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Laser time transfer and its application in the Galileo programme

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Abstract

We are presenting the new instrument, new technology available and new measurement technique proposal for the Galileo programme – optical detector for the laser time transfer and one way laser ranging ground to space.

Combining the laser pulse emission times, propagation delays and satellite arrival times the ground to space clock comparison may be accomplished. The timing precision of the order of 1×10^{-12} s and a time transfer accuracy of 50 ps is achievable. This precision and accuracy is at least one order of magnitude better in the optical region than in the radio frequency wavelength region. All the components of the proposed instruments are available in Europe, the ground segment of the proposed project is existing, the measurement techniques and data flow and processing procedures are well established. The implementation of new picosecond timing technologies and the laser time transfer into the Galileo programme will improve the precision and accuracy of the satellite on-board time scale and position prediction with unprecedent precision and accuracy. Both these facts will contribute to the Galileo system overall accuracy and performance and simultaneously will enable new experiments in fundamental physics.

Keywords: Time transfer; Laser ranging; Photon counting; Compass M1; Jason-2

1. Operating principle

We are presenting the new instrument, new technology available and new measurement technique proposal for the Galileo programme: optical detector for the laser time transfer ground to space with unprecedent precision and accuracy. The idea of laser time transfer itself is not a new one (Fridelance and Veillet, 1995; Fumin et al., 2008), however, the recent achievements in picosecond lasers, photon detectors, timing technology and the availability of on-board hydrogen maser frequency reference open new perspectives for applications. The Galileo navigation network might benefits from these achievements.

The project goal is the high accuracy comparison of time scales between the ground station and space clock located on the Earth orbiting satellite. The project is a spin-off of the existing projects of laser ranging to artificial Earth satellites (Pearlman et al., 2002). In satellite laser ranging, the satellite equipped with optical retro reflectors is ranged using short laser pulses. A short and powerful laser pulse is transmitted toward a satellite and part of the energy is reflected by the retro reflector on board the satellite back to the ground.

The operating principle is as follows, see Fig. 1.

The reflected optical pulse is detected at the ground station and the pulse propagation time is evaluated. The range ***D*** is determined on the basis of the measured laser pulse propagation time toward the target satellite and back again. The epoch of transmission of laser pulse ***T*** is monitored with respect to the local clock for each laser pulse emission. For the laser time transfer experiment the existing satellite laser ranging ground stations will be used. The satellite will be equipped with retro reflectors to enable the laser ranging and, additionally, with an optical detector which detects and time tags the arrival of laser pulse at the

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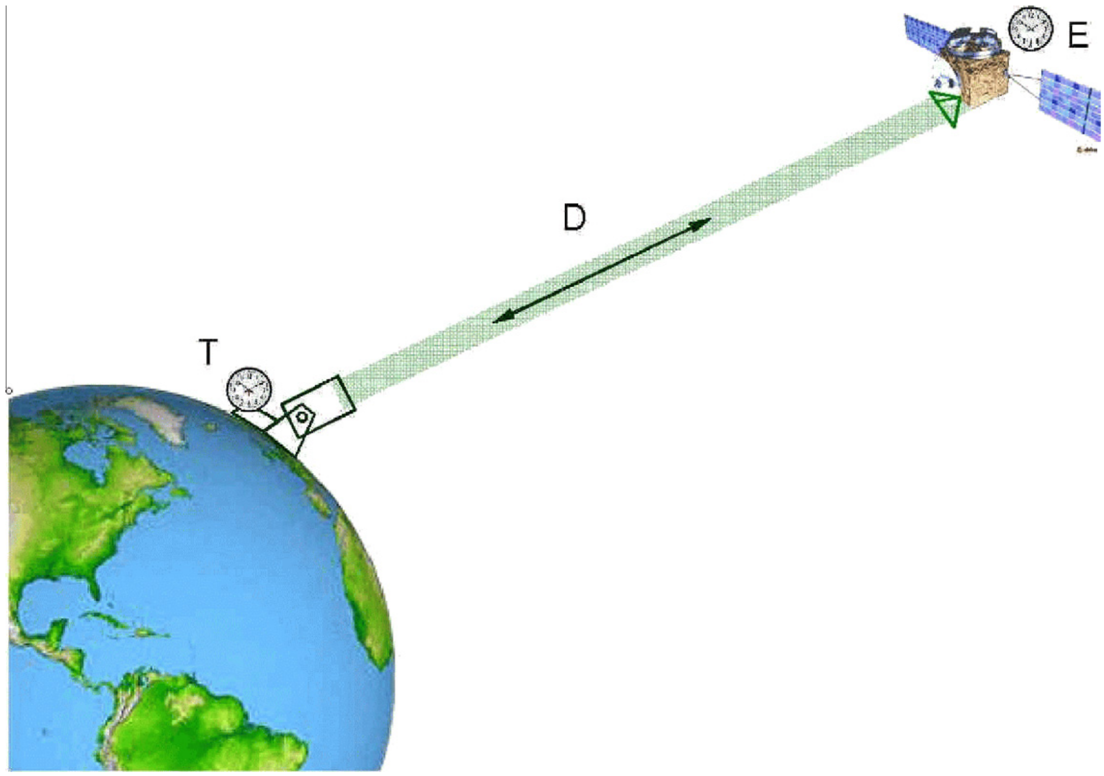

Fig. 1. The principle of ground to space clock synchronization by means of laser pulses. The satellite range ***D*** is measured by laser ranging technique, the laser emission time ***T*** is recorded with respect to ground clock, the arrival time of the laser pulse to the satellite ***E*** is recorded by on-board clock.

satellite. The satellite range ***D*** is measured by laser ranging to the on-board retro reflectors and the arrival time of the laser pulse to the satellite ***E*** is recorded by on board clock and the recorded time tags are transmitted to ground via satellite telemetry channel. Combining the laser pulse emission times, propagation and instrumental delays and satellite arrival times, the space clock and the station clock may be compared. The Satellite laser ranging (SLR) technique has been well developed in recent years, ranging and epoch timing precision of the order of 1×10^{-11} s may be achieved. The range is related to time interval via the speed of light; one millimeter range corresponds to 6.7 ps of two way propagation time.

The accuracy of the ground to space signal propagation delay is extremely difficult to quantify. Typically the consistency of results acquired using different techniques and/or the results of multiple frequency experiments are used to estimate the propagation delay accuracy. The accuracy of the laser ranging measurements is limited mainly by the atmospheric propagation delay model. Its accuracy is high; the absolute error is expected to be well below 4×10^{-11} s (Pearlman et al., 2002). This accuracy is more than one order of magnitude better in the optical region than in the radio frequency region, which is expected to be in the order of 1×10^{-9} s (Defraigne et al., 2008). Fortunately, the absolute error in the atmospheric correction is completely compensated in a one way laser time transfer when combined with satellite laser ranging at the same time. The absolute propagation delays associated with the optical timing chain may be calibrated down to the level of several tens of picoseconds. This enables to carry out the laser time transfer ground to space with the precision of units of picoseconds and with the accuracy of 50 ps.

2. Existing laser time transfer missions

2.1. Laser time transfer (LTT)

The very first laser time transfer ground to space was carried out using the LASSO experiment in the nineties (Fridelance, 1995). However, the laser, optical detection and timing technology available were limiting both the precision and data yield at that time.

The first laser time transfer (LTT) in picosecond time domain was completed on board of the Compass M1 satellite launched April 14, 2007. The satellite is a part of the Chinese global navigation system. Its orbit height is about 21 000 km.

Extremely simple and rugged design of the optical receiver has been used (Prochazka et al., 2007). It relies completely on single photon approach, only. This approach permits to minimize the systematic errors due to the optical signal intensity fluctuation and to minimize the on-board hardware complexity at the same time. The photo of the technology demonstrator of the optical receiver in a dual setup is in Fig. 2.