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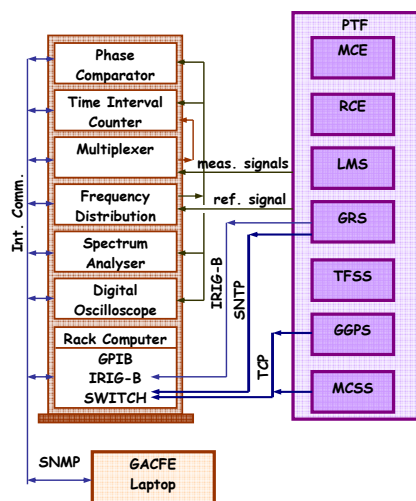
Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary



AIV Platform for the Galileo Precise Timing Facility

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The Precise Timing Facility (PTF) is an element of the Galileo Mission Segment (GMS) responsible for maintaining and distributing the Galileo System Time (GST). The PTF is based on a set of Caesium clocks and Active Hydrogen Maser clocks, the combination of which should be able to provide the required precision and stability of the GST.

To perform the Assembly, Integration and Verification (AIV) activities of the PTF, a dedicated test platform, PTF-AIVP, is needed to prove that the PTF meets the requirements.

The PTF-AIVP will be used to measure and analyse the (physical)

output of the PTF, so that the stringent precision and stability requirements can be verified. Furthermore, it will simulate other Elements in the GMS that are connected to the PTF.

Description of work

NLR together with NMI are responsible for the development of the PTF-AIVP. This includes the overall design, the selection, procurement, and assembly of the hardware, and the development of measurement, control and simulation software.

After integration, the PTF-AIVP is tested at NMI to show compliance with the requirements.

This report is based on a presentation held at the DASIA 2008 conference, Mallorca, 1 June 2008.

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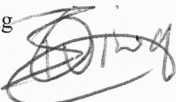
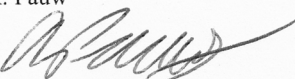
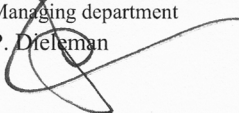
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¹ NMI

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Summary

The Precise Timing Facility (PTF) is an element of the Galileo Mission Segment (GMS) and is responsible for maintaining and distributing the Galileo System Time (GST). The PTF is based on a set of Caesium clocks and Active Hydrogen Maser clocks, the combination of which should be able to provide the required precision and stability of the GST. As the PTF is a critical element within the GMS, diversity is applied in that two PTFs are made by two different companies. The subject of this paper is the PTF that is being developed by Kayser-Threde.

To perform the Assembly, Integration and Verification (AIV) activities of the PTF, a dedicated test platform, PTF-AIVP, is developed by the National Aerospace Laboratory, NLR (the Netherlands) and the Nederlands Meetinstituut (NMI). The PTF-AIVP will be used to measure and analyse the (physical) output of the PTF, so that the stringent precision and stability requirements can be verified. Furthermore, it will simulate other Elements in the GMS that are connected to the PTF.



Contents

1	Introduction	4
2	Time	6
3	PTF Architecture	7
4	Test System Description	9
5	Test System Architecture	9
6	Test System Hardware	10
7	Test System Software	12
	References	15

1 Introduction

The Galileo system provides several services to users around the globe. The satellites in the space segment transmit signals containing time, navigation, and integrity information with which users are able to determine their position.

A network of ground stations all over the world containing Galileo receivers continuously measures the satellites' positions¹. These measurements are sent to the Galileo Control Centres in Europe, to be processed by the Orbital Synchronisation Processing Facility (OSPF) and the Integrity Processing Facility (IPF). The OSPF is responsible for updating the navigation data, such as satellite position parameters and clock parameters, whereas the IPF produces integrity status flags for each satellite.

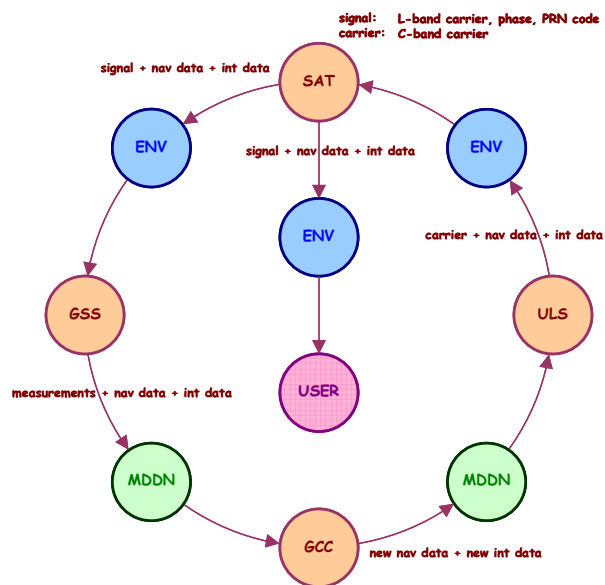


Figure 1 Overview of Galileo navigation & integrity service

Figure 1 shows this continuing process as a closed-loop system, where the ground segment is composed of Galileo Sensor Stations (GSS), Mission Data Dissemination Network (MDDN), Ground Control Centre (GCC), and Up-Link Stations (ULS).

The navigation and integrity data is disseminated by the Message Generation Facility (MGF), residing inside the GCC, to the various UpLink Stations (ULS) that uplink the data to the satellites.

¹ Actually, the pseudo-range from satellite to receiver is measured as a time difference.

For navigation, accurate positioning is necessary. Satellite navigation systems such as GPS and Galileo are based on electromagnetic signals travelling at the speed of light c ($3E8$ m/s). These signals are generated by atomic clocks that generate a frequency upon which a code is modulated at a certain chipping rate. A receiver calculates the pseudo-range by locking on the signal, determining which 'chip' was sent, and subtracting this from the current 'chip' time of its internal clock.

The orbit of the satellites is about 20.000 to 25.000 km above the earth's surface, which means that the signal travels for less than 0.1 seconds. Even a small deviation in the 'chip' time of 1 millisecond would lead to a positional error of 300 meters. For accurate positioning, the error in the on-board clocks must be in the order of 1 nanosecond per day (equivalent to a stability of about $1E-14$).

The more stable a clock, the better the result. Therefore, the on-board clocks are closely monitored and on-board clock corrections are applied frequently. These corrections allow the on-board clocks to be synchronised to the Galileo System Time (GST), which is a unique time reference used by the entire Galileo system: measuring Galileo Ground Stations (GSS), various Processing Facilities (OSPF, IPF), and the message distribution elements (MGF, MUCF, ULS).

The Galileo ground segment has two GCCs, each with a Precise Timing Facility (PTF) providing a very stable reference GST to all elements in the GCC. The two PTFs are developed by separate companies; this diversification is applied to reduce the possibility of common failures in this important element.

2 Time

Even in today's physics, time is still a difficult quantity to grasp. It seems that time is virtual, and can only be measured indirectly by observing physical phenomena. Time can be measured as a duration Δt :

$$\Delta t = \Delta l / V \quad (1)$$

where V is a constant (eigen)speed and Δl is a known distance. For example, if a canon is fired at 3.4 km distance, you can hear the bang after 10 sec. In the opposite way, you can also derive the distance to a thunder storm.

If the distance is not known, then a frequency can be used:

$$\Delta t = l / f \quad (2)$$

This is the basis of almost all clocks: the rotation of the earth (with its 'fixed' rotational speed and 'fixed' radius) has provided time to mankind since thousands of years.

Today's best clocks are based on behaviour of atoms and electrons. They act as a frequency standard generating a clock signal with a fundamental frequency that achieves a high degree of accuracy and precision.

Time is usually represented absolutely (see the wall clock). For this, a point of origin, 'epoch', has to be set: 11:00 stands for the 11th hour after midnight and 2008 stands for the 2008th year Anno Domini. With the measured duration e.g. by counting number of intervals of a clock signal, a wall clock time can be obtained.

$$t = epoch + \Delta t \quad (3)$$

3 PTF Architecture

The PTF is the element responsible for maintaining and distributing a stable GST. It is located in the GCC in a specially designed room to minimise external influences such as vibrations and electromagnetic interference (EMI). Distribution is done via dedicated 1pps signals (IRIG-B) and via the site network through the Simple Network Time Protocol (SNTP).

Figure 2 shows the PTF divided in its subsystems:

- Master Clock Ensemble (MCE)
- Reference Clock Ensemble (RCE)
- Local Measurement Subsystem (LMS)
- GST Realisation Subsystem (GRS)
- GST/GGTO Processing Station (GGPS)
- Time & Frequency Data Transfer Subsystem (TFSS)
- Monitoring & Control Station (MCSS)

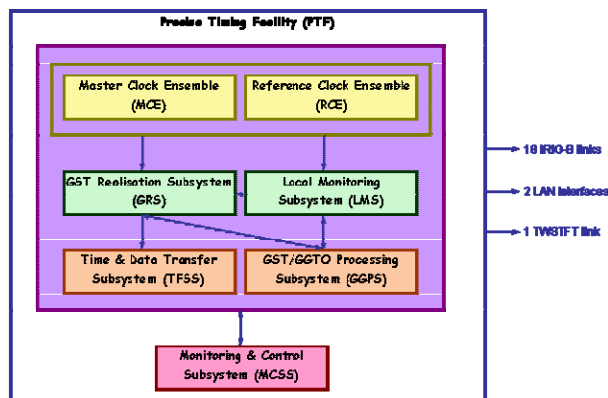


Figure 2 PTF Architecture

The MCE consists of a set of Active Hydrogen Masers (AHM) and the RCE of Caesium (Cs) clocks. The two AHMs and four Cs clocks will be able to provide both short-term frequency stability and long-term time stability. The AHMs are responsible for short-time timing, while the Cs clocks are used to remove long-term drift. The GST Frequency Offset (normalized to TAI) should be better than $5.5E-14$ per day.

The LMS is used for measuring the output of the clocks through a time interval counter and a phase comparator. Physical realisation of the GST is provided by the GRS, which serves as a Simple Network Time Protocol (SNTP) server. The GRS provides 18 IRIG-B links, one to each of the GMS Elements.

The primary responsibility of the GGPS is to monitor the performance of the clocks via the LMS and to command the GRS. Furthermore, it calculates the GGTO, which is the offset between GPS System Time and Galileo System Time. The TFSS is used to synchronise the time with the other PTF element via Two Way Satellite Time and Frequency Transfer (TWSTFT). All of the above-mentioned subsystems are monitored and controlled by the MCSS, which in turn reports to the Galileo Assets Control Facility (GACF).

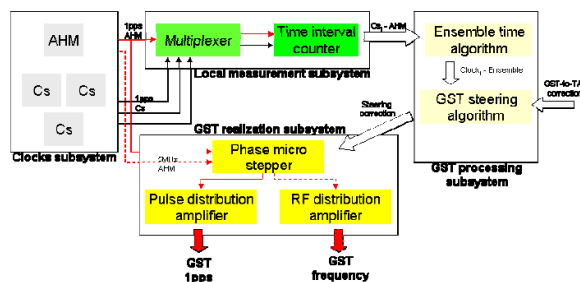


Figure 3 PTF Time Generation/Steering Chain [1]

Besides the IRIG-B links, the PTF has network interfaces to the other GMS Elements, as well. In total, the PTF has the following interfaces:

- PTF - GMS SNTP timing interface: via the Mission Data Dissemination Network (MDDN) to the whole of the GMS, i.e. also to remote sensor stations and uplink stations
- PTF - GCC IRIG-B timing interface: to the GMS Elements located in the Galileo Control Centre (GCC)
- PTF - GCC GSS timing interface: to the Galileo Sensor Station (GSS) located in the GCC
- PTF - GACF interface: to the Galileo Assets Control Facility (GACF) located in the GCC
- PTF - MUCF interface: to the Mission Uplink & Control Facility (GACF) in the GCC
- PTF - SPF interface: to the Service Products Facility (SPF) located in the GCC
- PTF - TSP interface: to the Time Service Provider (TSP) outside the GCC via the SPF
- PTF - GSS interface: to the Galileo Sensor Station (GSS) located in the GCC
- PTF - PTF interface: to the other PTF located in the other GCC
- PTF - OSPF interface: to the Orbit & Synchronisation Processing Facility (OSPF) in the GCC
- PTF - AIVP interface: to the PTF AIV Platform (PTF-AIVP)

4 Test System Description

To verify PTF requirements, test scenarios are defined in the PTF test plan. The Assembly, Integration & Verification Platform (AIVP) must be able to execute these scenarios.

For this, the PTF-AIVP functions both as a measurement system, acquiring data directly from internal equipment such as the clock ensembles and analysing the external output (IRIG-B, SNTP), and as a simulation system, emulating the LAN interfaces.

The main focus is on the measurement functions, as a stable GST is the key output of the PTF.

5 Test System Architecture

The design of the PTF-AIVP therefore contains mainly measurement equipment, see figure 4.

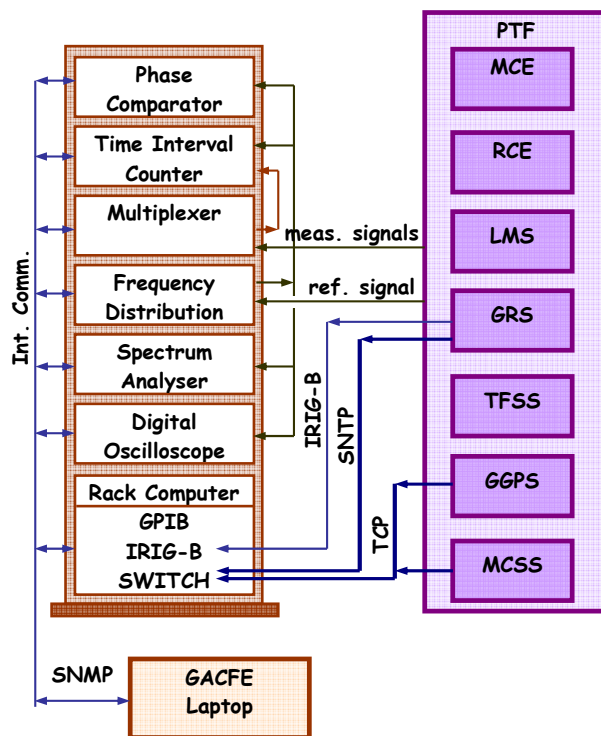


Figure 4 PTF-AIVP Hardware Architecture

The PTF-AIVP consists of hardware and software components. Most of the hardware will be used for measurements of the signal outputs of the PTF. The software controls the measurement equipment and simulates the counterparts of the PTF.



6 Test System Hardware

The PTF-AIVP has the following hardware components:

- Multi-Channel Phase Comparator (MCPC), responsible for measuring the phase of a clock signal and compare this to a reference signal.
- Time Interval Counter (TIC), single channel, responsible for measuring the time intervals of a clock signal using a reference signal.
- Multiplexer (MUX), used to connect multiple clocks to the TIC and to switch sequentially to the clock signal to be measured.
- Frequency Distribution Amplifier (FDA), responsible for distributing the reference clock signal to the other PTF-AIVP equipment.
- Spectrum Analyser, responsible for measuring the physical characteristics of the clock signals.
- Digital Oscilloscope, general purpose, among others for obtaining the trigger level of the TIC.
- Rack Computer, running the software for measuring, logging, and simulating.
- Laptop, responsible for running the GACF Emulator software.
- Switch, responsible for LAN conversion from the Ethernet ports of the PTF to the Ethernet ports of the AIVP.

The block diagram in figure 5 shows how the components are connected.

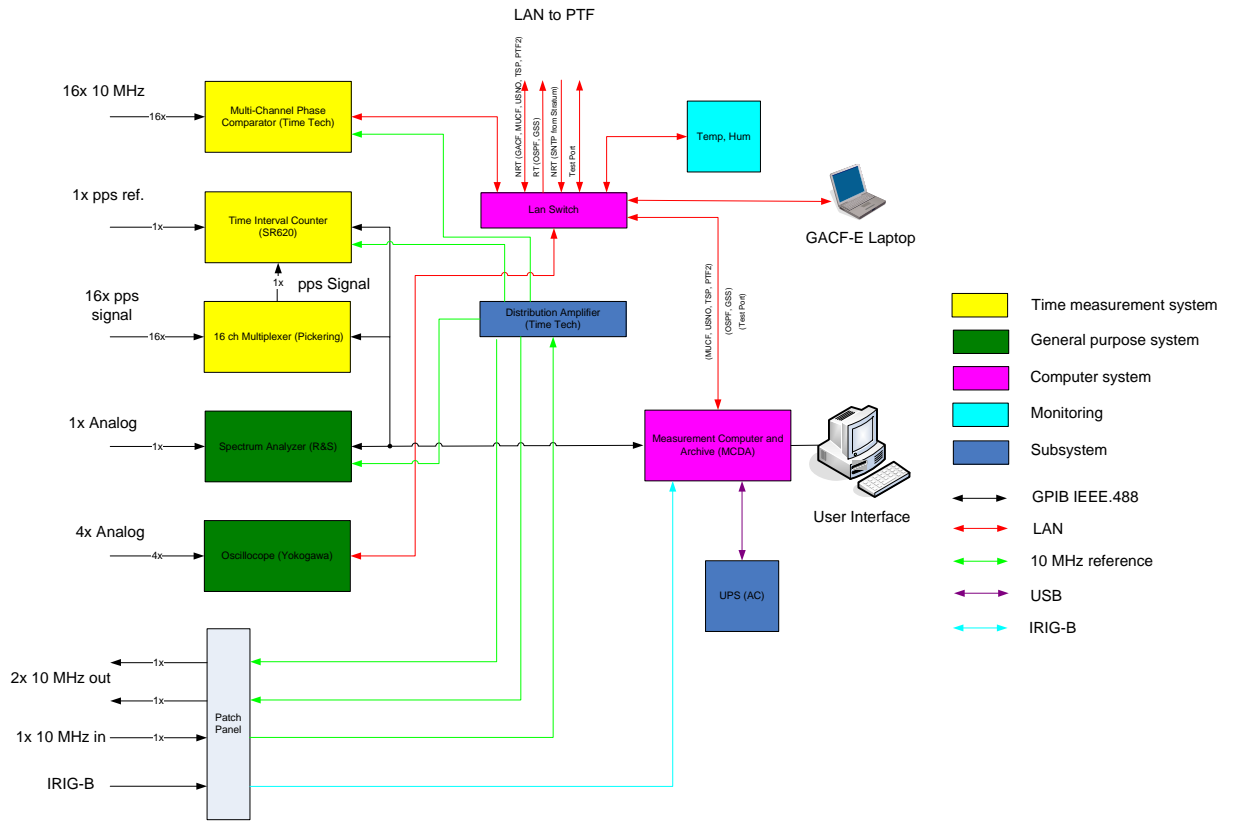


Figure 5 PTF-AIVP Block Diagram

7 Test System Software

The software is developed in LabView, a high-level graphical software development tool that is used often in a laboratory environment for data acquisition.

The following PTF-AIVP software components are identified (figure 6):

- Test Equipment Software (TESW), for controlling the AIVP equipment for triggering & acquisition, and for storing the acquired measurements data sets.
- Clock Behaviour Software (CBSW), for a quick overview of the behaviour of the clocks and GST(MC) from the signals acquired by the AIVP hardware, and for comparing the reference and actual time data.
- External Interfaces Software (EISW) for handling the interfaces with the PTF.
- Software for monitoring & commanding of the PTF (GACFE).

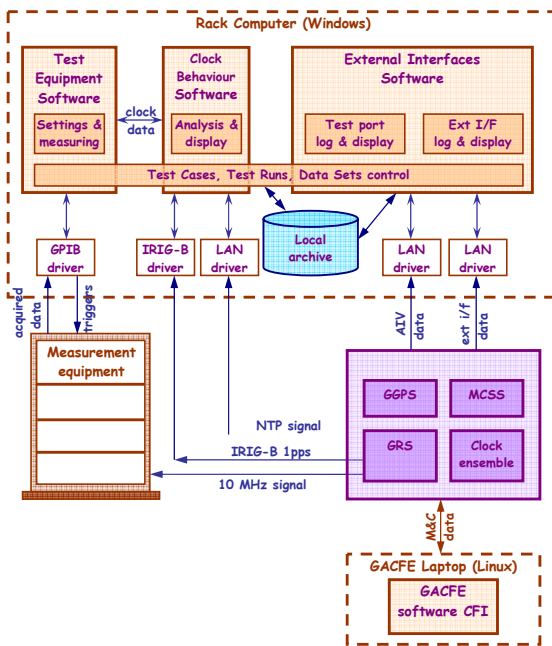


Figure 6 PTF-AIVP Software Architecture

The software components are embedded in user interface. When starting the software, a main panel appears that shows relevant information and allows the user to start measurements and/or to run a simulation.



Figure 7 PTF-AIVP Main Panel

Before starting the measurements, the equipment must be configured. For example, the trigger levels of the TIC need to be set for each channel.

Since the TIC can only measure a single channel at a time, the software must command the MUX to activate the channel to be connected to the TIC. Then, the TIC should be commanded to set the applicable trigger level and to perform a measurement. This process is repeated for all selected channels.

It takes some time to issue the commands and perform a measurement. A dedicated setting can be used to set the interval between consecutive measurements.

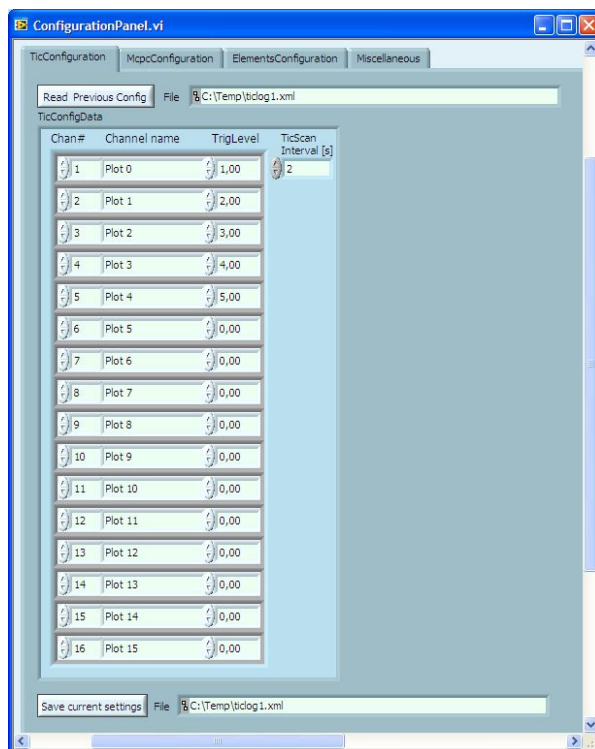


Figure 8 PTF-AIVP Configuration Panel

While the PTF-AIVP is measuring, the results can be viewed in separate displays for the MCPC and the TIC (see figure 9).

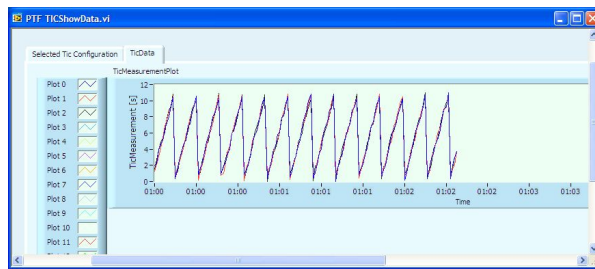


Figure 9 PTF-AIVP TIC Display

The simulation software implements the communication protocols between PTF and GMS Element, as described in the PTF Interface Control Document (ICD).

Six interface types can be discerned for the PTF:

- a message interface for real-time data exchange, based on TCP/IP or UDP/IP over Ethernet;
- a message interface for status management, based on the *Simple Network Management Protocol* (SNMP) over Ethernet;
- a file transfer interface using the *File Transfer Protocol* (FTP) over TCP/IP over Ethernet;
- a time synchronisation interface for timing, based on the *Simple Network Time Protocol* (SNTP);
- a time synchronisation interface using *IRIG-B* standard;
- 1 pps and 10 MHz time and frequency signals.

The PTF-AIVP software deals with most of these interfaces: only the SNMP interface is handled by the GACF Emulator software, which is provided by GMS.

The simulation models are simple emulators that read messages from a file to be sent to the PTF, that send files to the PTF via FTP, and that record all incoming messages and files from the PTF.

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2. Bedrich, S., Müncheberg, S., Boulay, J., Kroon, E., Oving, B., Davis, J., Bauch, A., Rost, M., Wolf M. (2008). Design and Performance of the Precise Timing Facility for Galileo. 22nd European Frequency and Time Forum (EFTF) Meeting (paper 095).