TIME TRANSFER WITH THE GALILEO PRECISE TIMING FACILITY

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Abstract

The PTF is an Element of the Galileo Mission Segment in charge of generating the Galileo System Time (Master Clock) as the physical time reference of Galileo.

The PTF C/D/E1 phase contract acquired by Consorzio Torino Time (Italy) started on December 2005. The detailed design is almost completed and the implementation phase will begin soon.

To meet the Galileo system requirements, the time transfer functions have being designed on the basis of three techniques: TWSTFT, CV, and use of OSPF products. The last technique implies interfacing an external facility, i.e. the OSPF (Galileo Orbitography & Synchronization Processing Facility), onboard clocks, and GSS clocks.

This paper addresses the current PTF design status, including:
- ***PTF overview***
- ***Architecture***
- ***Algorithms SW***
- ***Time transfer HW***
- ***Time transfer performance.***

PTF OVERVIEW

GENERAL

Consorzio Torino Time (CTT, constituted by INRIM, Politecnico di Torino, Thales Alenia Space Italia, Altec, Alenia SIA, SEPA, Fondazione TorinoWireless and Finpiemonte) is conducting the C/D/E1 phase for the implementation of the PTF Element. AOS cooperates with CTT on the Time Transfer functions, and with SpectraTime on the AH-maser steering.

The PTF is an Element of the Galileo Mission Segment **[1]**. The PTF can be considered as the modern version of the clock invented by John Harrison in the 18th century to solve the longitude determination problem of maritime navigation (see Fig.1). In fact, it is in charge of generating the physical time scale of Galileo, the Galileo System Time (Master Clock), GST (MC).

Fig. 1 Pictorial interpretation of the Harrison clock, 18th century.

CTT is taking advantage of its experience on the Experimental Precise Timing Station at INRIM. Currently the PTF is finalizing the detailed design and the SW Coding and Integration & Test phase will start in a short time. The PTF will be transported to the "On-Site," i.e. either Telespazio/Fucino Italy or DLR/Oberpfaffenhofen Germany, where system testing will take place. After that the Initial Operations Verification phase will take place (IOV with four satellites), followed by the Final Operational Configuration phase (FOC with 30 satellites).

KEY REQUIREMENTS

The two main purposes and requirements of GST (MC) are the following:

- NAVIGATION TIMEKEEPING (the most critical one):
  - GST(MC) to TAI frequency stability: ADEV @ 24 h $< 4.3 \times 10^{-15}$
- METROLOGICAL TIMEKEEPING:
  - with the support of the Time Service Provider (TSP):
    GST (MC) - UTC offset @ 1 year < 50 ns 2σ , with an uncertainty < 28 ns 2σ
  - without TSP support (i.e. in Autonomy):
    GST (MC) – TAI predicted offset uncertainty @ 10 days < 20 ns 2σ.

FUNCTIONAL AND DESIGN REQUIREMENTS

The PTF is designed to ensure:

- Cooperation with TSP for GST(MC) to TAI steering
- Master /slave operations with the 2nd PTF, and in case of TSP loss, Autonomy Mode
- Supply GST (MC) signals as physical time reference to the co-located **Galileo Sensor Station** (GSS) receiver for the measurement of the Galileo satellite clocks
- Unmanned operations with automated failure management and detection of clock anomalies
- High dependability, based on redundancy management, HW and SW design standards (e.g., Galileo SW standards), etc. to afford all PTF functions and, in particular, the GST Master Clock generation chain for a 20-year lifetime.

THE PTF SCENARIO

The PTF operates as part of the Galileo Mission Segment (GMS). On the GNSS level, it is involved in both the Galileo and GPS scenarios to ensure their interoperability. To this purpose, time & frequency transfers are conducted with several entities including European UTC (k) laboratories, the second PTF, and the USNO laboratory as shown in Fig. 2.

PTF ARCHITECTURE

FUNCTIONAL BLOCKS

The PTF Architecture implements the functional blocks and the interfaces shown in Fig. 3. The main functions are the GST generation, time transfer, all under the Monitor & Control function, which in turn is remotely controlled by the GMS GACF (Galileo Asset Control Facility). The subfunctions are described in the following.

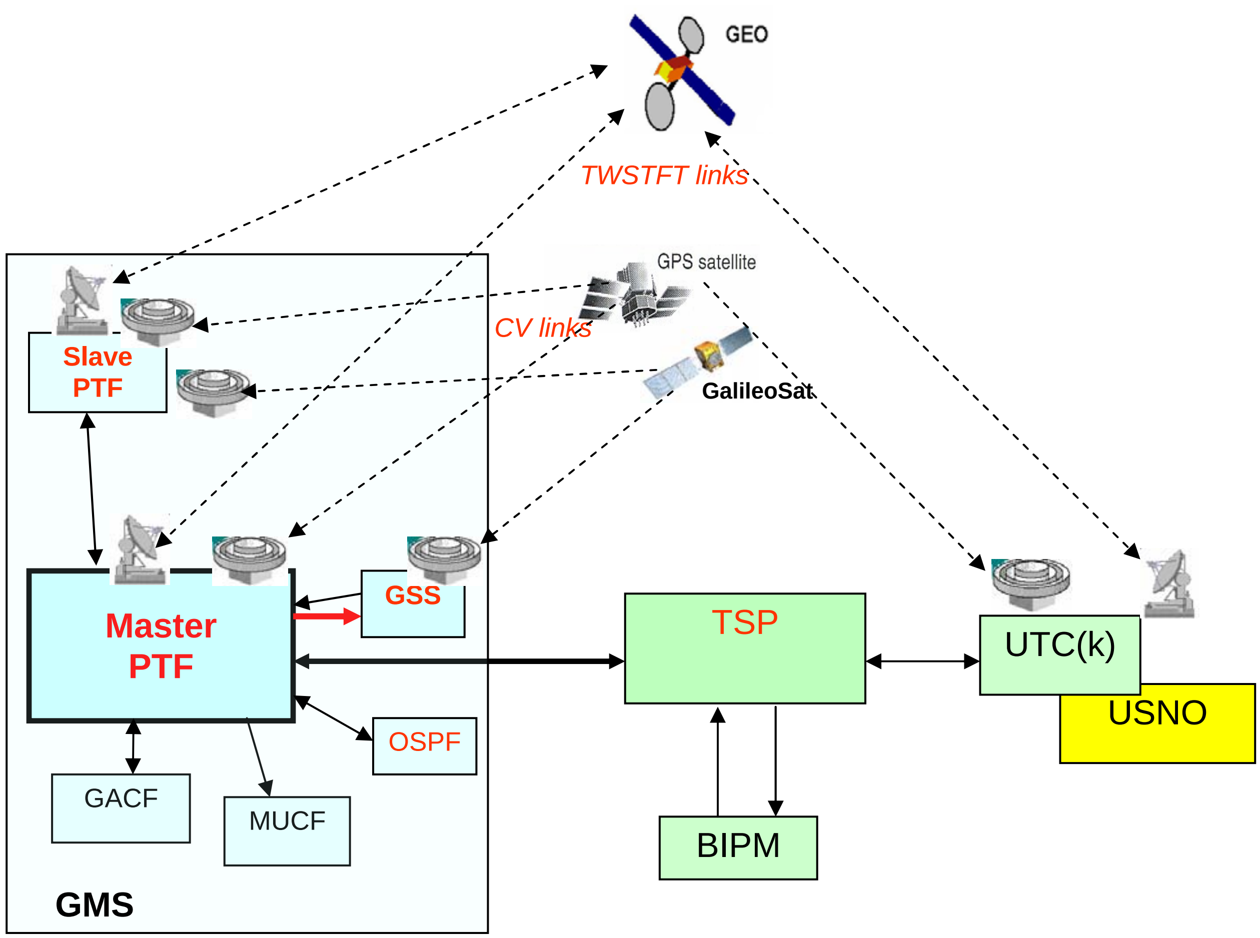

Fig. 2. The PTF Galileo/GPS scenario.

PTF SUBSYSTEMS

The PTF architecture is organized on the following subsystems:

- Time Generation Subsystem
  This S/S includes the timing instrumentation to generate and distribute GST (MC), namely the two active hydrogen masers (AHM) manufactured by T4S (Switzerland) and the 4 cesiums by Symmetricom.

- Time Transfer Subsystem
  This includes the TWSTFT Station, the GPS Time Rx, the OSPF and GSS I/F's, and the time transfer SW for the synchronization links.

- Measurement and Control Subsystem
  This includes the computers with the main SW and the time measurement instruments, namely a time-interval counter and a phase comparator.

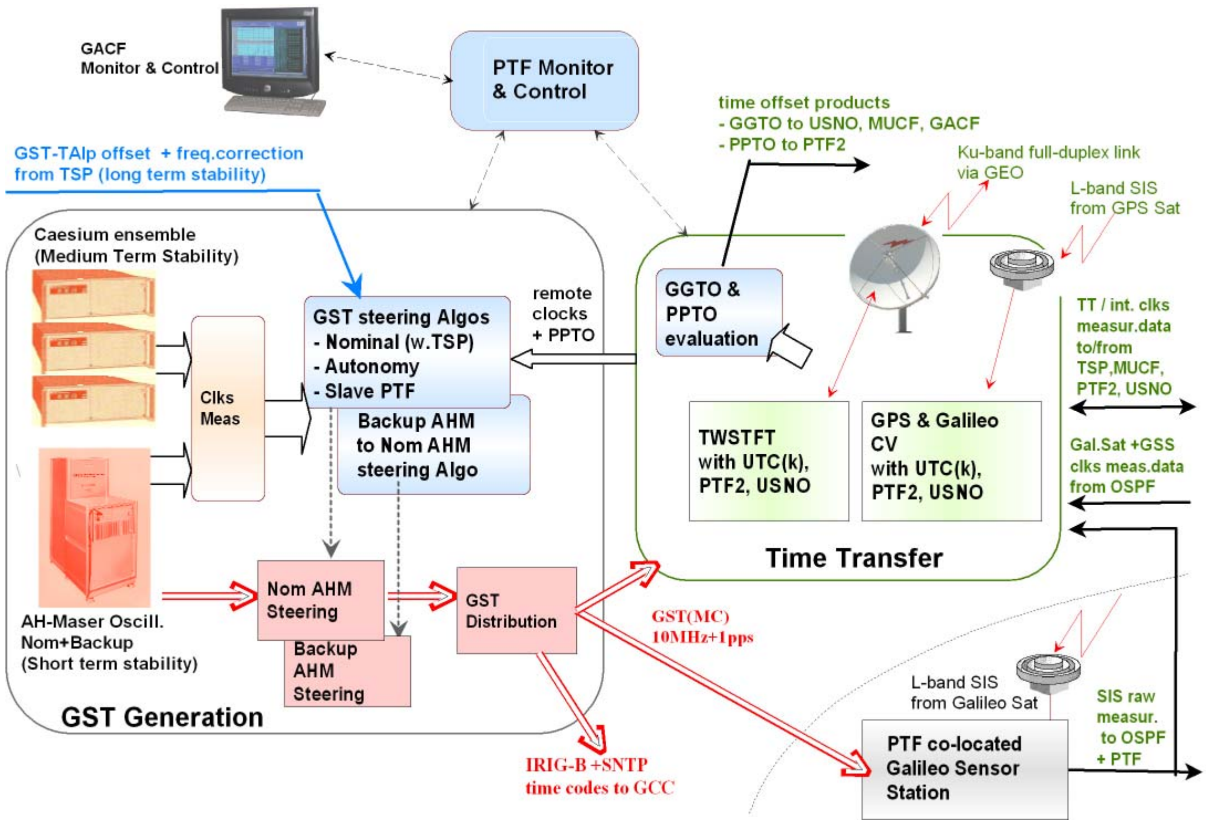

Fig. 3. PTF functional block diagram.

PTF SOFTWARE

The PTF software provides for the control and monitoring of all functions as the timing instrumentation and the external interfaces.

The following special algorithms are foreseen:

- GST Algorithms
  These algorithms are developed with the scientific support of INRIM and are aimed to steer the nominal AHM and generate the GST (MC) in the various operational modes.

- Backup AHM Steering Algorithm
  This algorithm is being developed with the scientific support of SpectraTime to steer the Backup AHM in phase with the Nominal one.

- TWSTFT and CV Algorithms
  These algorithms are being developed by AOS to perform time transfer with UTC (k), USNO, and the PTF2. TW is the baseline measurement technique conducted each hour, and CV is the backup one conducted each 16 minutes.

- GGTO and PPTO Evaluation Algorithms
  The following algorithms are developed with the scientific support of AOS:

  - GGTO (GPS/Galileo Time Offset), coordinated with USNO, estimated for next 24 h and needed for GPS/Galileo interoperability
  - PPTO (PTF1-PTF2 Time Offset) to smooth the transition in case of PTF switching
  - The algorithms are averaging the TWSTFT and CV measurements based on Vondrak filtering
  - PPTO uses also the time measurements from the OSPF (Orbitography & Synchronization Processing Facility). As OSPF continuously measures the satellite and the GSS clocks, it is more accurate.

PTF TIME TRANSFER SUBSYSTEM EQUIPMENT

TWSTFT STATION

The VSAT TWSTFT Station is mainly composed of the following equipment allocated to indoors and outdoors environments (see Fig. 4):

- Satre Modem, interfaced with the transponder at the 70 MHz Intermediate Frequency
- Transponder
- Orto Mode Transducer
- Parabolic Antenna.

The **Satre modem** (see Fig. 5) is manufactured by Timetech, who also manufactures the transponder. This one includes the L-Band to Intermediate Frequency (I/F) down-converter, the I/F to Ku-Band up-converter, and the high-power amplifier.

Considering the recent requirements established by Intelsat in terms of flexibility, a four-port feed Orto Mode transducer is envisaged for the transatlantic TWSTFT links. It affords the capability to cope with any change of horizontal/vertical polarizations in the Tx/Rx of the onboard transponder.

The TWSTFT Station antenna, with support and rotor is shown in Fig. 6.

For frequent calibrations to verify the stability of the TWSTFT Station, the **Satsim** is utilized (see Fig. 7).

Fewer calibration operations are also foreseen by means of the transportable TW station of TUG (Technology University of Graz).

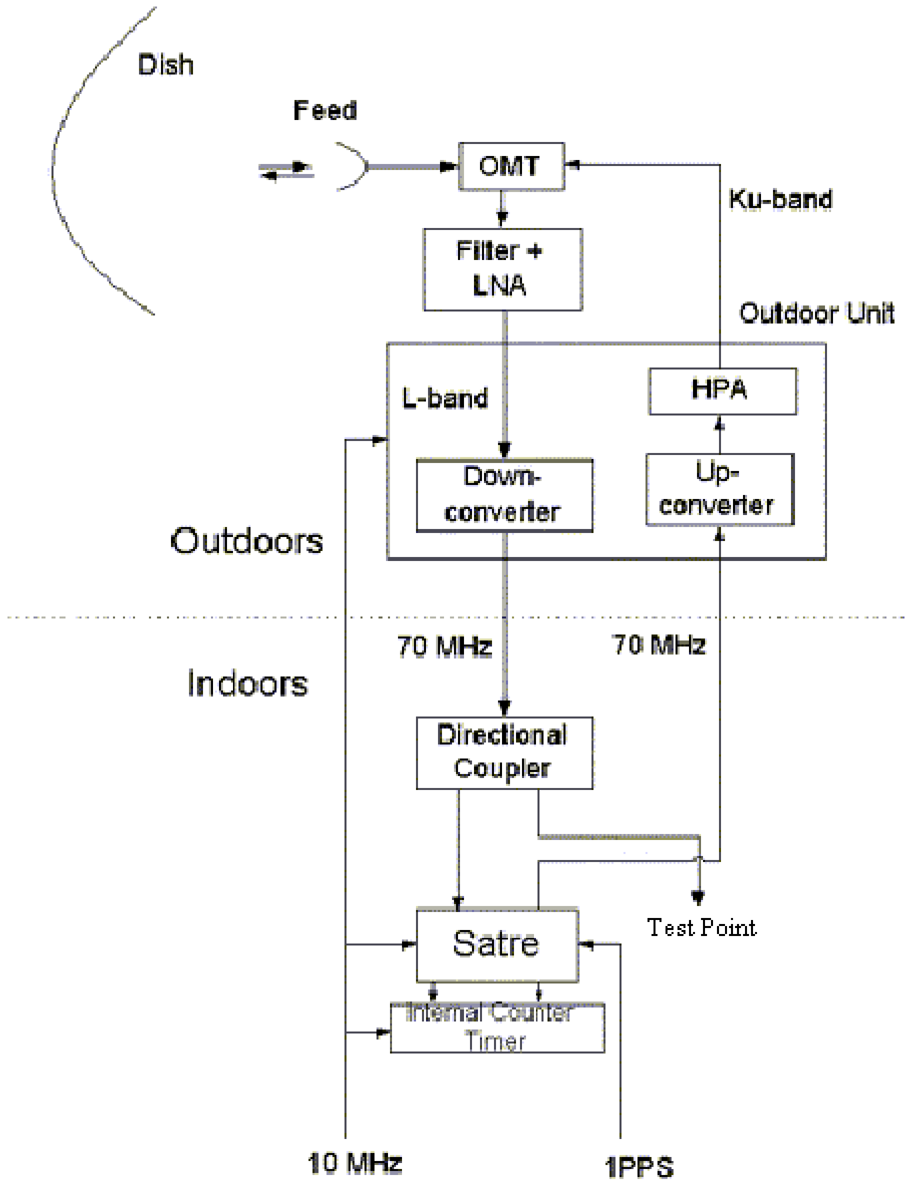

Fig. 4. TWSTFT Station block diagram.

Fig. 5. Satre modem.

Fig. 6. TWSTFT antenna with support and rotor.

Fig. 7. TWSTFT Satsim Controller and outdoor unit.

GNSS TIME RECEIVER

As a backup of the TWSTFT technique, the PTF utilizes Common View. For GPS Common View, it is utilizes the **TTS-3 Time Receiver** (see Fig. 8) made by AOS, showing these features:

- Receiver section based on Javad
- Compatibility with GPS, GLONASS, WAAS, and EGNOS
- GPS pseudorange measurements output in CGGTTS standard: L1C, L1P, L2P, L3P. L3P is used for PTF GPS CV.
- Availability of RINEX standard output.

Fig. 8. TTS3 GNSS Time Receiver.

A future upgrade is foreseen by replacing the TTS3 with a GPS/Galileo dual receiver, allowing directly a GGTO technique of measurement.

TIME MEASUREMENTS

The time transfer S/S equipment and the OSPF I/F allow the PTF to implement several measurement techniques and to generate the time products shown in Table 1.

Table 1. Measurement techniques and time products.

Time Transfer Methods / Time Products	OSPF	TWSTFT	SIS			
			GPS CV (GPS Rx)	Autonomy (GPS Rx)	Autonomy GPS Rx+GSS Rx	GAL CV (GSS Rx)
PTF-UTC(k)		X	X			In future
GGTO		X	X	X	X	
PPTO	X	X	X			X

TIME TRANSFER PERFORMANCE

The time measurement performance required for the **TWSTFT** technique, assuming symmetry of the two sides, is the following:

- **PTF uncertainty contribution : $\leq$ 1.4 ns 1σ**
  For the overall link: $\leq$ 2.0 ns 1σ.

The time measurement performance required for the **CV** technique, after averaging over 24 hours, is:

GPS CV, based on the PTF GPS Rx

- **PTF uncertainty contribution $\leq$ 3 ns 1σ**

Galileo CV, based on the Galileo Receiver of the co-located GSS:

- **PTF uncertainty contribution $\leq$ 1 ns 1σ**

The required performance **of the GGTO** prediction, assuming symmetry between PTF and GPS/USNO, is:

- **PTF uncertainty contribution** (TW and CV) **$\leq$ 3.6 ns 2σ**
- **PTF stability contribution** (TW only)**: ADEV $\leq 2 \times 10^{-14}$ @1 day.**

CONCLUSION

The CTT PTF project is based on a consolidated design and algorithms and state-of-the-art instrumentation. In a short time, we will be ready to enter the implementation phase and finally to start generating the Time Scale for Galileo.

ACKNOWLEDGMENTS

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