Preliminary Results of the Laser Time Transfer (LTT) Project

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Abstract

The LTT payload onboard the Chinese experimental navigation satellite COMPASS-M1 with an orbital altitude of 21500 km was launched on April 13, 2007. The payload included dual-SPAD-detector, dual-timer based on TDC device, DSP, power supply and a LRA with the total mass of 7.05 kg (including LRA's 2.45 kg) and the power consumption of 18 W. The time transfer experiment at the Changchun SLR station has been performed since August 2007. The experiment has shown that the time and relative frequency differences between the ground hydrogen maser and the China-made space rubidium clocks have been obtained with the time precision of about 300ps for single measurement and the uncertainty of frequency difference measurement of about 3×10^{-14} *in 2000 seconds. After 17 months orbital flight, the LTT payload has kept its good performance.*

Introduction

The laser time transfer (LTT) project is a dedicated one for the COMPASS navigation system that uses for the time comparison between the space and the ground clocks with the laser ranging technique. The principle of LTT project and some ground testing of the flight module of the LTT payload were introduced in detail on the Laser Ranging Workshop in Canberra in 2006. [1]

The LTT payload onboard the Chinese experimental navigation satellite COMPASS-M1 was launched on April 13, 2007 (UTC). The time transfer experiment at the Changchun SLR station has been performed since August 2007. The time differences and the relative frequency differences between the onboard rubidium clocks and the ground hydrogen maser have been obtained.

Principle and Specification of LTT payload

The principle of LTT is shown in Fig. 1.

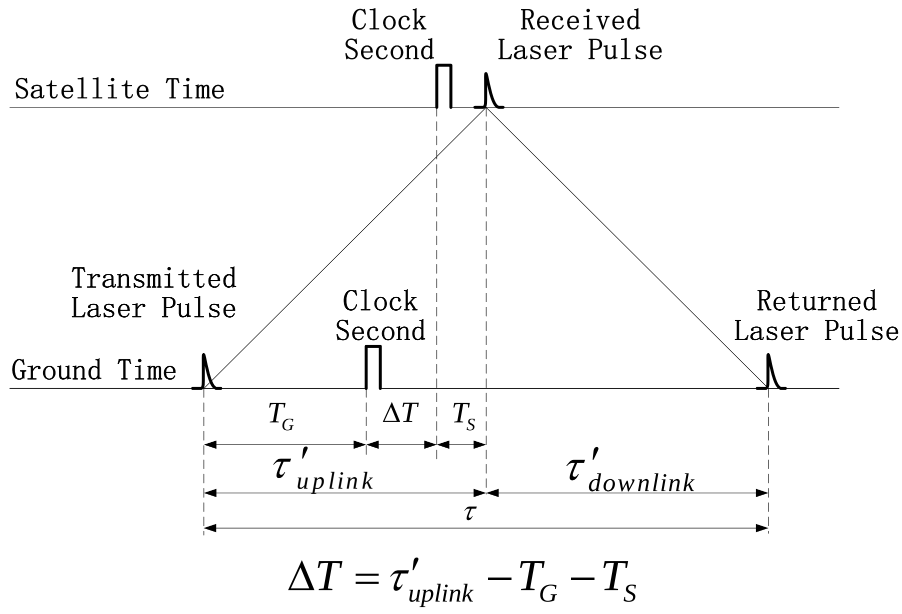

Figure 1. Principle of Laser Time Transfer (LTT)

The specifications of the 40 μm SPAD detector, the photos of LTT detector and timer can be seen on the Proceedings of Canberra Workshop in 2006 [1] [2]. The field of view of the detector is about 28°, and the bandwidth of the interference filter is about 8.8 nm.

Performance of the LTT ground station at Changchun

The Changchun SLR station was identified for the LTT experiment at the beginning of 2007. Some modifications were made, including a new powerful laser, a new transmitting telescope (210 mm aperture), two event timers (A032-ET), one set of hydrogen maser (made by Shanghai Observatory) and a LTT control package. The new laser borrowed from the North China Research Institute of Electro-Optics (NCRIEO) in Beijing is an active-active mode-locked Nd:YAG laser. The output is as follows: 100-150 mJ in 532 nm, 250 ps width, 20 Hz repetition. The laser firing at the Changchun SLR station was strictly controlled by the controller according to the range variation of the satellite. Therefore the laser pulses can arrive at the LTT detector in a short time interval behind the second pulses of the rubidium clock, in order to avoid the influence of the noises from the Earth’s albedo. The laser firing jitter is about 10 ns.

Fig. 2 shows the LTT control room at Changchun. Fig. 3 shows the block diagram of the Changchun station for LTT experiment.

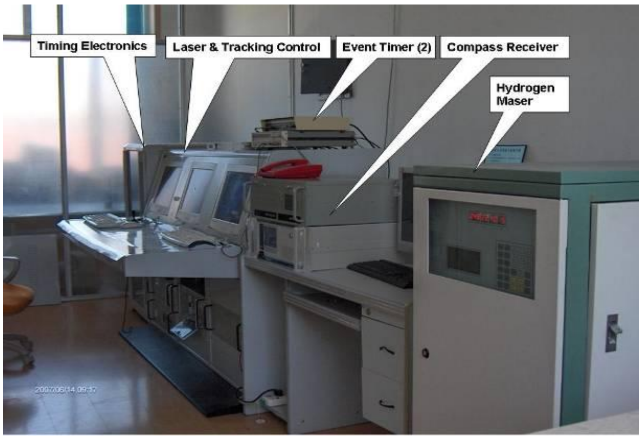

Figure 2. Changchun SLR & LTT Control Room

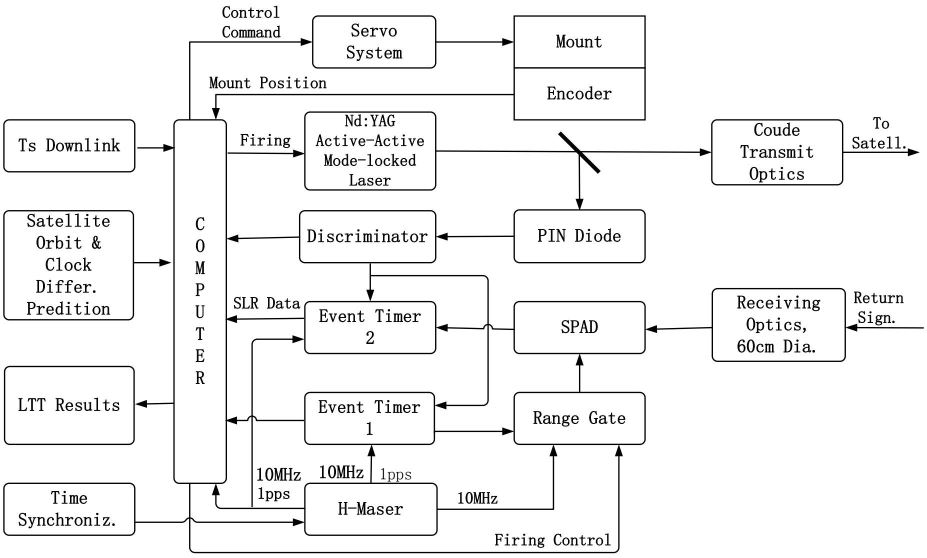

Figure 3. Block Diagram of Ground Station for LTT Experiment

Some results of the LTT experiment

The LTT experiment has been performed in August 2007. At the beginning, the experiment was suffered from the strong background noises due to the wide FOV.
Until December 2007, more LTT data had been obtained, but the experiment can be carried out in the nighttime only.

During the period of flight, the LTT detector had been directly exposed to the sun several times, but it has been rugged and safe. Some results of the LTT experiment are shown in the following figures (Fig. 4, and Fig. 7-10). Fig. 4 shows the 1552 clock differences were obtained during the pass of about 46 minutes when the satellite was in the Earth's shadow. Fig. 5 shows that sunlight can enter into the FOV of the detector when the satellite is nearby the Earth's shadows, because the FOV of the detector is about 28° which is bigger than the Earth's disk angle (26.4°) for the COMPASS-M1. Fig. 6 shows the whole process that the COMPASS-M1 was before, pass into and after the Earth's shadow on January 10, 2008. The passes B and D show the very strong noises caused by the direct sunlight.

Fig. 7, 8 and 9 shows the LTT results during the three time intervals respectively. We can see the detector recovered quickly and can keep the good timing performance after being exposed directly to the Sun (see Fig. 9). Fig. 10 shows the LTT payload was not in the Earth's shadow for 2 hours.

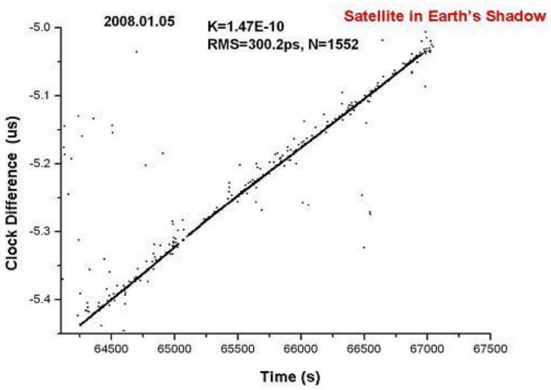

Figure 4. Clock differences from LTT on Jan 5, 2008

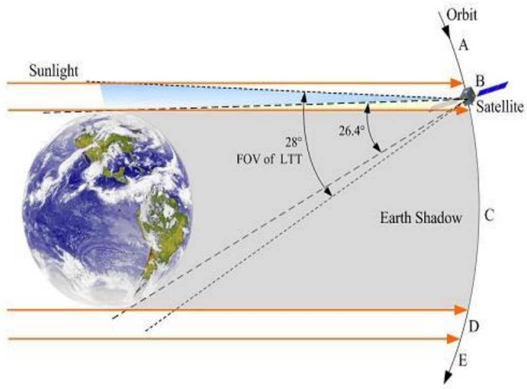

Figure 5. Sunlight can enter the FOV of detector nearby the Earth's shadow

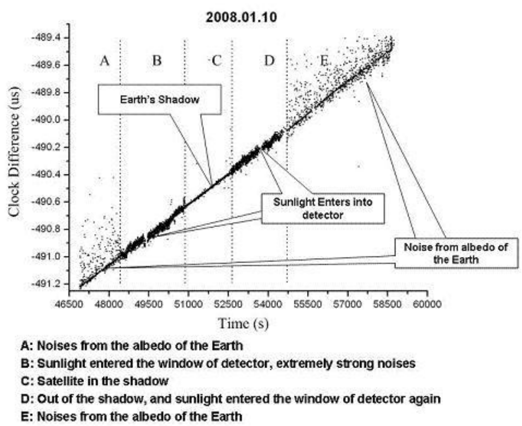

Figure 6. The whole process from LTT on Jan 10, 2008

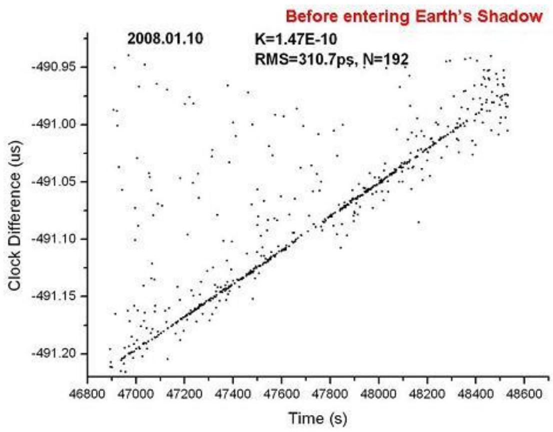

Figure 7. Clock differences before Earth's shadow on Jan 10, 2008

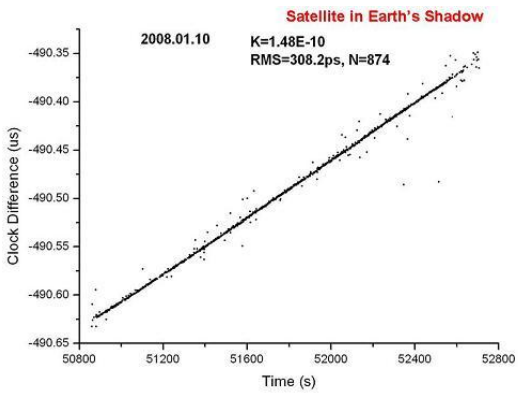

Figure 8. Clock differences in Earth's shadow on Jan 10, 2008

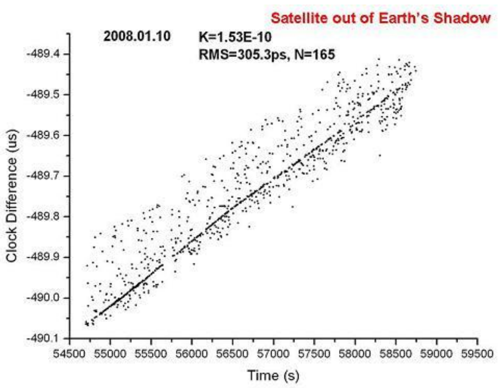

Figure 9. Clock differences after Earth's shadow on Jan 10, 2008

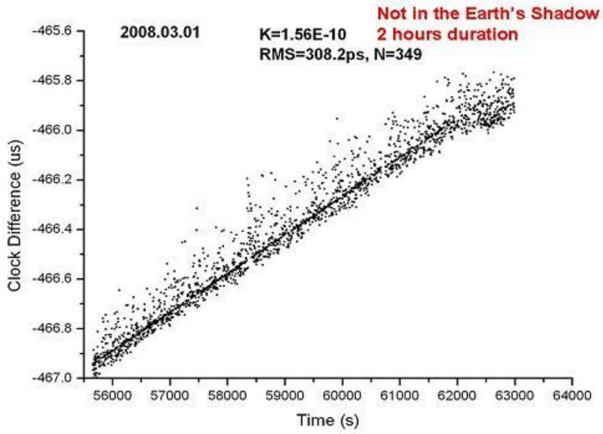

Figure 10. Clock differences on Mar 1, 2008 (no Earth's shadow)

During the LTT experiment, the time differences and the relative frequency differences between the China-made space-borne rubidium clocks and the ground hydrogen maser have been obtained successfully. The precision of the measurement for the time differences is about 300 ps (single measurement). The frequency drift of the China-made rubidium clocks is about 1.47E-10 and the stability of frequency is about E-13. The uncertainty of the measurement of the relative frequency differences is about 3E-14 in 2000 seconds.

Plans for Next Missions

2 new LTT payloads for the next Compass missions, IGSO orbit (24 hr period, with 55° inclination). One mission will be in orbit by mid-2009, another will be by the beginning of 2010.

Some upgrading of the new LTT payloads:

1) Add gating circuit in the payload for reducing the effect of the dead time of SPAD. It is of importance when the noises are strong.[3]
2) Reducing the FOV and adopting two FOV for two detectors respectively: one is bigger for nighttime experiment, another is smaller for daylight experiment.
3) 20 Hz onboard timing data will be downloaded in stead of 1 Hz before. During last mission(Compass-M1), only 1Hz timing data were downloaded in spite of 20Hz laser firing at the ground station, so a lot of useful data were lost.
4) Narrowing the bandwidth of the interferometric filter from 8.8nm to 4nm due to smaller FOV for IGSO orbit.

References

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[3] Ivan Prochazka, Josef Blazej, Photon Counting Detectors for future Laser Time Transfer Missions, this Proceedings, Poznan, Poland, 2008.