

---

## Progress on Laser Time Transfer Project

Yang Fumin<sup>1</sup>, Huang Peicheng<sup>1</sup>, Chen Wanzhen<sup>1</sup>, Zhang Zhongping<sup>1</sup>,  
Wang Yuanming<sup>1</sup>, Chen Juping<sup>1</sup>, Guo Fang<sup>1</sup>, Zou Guangnan<sup>2</sup>, Liao Ying<sup>2</sup>,  
Ivan Prochazka<sup>3</sup>, Karel Hamal<sup>3</sup>

1. Shanghai Observatory, Chinese Academy of Science, Shanghai, China
2. China Academy of Space Technology, Beijing, China
3. Czech Technical University in Prague, Czech Republic

### Abstract

*The purposes of the Laser Time Transfer (LTT) experiment are to synchronize the atomic clocks in space to ones on the ground, and to verify the relativity theory. The LTT payload in space includes a dual-SPAD detector, a timer based on TDC device, control unit and a LRA. The expected uncertainty of measurement of clock differences for single shot is about 200ps, and the uncertainty of measurement for the relative frequency differences for two rubidium clocks is about  $5 \times 10^{-14}$ /1000 seconds. The LTT flight module is ready and is waiting for the flight mission in 2007-2008.*

### Introduction

Based on the successful time transfer by laser pulses between ground stations in 2003<sup>[1]</sup>, the Laser Time Transfer (LTT) project between satellite and ground stations was initiated in 2004. The goals of the LTT are as follows: 1) Evaluation of performance of space clocks which are rubidium's now, and will be hydrogen clocks in the future. 2) Verification of the relativity

Shanghai Astronomical Observatory, in cooperation with the China Academy of Space Technology in Beijing, has been in charge of the LTT project. The Philosophy of the project is to make a payload as simple as possible on a satellite in a short time to verify the capability of the time transfer by laser pulses between space and ground clocks. So, a simple 40um SPAD detector with 100ps timing resolution<sup>[2]</sup> and the TDC devices with lower resolution(125ps)<sup>[3]</sup> have been chosen for the space module. The LTT project has kept going smoothly since 2004. The flight module has been built and has passed the space environmental testings.

### Principle of LTT

Fig.1. shows the principle of LTT.  $\Delta T$  –time difference of second pulses between space and ground clocks.  $T_G$  – time interval between the transmitting laser pulse and second pulse of the ground clock.  $T_s$  – time interval between the received laser pulse and second pulse of the space clock.  $\tau$  – flight time of laser pulse between ground station and satellite. So we have:

$$\Delta T = \frac{\tau}{2} - T_G - T_s$$

where the relativity effect, system delays, atmospheric correction and so on are not included.

Fig.2. shows the block diagram of LTT. There are three main parts onboard: detector, timer and retro-reflectors.

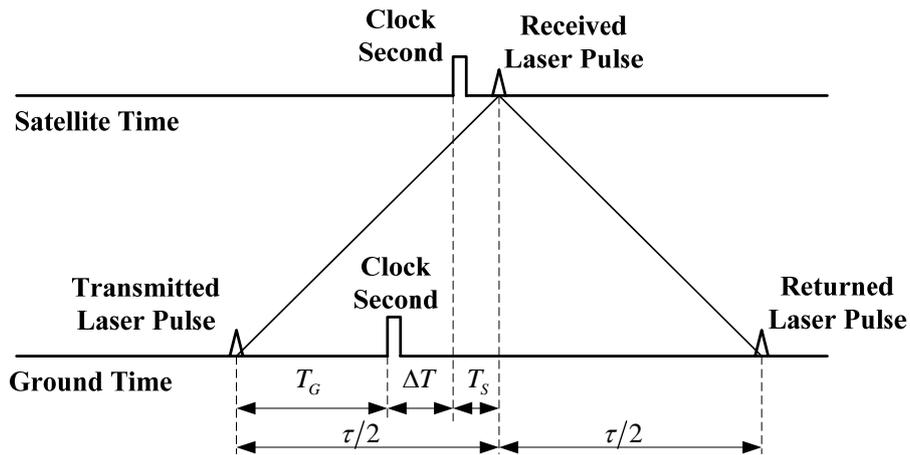


Fig.1. Principle of Laser Time Transfer

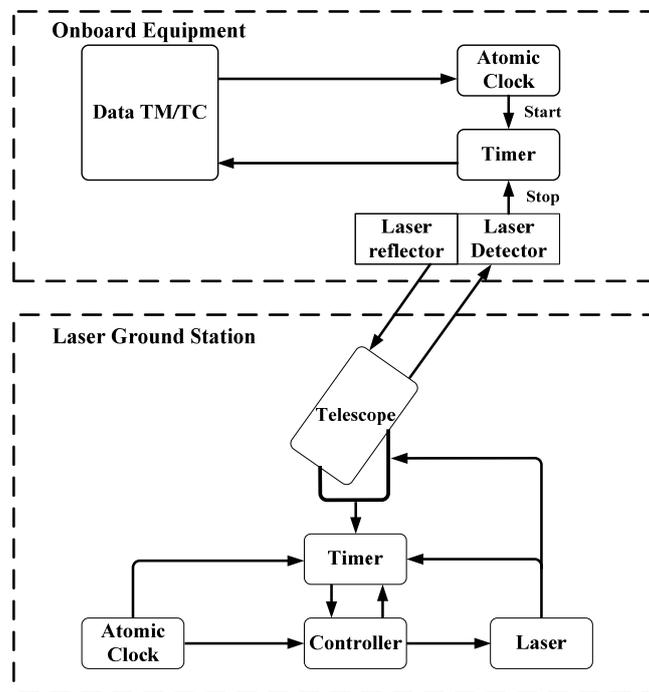


Fig.2. Diagram of LTT

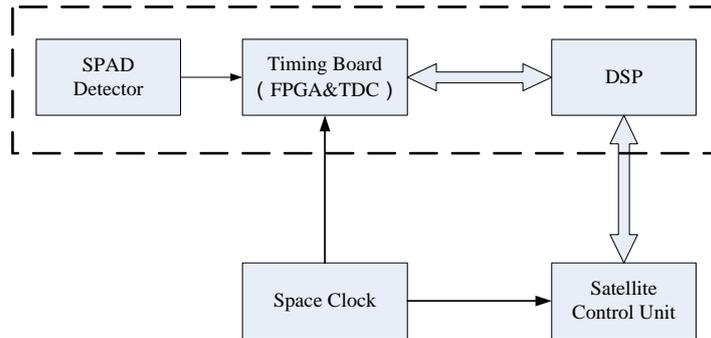
## Specifications of space module

### Laser Reflector Array (LRA)

The LTT module will be installed on the satellite with an orbital altitude of about 20000km. The LRA made by Shanghai Astronomical Observatory has a planar panel with 42 retros. The single retro has an aperture of 33mm without coating on back surfaces. The LRA has the reflective area of 360cm<sup>2</sup>, and total mass of 2.5kg.

### LTT module

Fig.3. is the block diagram of the LTT module. The detector is 40um SPAD made by the Czech Technical University.

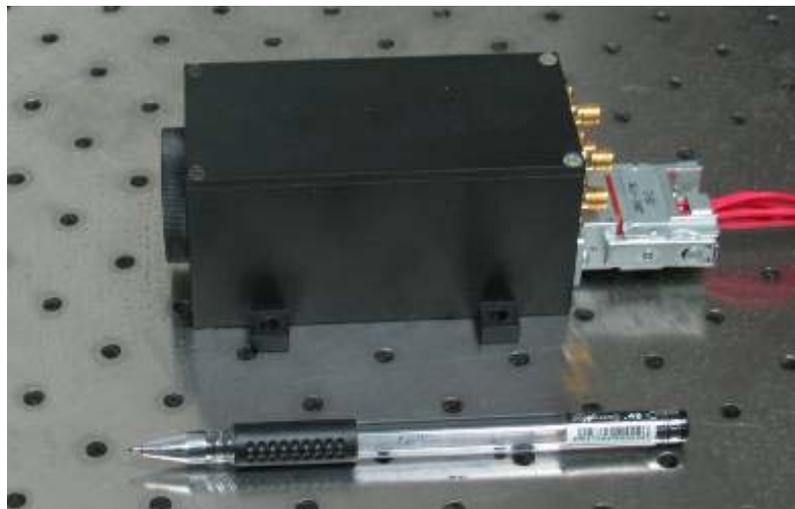


**Fig.3.** Block Diagram of LTT Module

The Specification of the detector is as follows:

- Configuration            dual photon counting detector based on Silicon K14 SPAD
- active area                circular 25 um diameter
- timing resolution        < 100 psec
- operating temp.         -30°C~ +60°C, no cooling, no stabilisation
- power consumption     < 400 mW
- optical damage th.     full Solar flux 100 nm BW > 8 hr
- lifetime in space        > 5 years

Fig.4. shows the LTT detector. There are two SPAD detectors in the box, one is for spare part and can be switched by telecontrol command from ground. There aren't any lenses in front of the SPAD chips, so the receiving area on board is 40um SPAD chip only. The field of view of the detector is about 30°. There is a 10nm bandwidth filter in front of the SPAD chips.



**Fig.4.** LTT Detector

The received photons onboard NP can be estimated by:

$$N_p = \frac{4 \cdot E \cdot S \cdot A_p \cdot K_t \cdot K_r \cdot T \cdot \alpha}{\pi \cdot R^2 \cdot \theta_i^2}$$

where

- E: Laser pulse energy, 50mJ (532nm)
- S: Number of photons per joule (532nm),  $2.7 \times 10^{18}$

- $A_p$ : 40 $\mu$ m SPAD without any lenses, diameter of active area, 0.025mm
- $K_t$ : Eff. of transmitting optics, 0.60
- $K_r$ : Eff. of receiving optics, 0.60
- $T$ : Atmospheric transmission (one way), 0.55
- $R$ : Range of satellite, for MEO orbit at elevation 30°, 22600Km
- $\theta_t$ : Divergency of laser beam from telescope, 10 arcsec
- $\alpha$ : Attenuation factor, 0.5

We have,  $N_p=7.0$  (Photons)

It can be detected by the 40  $\mu$ m SPAD detector.

The principle of the LTT timer is shown in Fig.5. The main device is TDC (Time Digit Converter) made by ACAM company in Germany. The TDC-GP1 with resolution of 125ps which had passed the radiation testing in Germany was adopted. Fig.6. shows the LTT timer.

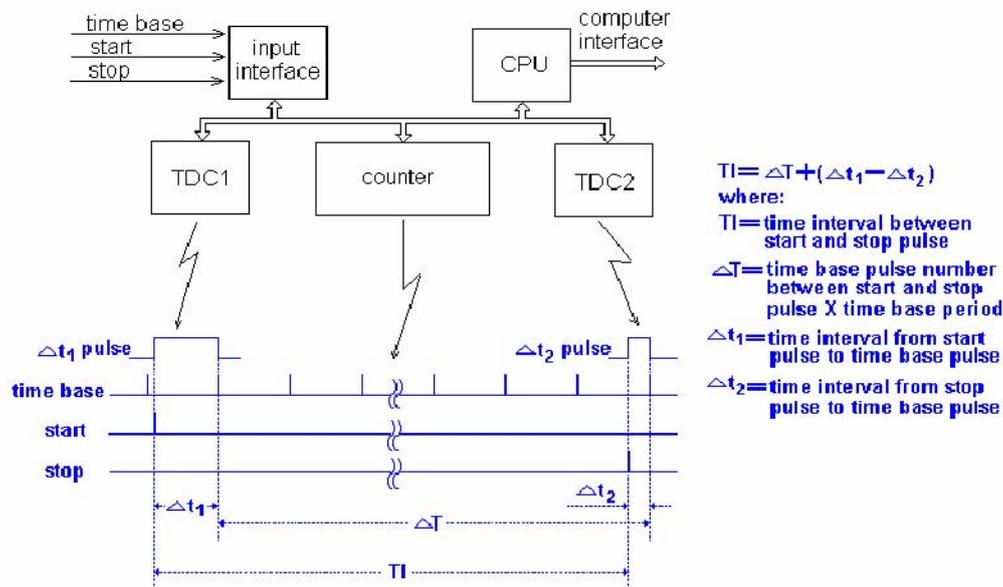


Fig.5. Principle of the LTT Timer

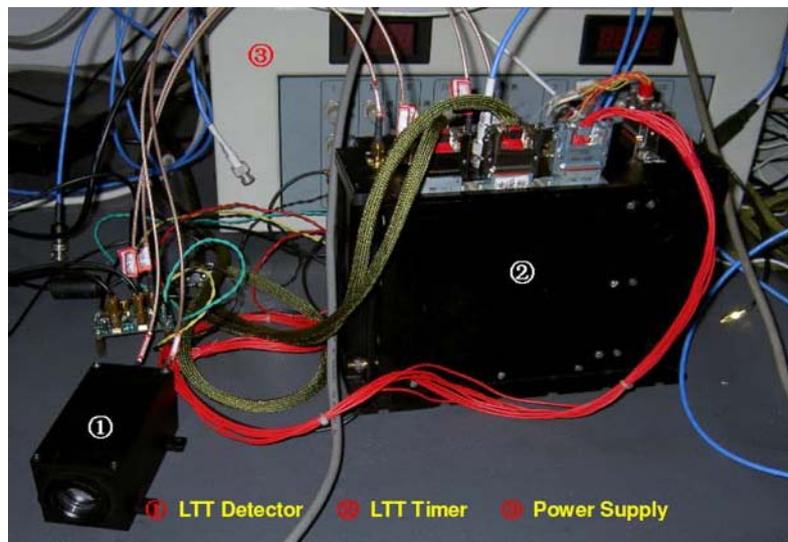


Fig.6. LTT Timer and Detector

The specification of the LTT timer is as follows:

- Resolution of timing        10ps
- Precision of timing        100ps
- Mass (dual-timer)        4.3Kg
- Power consumption        17W
- Size                        240×100×167mm

### ***Laser firing control for ground stations***

For simplification of the module, a 40um SPAD detector without gating circuit and cooling was adopted. In order to keep from the noises produced by the albedo of the ground and the atmosphere, and the detector itself, the ground station will be asked to control strictly the laser firing epoch according to the flight time from ground station to the detector onboard, and let the laser signals arrive at the detector just after the second pulses of the clock onboard, which will start the timer onboard, by 200 ns or so. The laser pulses will stop the timer. So, it is equal to have a gate onboard.

To meet the timing requirement, the laser on the ground station should be actively switched, and the passive switch (or active-passive) can not be used. The accuracy of the prediction of the satellite's range will be about 10m, it equals to 67ns. The uncertainty of laser firing pulses can be controlled within 10ns. The prediction of the difference between the space clock's second and the ground clock's one will be better than 20ns. So we can actually control the received laser pulses with relative to the second pulses of the space clock. Therefore, it means that the time intervals among the laser firings at the station are not constant, and will vary with the distances between the ground station and the satellite.

### **Ground testing for timing accuracy of LTT module**

Fig.7. is the block diagram for the ground testing on the timing accuracy of the LTT module. The specifications of the equipment for the testing are as follows:

- MicroChip Laser
  - Output performance
    - Output power        3μJ
    - Pulse width        650ps
  - Repetition rate        1-100Hz
  - Dimensions (L×W×H)    150×36.4×31mm
  - Weight:                250g
- Rubidium Standard        2 sets, Datum 8000
- Counter (SR620)        2 sets, Stanford Research

Fig.8. and Fig.9. show the instruments for the testing. Table 1 shows the measurement results of the ground testing.

As shown in Table 1, the accuracy of the time difference measurement is 196ps (rms). In Fig.10, line 1 is the result of clock differences by LTT, and line 2 is by the timer SR620 directly. The slope rates of the two lines are:  $-2.3279 \times 10^{-10}$  and  $-2.3285 \times 10^{-10}$  respectively, and they are coincident very well.

Fig.11. shows several LTT results with 2 sets of Rb clock. The uncertainty for measuring relative frequency difference is about  $4 \times 10^{-13}$  in 200 second and about  $5 \times 10^{-14}$  in 1000 seconds.

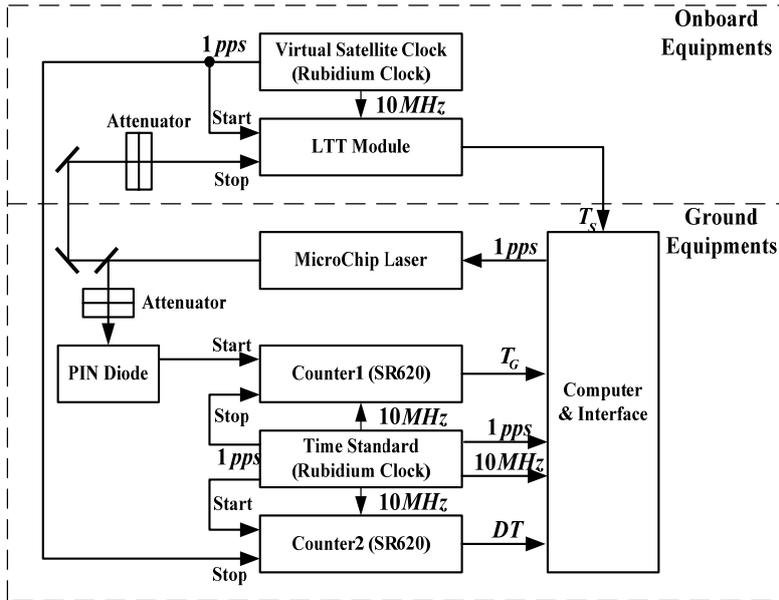


Fig.7. Diagram of the Testing



Fig.8. Ground Testing Instruments

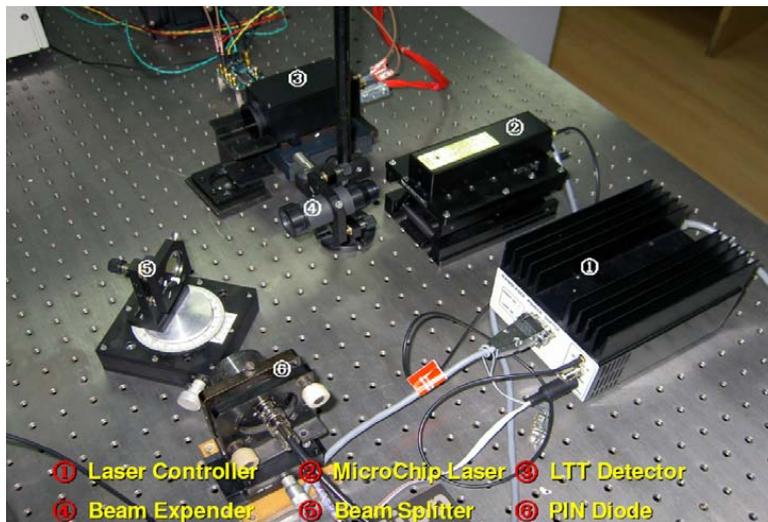
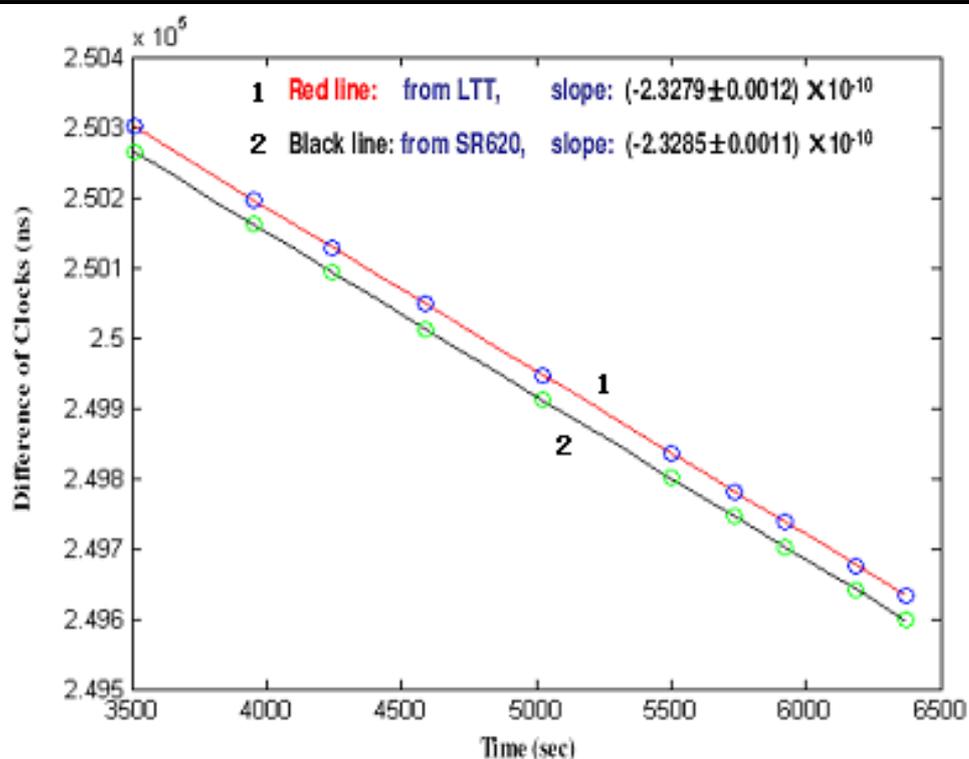


Fig.9. MicroChip Laser and transmitting Optics

**Table1. Result of the Ground Testing**

Epoch(s)	(1) Clock Difference by Laser(ns)	(2) Clock Difference by Counter (ns)	(1) (2) (ns)	RMS(ps)	Number of Measurement
3508.7	250300.4	250264.7	35.754	178.4	104
3953.8	250196.3	250160.5	35.783	190.6	139
4246.1	250128.3	250092.6	35.742	165.3	136
4588.9	250048.6	250012.8	35.748	266.7	148
5022.8	249946.8	249911.1	35.751	212.9	84
5498.9	249836.3	249800.5	35.792	73.1	56
5736.5	249781.4	249745.7	35.731	231.2	96
5923.8	249737.7	249702.0	35.687	224.1	103
6187.9	249676.3	249640.7	35.619	199.8	90
6374.8	249633.0	249597.5	35.488	221.6	96
<b>Mean</b>			35.709±0.092	196.4	



**Fig.10. Results of LTT with two Rb Clocks**

### Space Environment Testing

The LTT module has passed the following testing: vibrations, shock, acceleration, thermal circulation, -40--65°C, thermal vacuum, -40--65°C, EMC and long term testing in high temperature.

### Conclusions

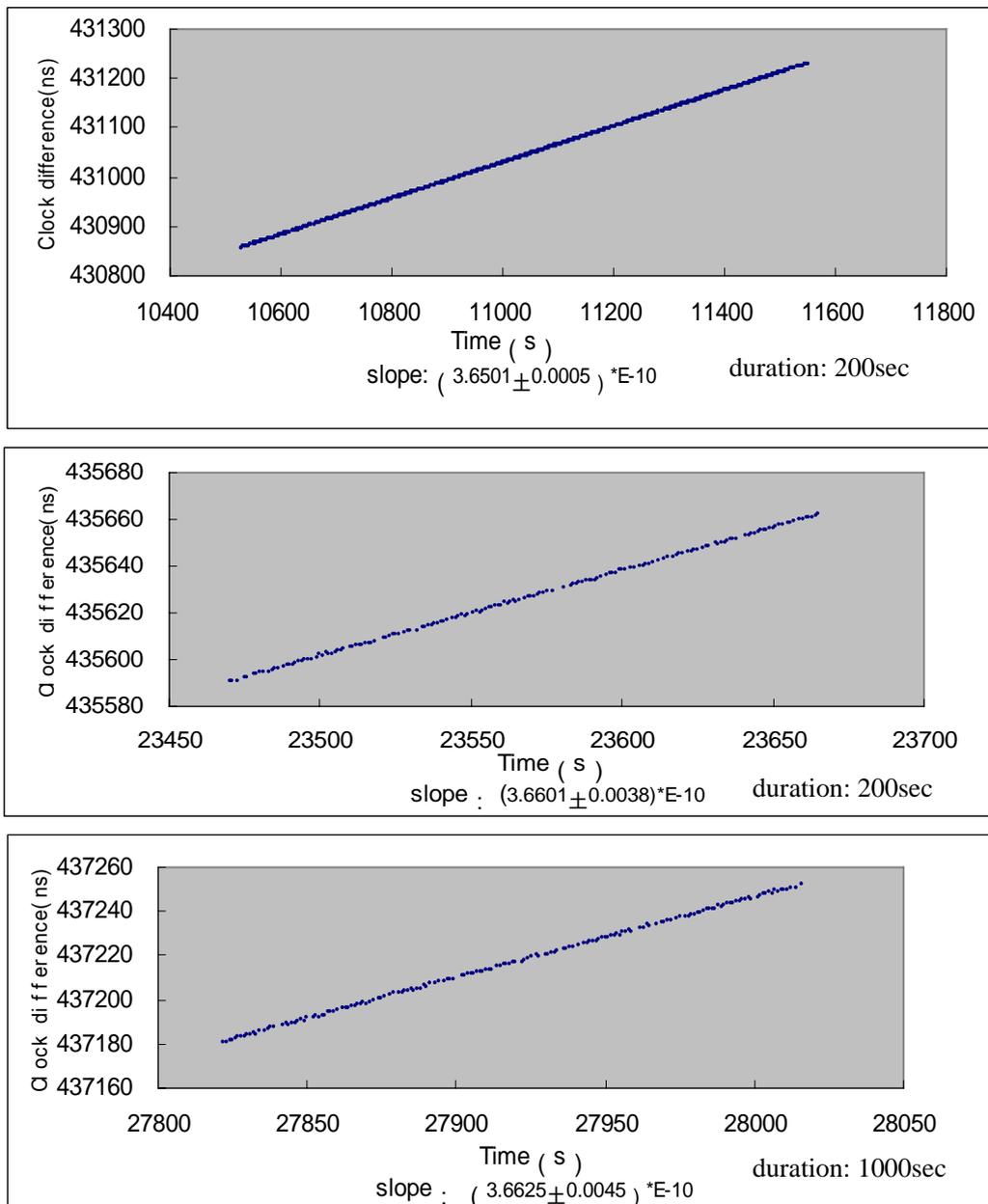
The flight module for Laser Time Transfer experiment has been completed and is waiting for the mission 2007-2008. With the built-in spare parts together, the characteristics of the flight module are as follows:

- Mass 4.6Kg
- Power consumption 17W
- Dimensions:

- 240×100×167mm ( dual-timer, interfaces and power supply )
- 105×70×50mm ( dual-detector )
- Uncertainty of measurement for the relative frequency differences by laser link for two rubidium standards:
  - $4.0 \times 10^{-13}$  in 200 seconds
  - $5 \times 10^{-14}$  in 1000 seconds

## References

- [1] Yang Fumin, Zhang Zhongping, Chen Wanzhen, Li Xin, Chen Juping, Wang Bin, Time Transfer by Laser Pulses between Ground Stations, 14<sup>th</sup> International Workshop on Laser Ranging, San Fernando, Spain, 7-11 June, 2004
- [2] Ivan Prochazka, Karel Hamal, Lukas Kral, Yang Fumin, Photon Counting Module for Laser Time Transfer Space Mission, 15<sup>th</sup> International Workshop on Laser Ranging, Canberra, Australia, 15-20 October, 2006
- [3] TDC-GP1 User Guide, [http://www.acam.de/Documents/English/DB\\_GP1\\_e.pdf](http://www.acam.de/Documents/English/DB_GP1_e.pdf)



**Fig.11.** LTT Results with 2 sets of Rb Clock