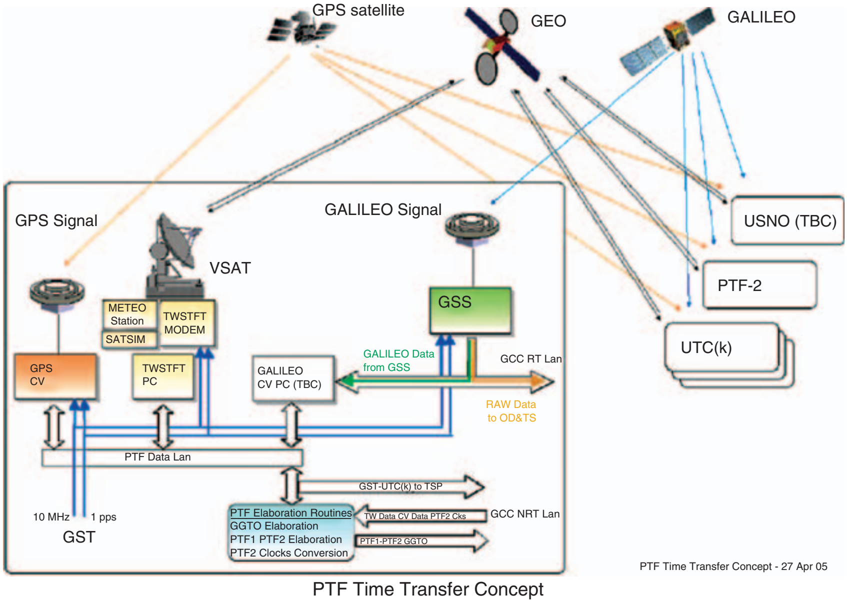

Fig. 4. CTT PTF time transfer concept.

The Time Transfer S/S is designed to actuate the measurement of the Time Offsets wrt the other Time keeping facilities as shown in the concept diagram of Fig. 4.

5 CTT PTF Technological Issues

The PTF technology is aimed to ensure the performance requirements of the Galileo System Time scale (see section 7).
To afford such performance the key technological issues of the PTF are:

- Eccellent short term stability provided by Active Hydrogen MASER (AHM): Allan Deviation in 24 hours ≤ 2. 10^{-15}
- Eccellent medium term stability provided by a Caesium clock ensemble: Allan Deviation in 5 to 30 days ≤ 1. 10^{-14}
- State-of-the-art measurement and data acquisition instrumentation capable of monitoring in real time the clocks performances
- GST generation algorithms used both to check the TSP corrections in nominal operations and to replace them in autonomy. These algorithms are based on the data processing of the local and remote clock measurements.
- Physical realisation of GST(MC) by controlling the output of one of the available Active Hydrogen Maser clocks via a precision Phase Pico-Stepper
- Redundant AHM continuously steered to the primary one by means of dedicated algorithm to ensure a smooth switch in case of failure

- High-accuracy synchronisation links to external laboratories (UTC(k)) to provide data to TSP for GST to TAI/(UTC) steering corrections elaboration. These synchronisation links are performed by state-of-the-art two-way modems and common-view GPS time transfer receivers
- Direct reference of GST to the OD&TS functions (Orbite Determination & Time Synchronization) via a co-located GSS receiver (feeding ranging data to the OD&TS) driven by physical realisation of GST(MC)

6 CTT PTF Algorithms

The PTF is operating on the basis of different algorithms, including the GST Generation Algorithm, that is the core, the Algorithms for the steering of the backup AH MASER to the nominal one, the steering of the backup PTF on the master one and those for the measurement and evaluation of the time offsets between the generated GST scale and the external time references of the UTC(k) European and GPS laboratories.

The GST Generation Algorithm is based on the prototype developed by INRIM (Fig. 5) and Politecnico di Torino since year 2000 and in particular through the experience and lessons learned on the Experimental Timing Station (EPTS) developed during the Galileo GSTB-v1 phase (see Reference [1]).

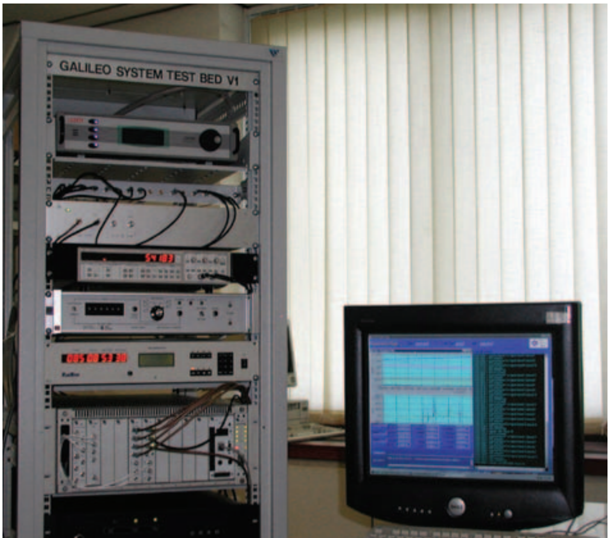

Fig. 5. Experimental Precise timing station at INRIM (2005, GSTB-v1).

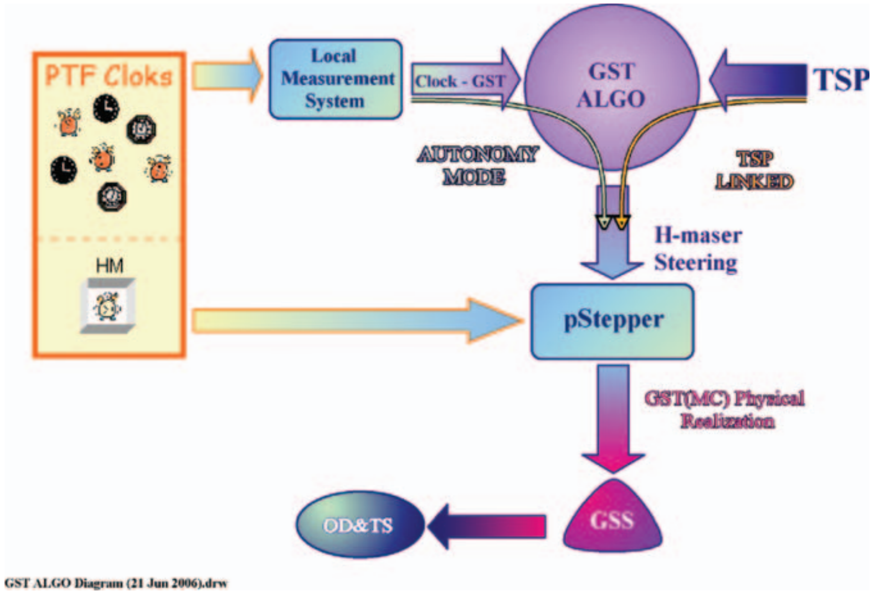

Fig. 6. GST generation algorithm concept.

The current GST Algoritms (Fig. 6) are being developed in front of PTF requirements, including difference wrt. the EPTS as:

- Corrections provided by the TSP (in nominal mode)
- Steering to the other PTF (in slave mode).

7 CTT PTF Performance

The PTF performance parameters are relevant to the goals of the Galileo System Time scale in the domains of Navigation and Time Metrology.
So far no performance results are available as the PFT implementation process is at preliminary design stage. Performance data are here-after given in terms of applicable requirements and design analyses.
In the domain of Navigation, the PTF is required to generate the GST(MC) physical time scale with the following main performance:

- Frequency stability to TAI $< 4.3 \times 10–15$ in terms of Allan standard deviation in 24 hours, including the contribution due to corrections for steering toward TAI

The main goals of the Time Metrology are implemented by the PTF in cooperation with TSP, BIPM and Time Metrology Laboratories and are established with the following requirements applicable at level of Galileo system:

- GST(MC) to UTC *(mod 1 sec)* Time Offset < 50 ns (2σ) over any yearly time interval
- Uncertainty of GST(MC) to TAI Offset < 28 ns (2σ).

Anyway the PTF, thanks to its reliability, shall ensure fully autonomous operations in case of failure of TSP or Time Metrology Laboratories (that are not industrial products) with the following requirement:

- GST(MC) degradation ≤ 20 ns (2σ) over 10 days (still under revision).

In addition, to ensure interoperability with the US GPS, the PTF shall accurately compute the GPS to Galileo Time Offset (GGTO) with following requirement:

- GGTO Accuracy ≤ 5 ns (2σ) over any 24 hours.

The PTF design analyses are on going in parallel to the design definition. The performance analyses have been conducted on the basis of the documentation of the foreseen instrumentation and of the results obtained from the GSTB-v1 experience.

These results are significant as the E-PTS Algorithms and its time instrumentation are basically reutilized for the PTF.

The Fig. 7 shows the results obtained in 10 months of test during the GSTB-v1 phase in terms of Experimental-GST to TAI Offset (Reference [1]).

The results of the current analyses show that the applicable requirements are expected to be met.

Figure 8 shows in particular the estimation of the GST stability.

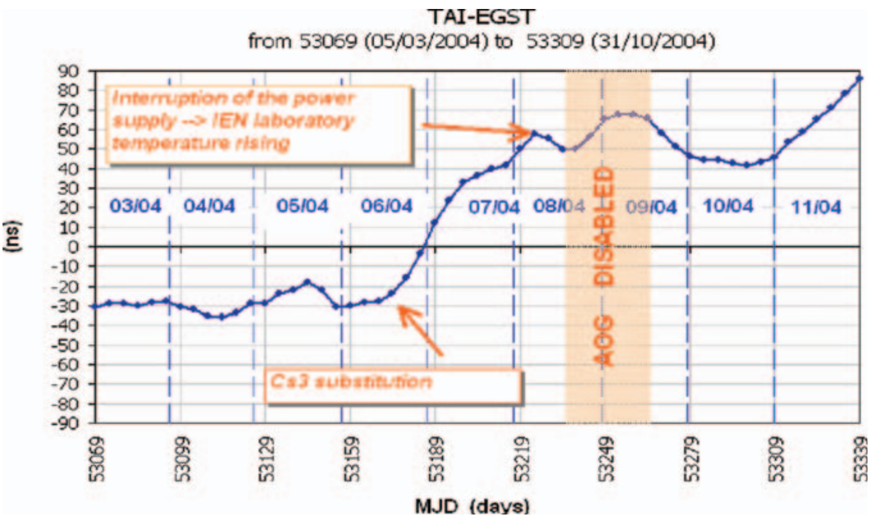

Fig. 7. E-PTS performance (2005, GSTB-v1).

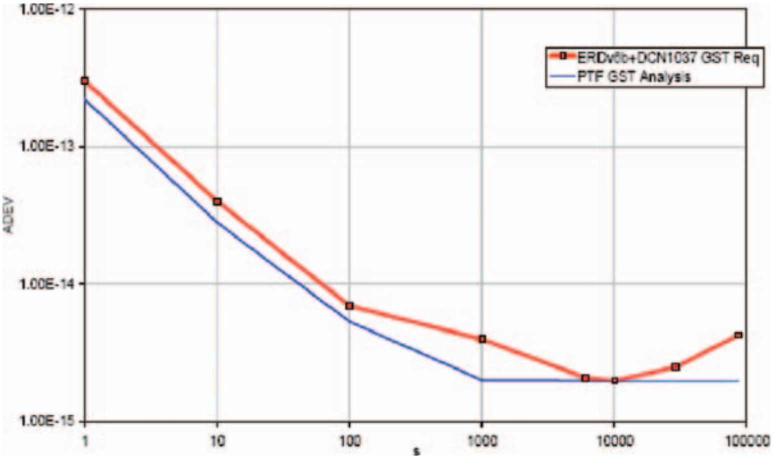

Fig. 8. GST(MC) expected stability vs. requirements.

References

[1] Cordara,Costa,Lorini,Orgiazzi,Pettiti,Sesia, Tavella (IENGF, Torino, Italy), Elia, Mascarello (Alenia Spazio, Torino, Italy), Falcone, Hahn (ESA, Noordwijk, The Netherlands): **E-GST: one year of real time experiment, 36th Annual PTTI Mtg, 2005**