Progress on Laser Time Transfer Project

Yang Fumin[1] Huang Peicheng[1] Chen Wanzhen[1]

Zhang Zhongping[1] Wang Yuanming[1] Chen Juping[1] Guo Fang[1]

Zou Guangnan[2] Liao Ying[2] Ivan Prochazka[3] Karel Hamal[3]

(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

Goals

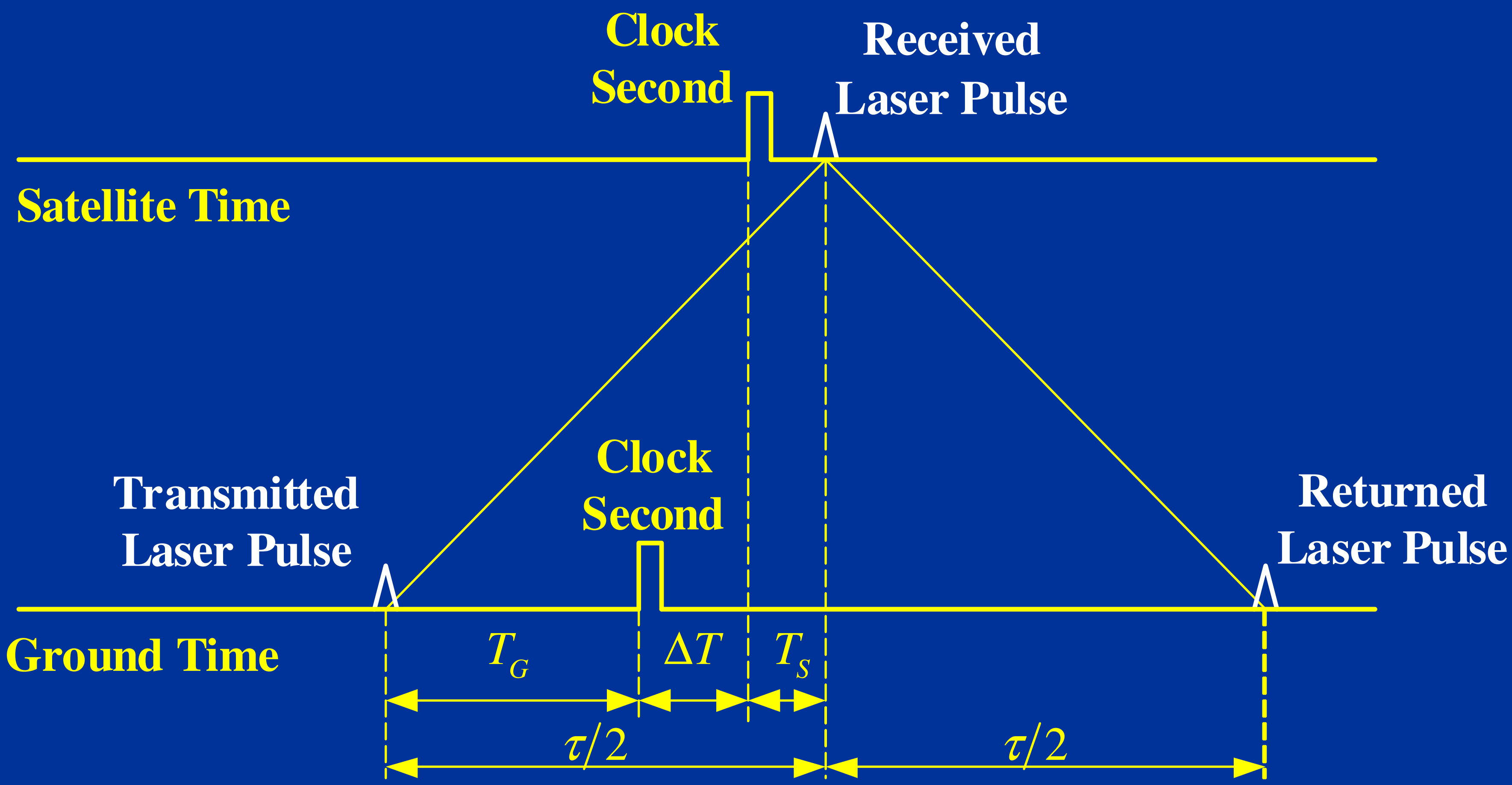
- Evaluation of performance of space clocks

  - now for rubidiums

  - in future for hydrogen masers

- Verification of the relativity

Principle of Laser Time Transfer (LTT)



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

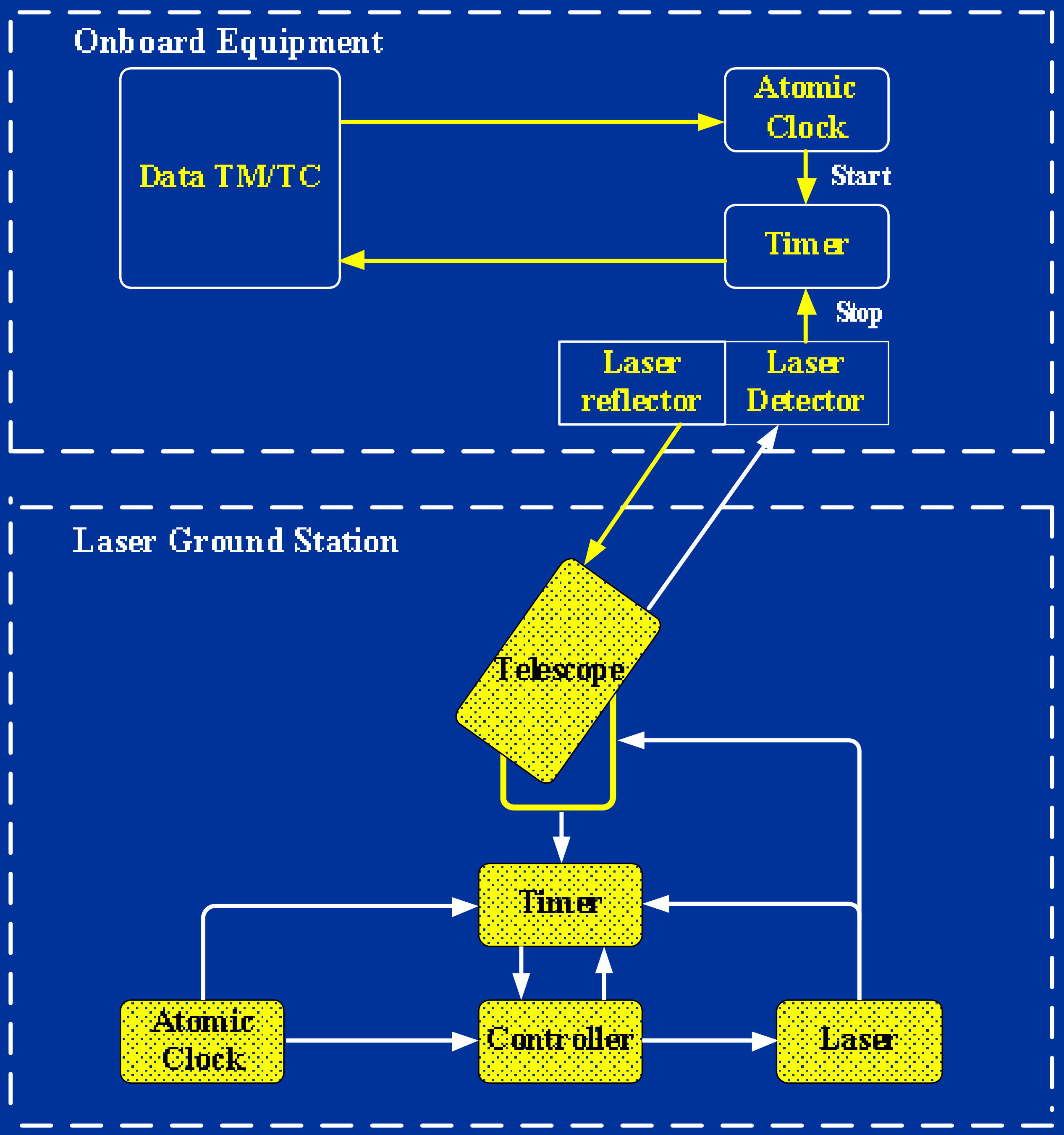
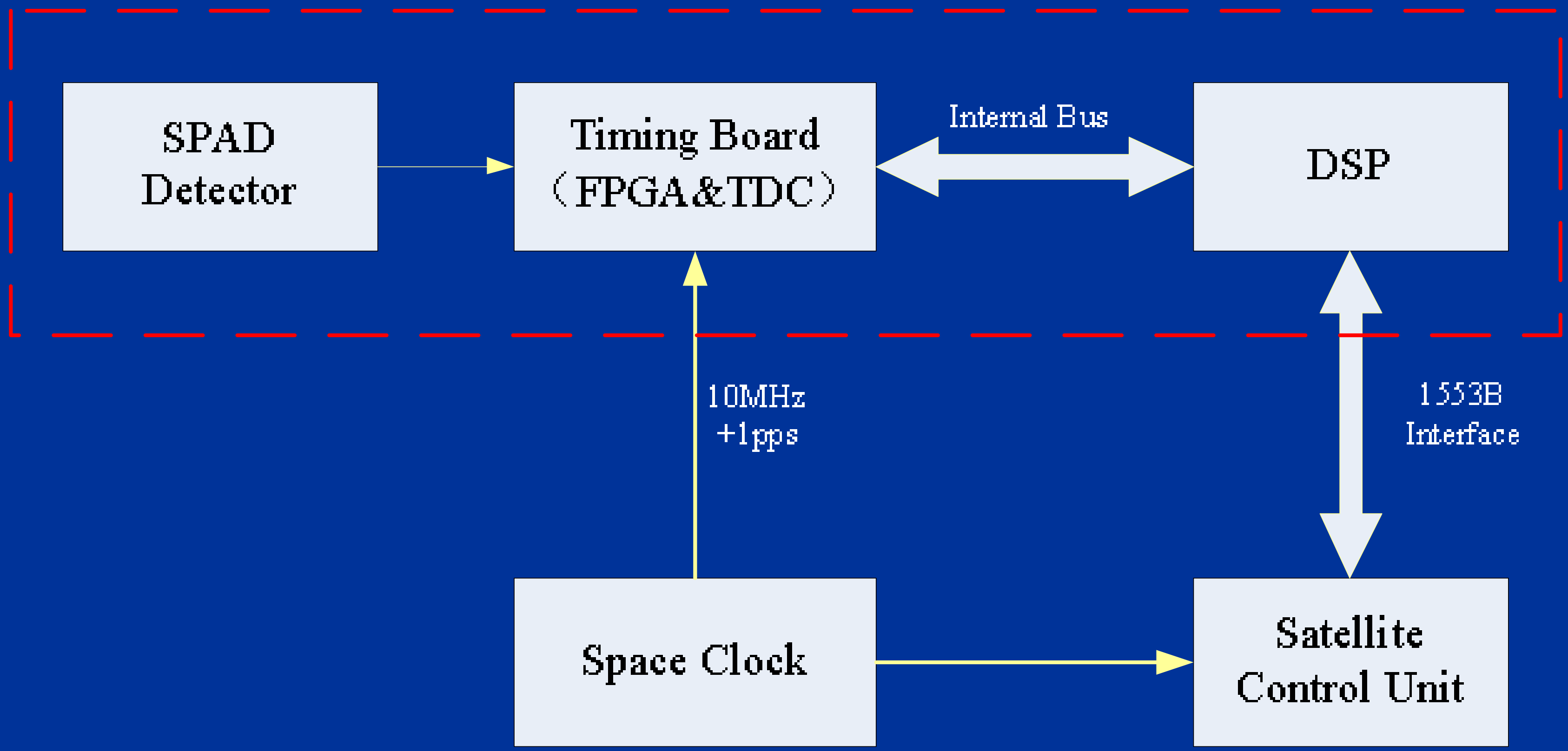


Diagram of LTT between Space and Ground

The LRA for LTT Experiment

- The orbit of the satellite for the LTT experiment will be about 20000KM
- The LRA is a planar panel
- 42 retros with aperture of 33mm
- Total reflective area is 360cm^2
- Total mass is 2.5 Kg

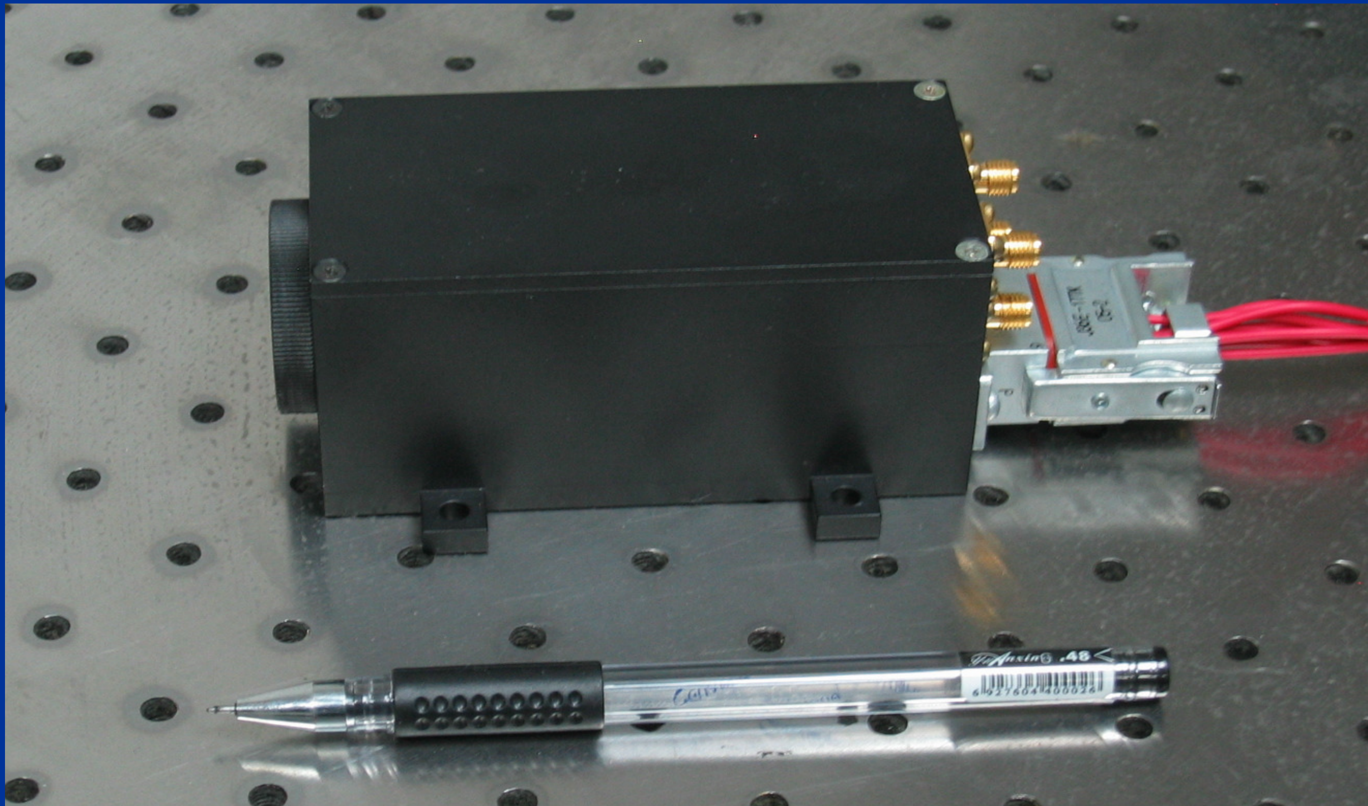


Block Diagram of LTT Module

Specifications of the Detector

➢ **configuration**	**dual photon counting detector based on Silicon K14 SPAD**
➢ **active area**	**circular 25 um diameter**
➢ **timing resolution**	**< 100 psec**
➢ **operating temp.**	**-30 … +60^{o}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**

LTT Detector



Dual SPAD detector, 300g, <1W, 105×70×50mm

Field of View: 30°, 10nm bandwidth filter

Estimate of the Received Photons by the Onboard Detector

The number of photons (N_P) received by the onboard detector can be estimated by:

$$N_P = \frac{4 \cdot E \cdot S \cdot A_P \cdot K_t \cdot K_r \cdot T \cdot \alpha}{\pi \cdot R^2 \cdot \theta_t^2}$$

Where

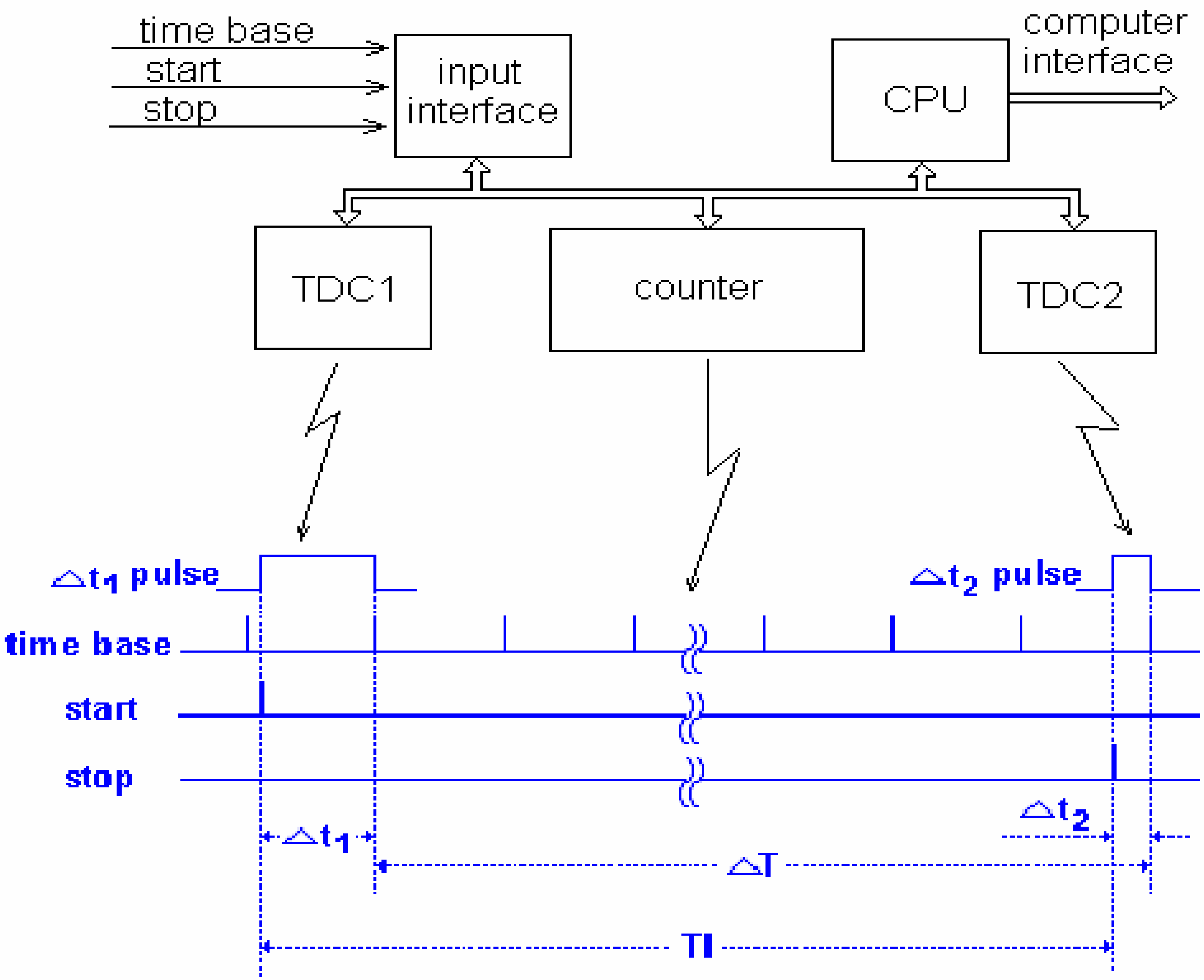
- E: Laser pulse energy, 50mJ(532nm)
- S: Number of photons per joule (532nm), 2.7×10^{18}
- A_P: 40μm SPAD without any lenses, diameter of active area, 0.025mm
- K_t: Eff. of transmitting optics, 0.60
- K_r: Eff. of receiving optics, 0.60
- T: Atmospheric transmission (one way), 0.55
- R: Range of satellite, for MEO orbit at elevation 30°, 22600Km
- θ_t: Divergency of laser beam from telescope, 10 arcsec
- α: Attenuation factor, 0.5

We have,

$$Np=7.0 \text{ (Photons)}$$

It can be detected by the 40 μm SPAD detector.

Principle of the LTT Timer



$TI = \triangle T + (\triangle t_1 - \triangle t_2)$

where:

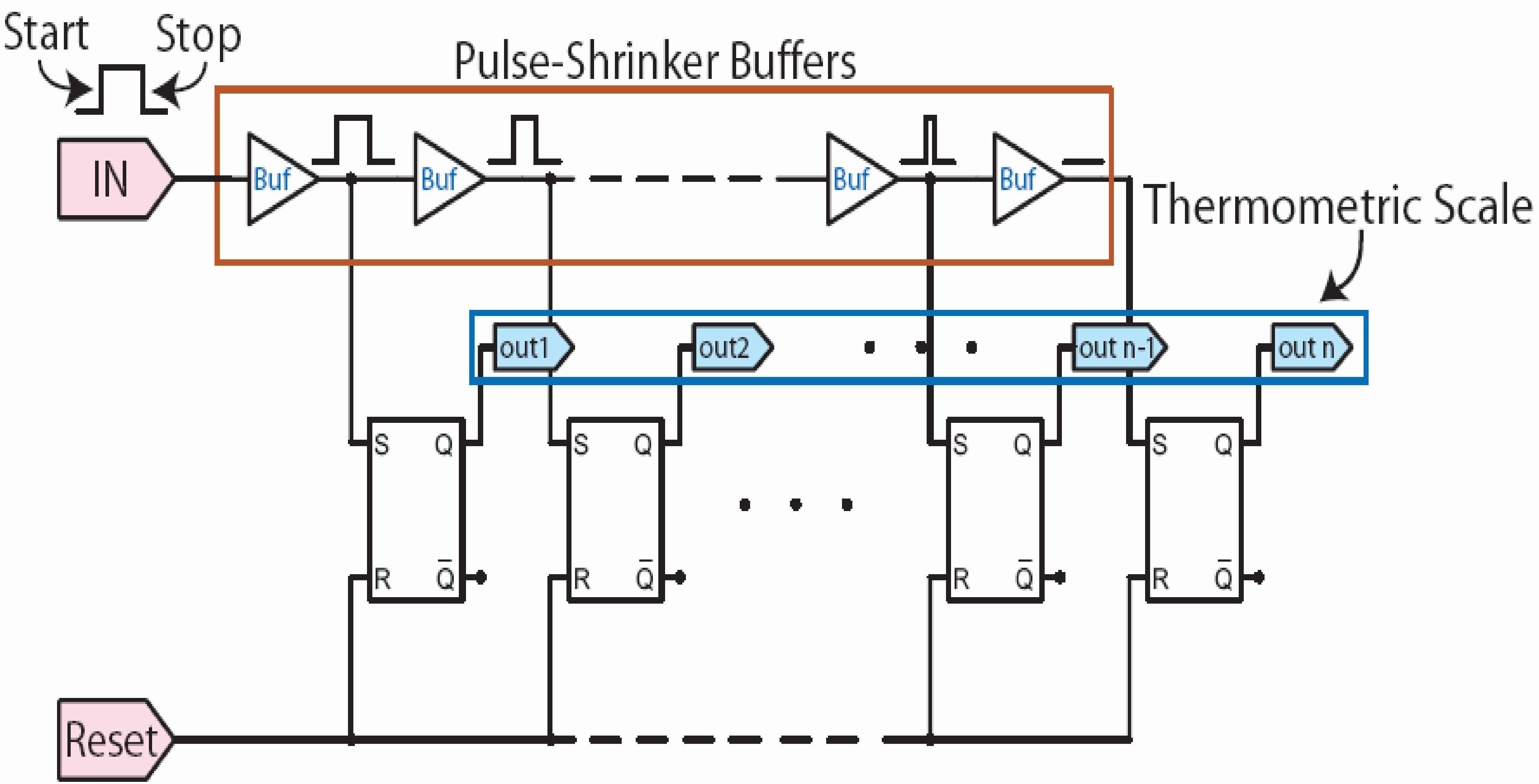
TI = time interval between start and stop pulse

△T = time base pulse number between start and stop pulse X time base period

$\triangle t_1$ = time interval from start pulse to time base pulse

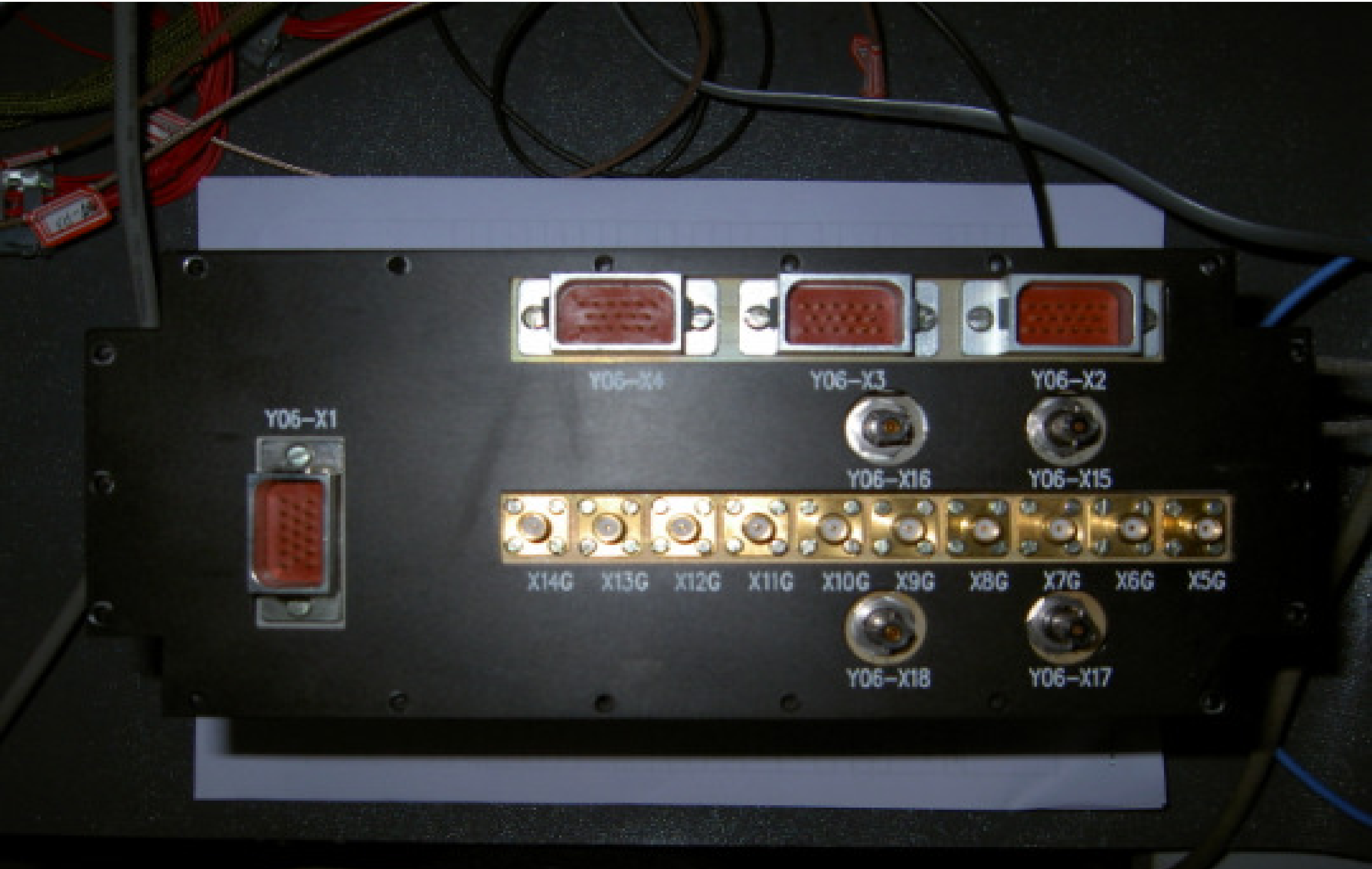
$\triangle t_2$ = time interval from stop pulse to time base pulse

Principle of the TDC
(Time to Digit Converter—from Germany)

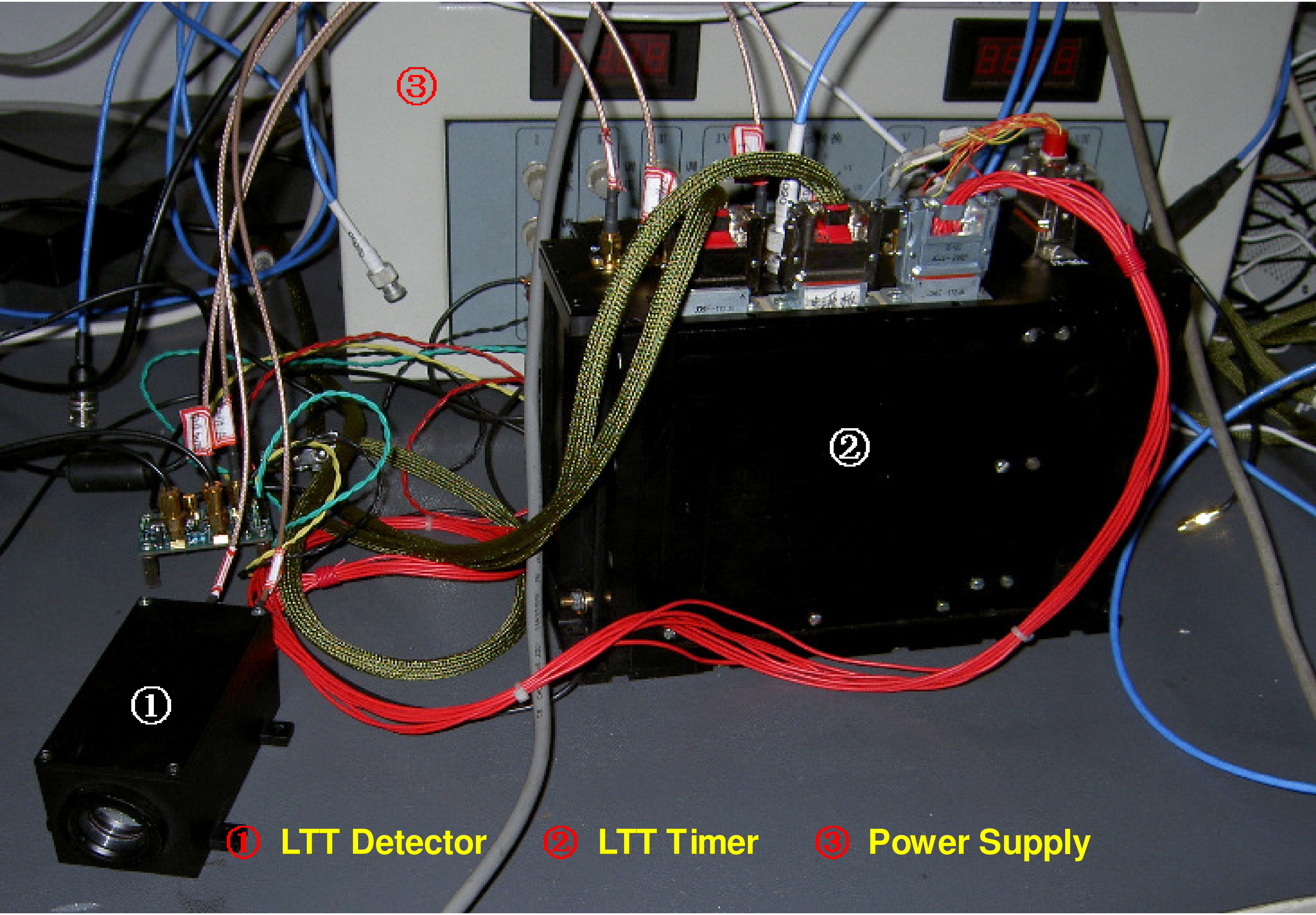


Specification of the Timer

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



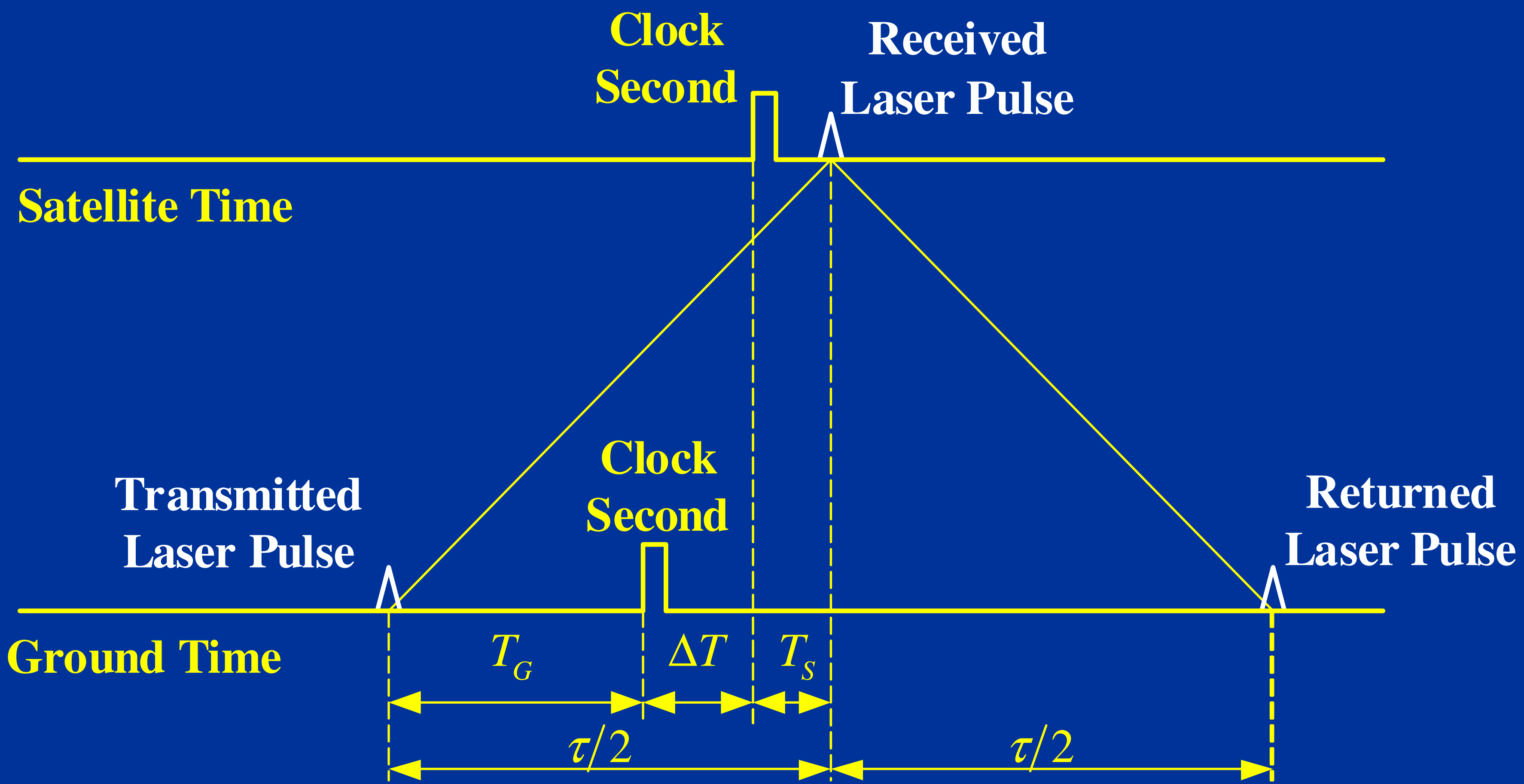
Top View of the LTT Timer


③
②
①
① LTT Detector
② LTT Timer
③ Power Supply

Laser Firing Control

- No gating on the 40um SPAD detector onboard
- 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.
- It means that the time intervals among the laser firings at the station are not a constant, and will vary with the distances between the ground station and the satellite.

Principle of Laser Time Transfer (LTT)



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

Laser Firing Control

- No gating on the 40um SPAD detector onboard
- 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 equals 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.
- It means that the time intervals among the laser firings at the station are not a constant, and will vary with the distances between the ground station and the satellite.

Ground Tests for LTT Module

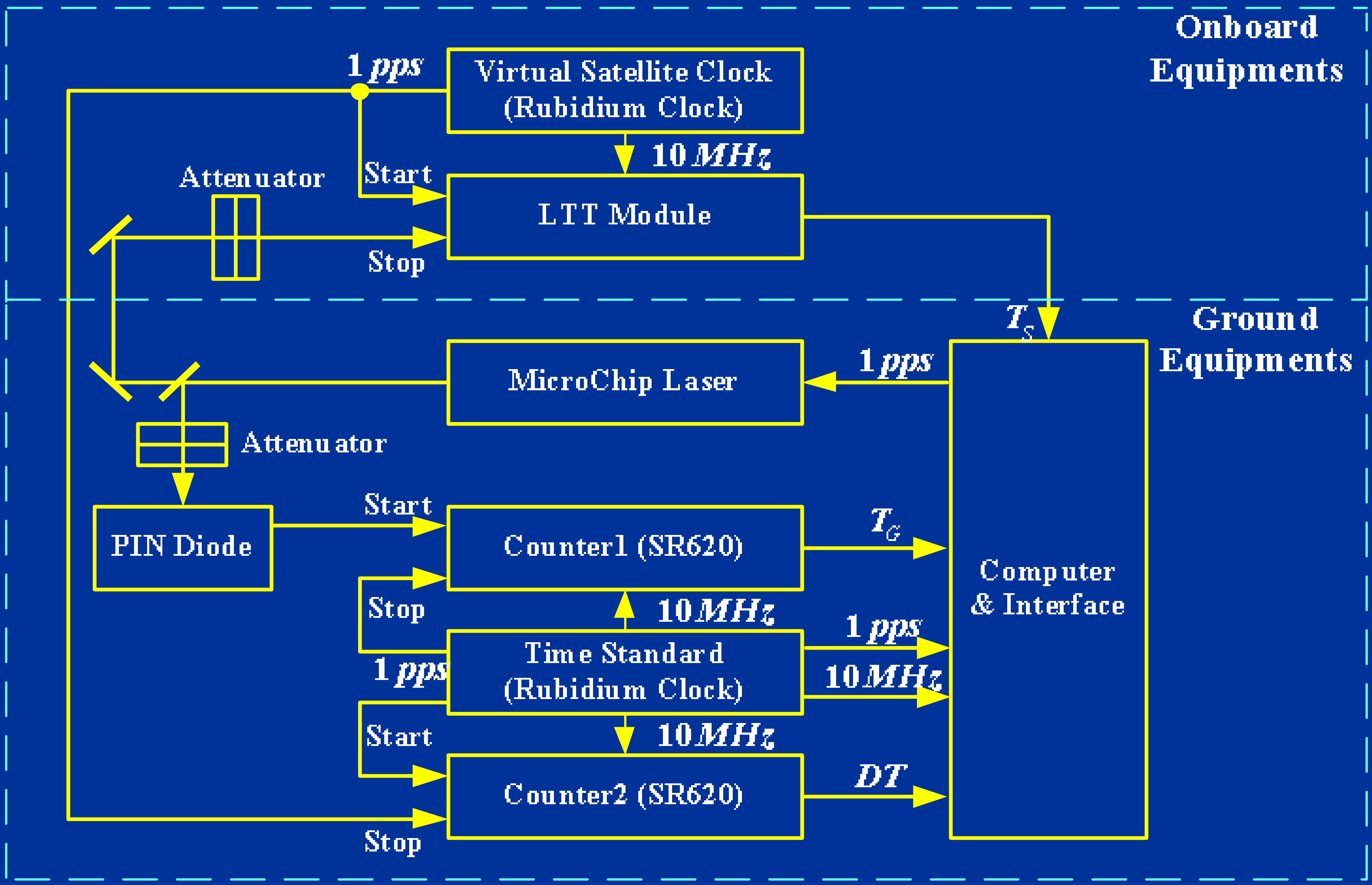
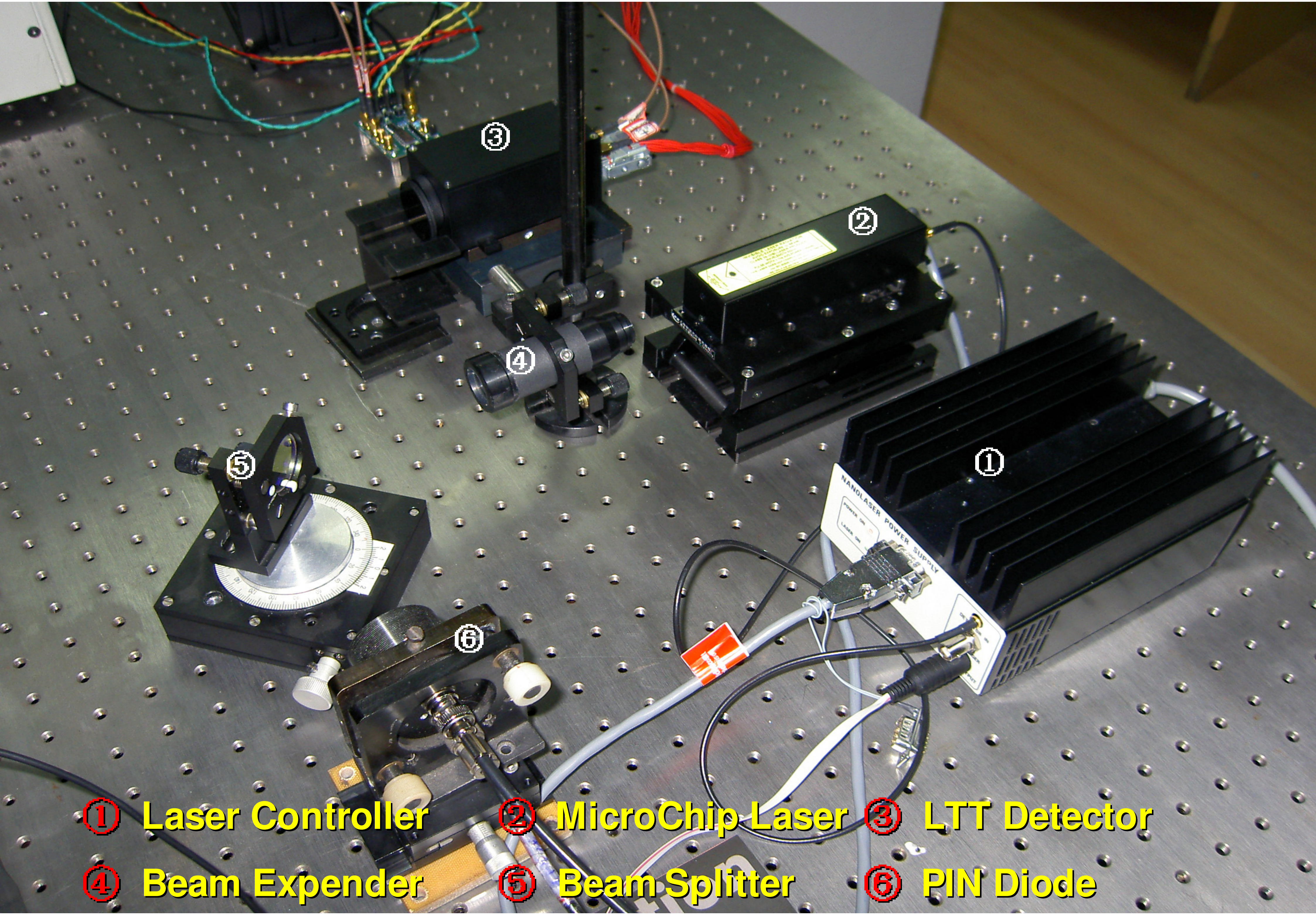
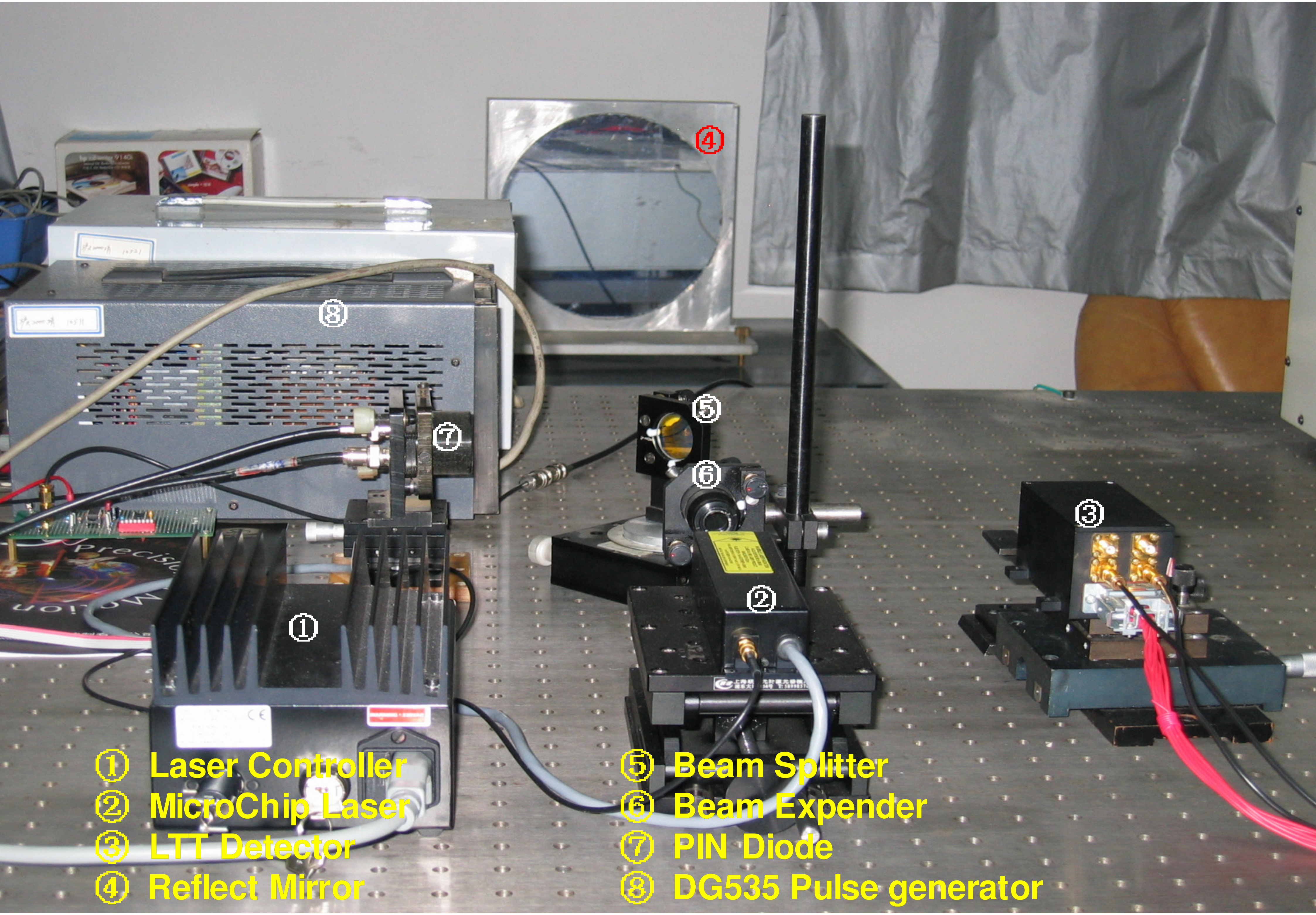


Diagram of the Testing


① Optical System
② Computer
③ Counter SR620 (2 sets)
④ Rubidium Standard (2 sets)
⑤ LTT Timer and supply


① Laser Controller
② MicroChip Laser
③ LTT Detector
④ Beam Expender
⑤ Beam Splitter
⑥ PIN Diode
NANOLASER POWER SUPPLY


④
⑧
⑤
⑦
⑥
③
②
①
① Laser Controller
② MicroChip Laser
③ LTT Detector
④ Reflect Mirror
⑤ Beam Splitter
⑥ Beam Expender
⑦ PIN Diode
⑧ DG535 Pulse generator

Specification of the Equipments for the testing

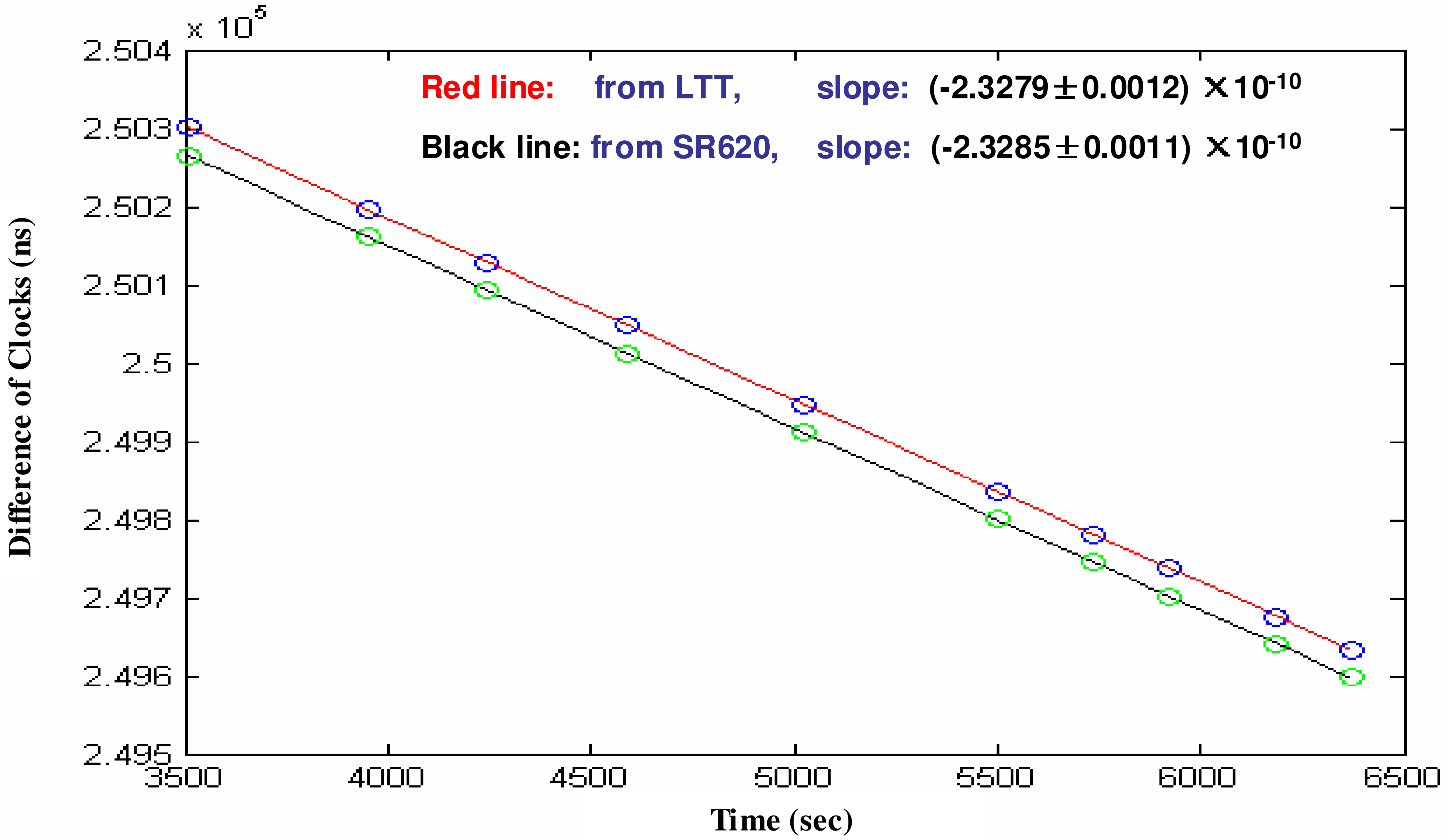
- **MicroChip Laser**
  - **Output performance**
    - Output power 3μJ
    - Pulse width 650ps
  - Repetition rate 1-100Hz
  - Dimensions (L×W×H) 150×36.4×31mm
  - Weight: 250g

- **Rubidium Standard** 2 sets, Datum 8000

- **Counter (SR620)** 2 sets, Stanford Research

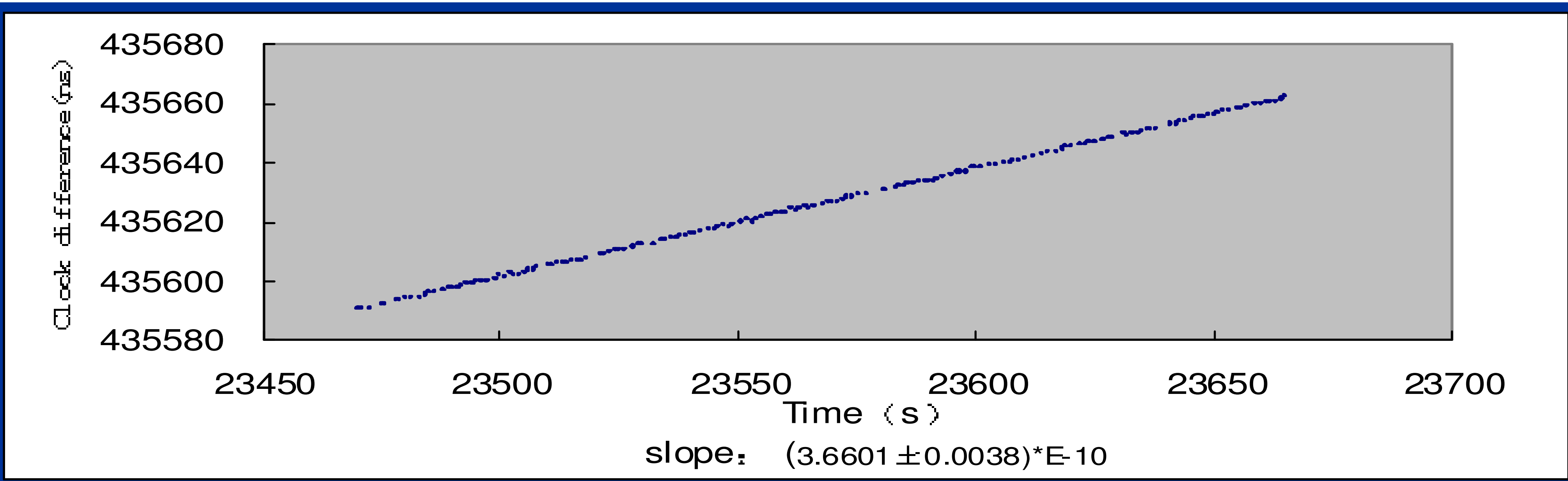
Results of the Ground Tests

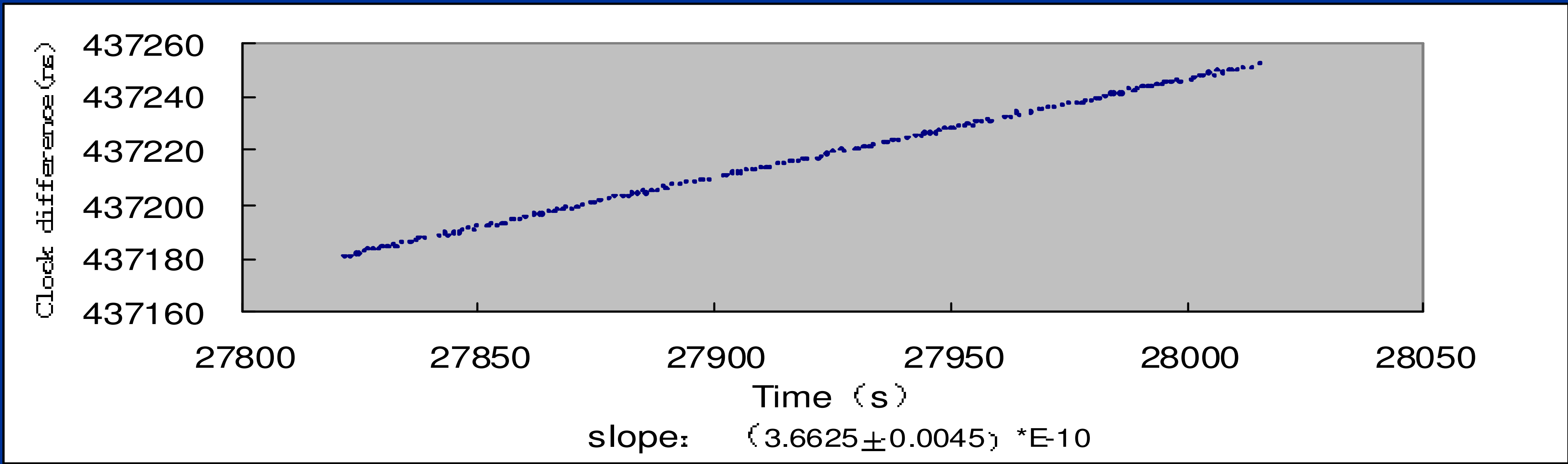
Epoch (s)	(1) Clock Difference by Laser (ns)	(2) Clock Difference by Counter (ns)	(1)－(2) (ns)	RMS (ps)	Number of Measurement
3508.7	250300.4	250264.7	35.754	178.4	104
3953.8	250196.3	250160.5	35.783	190.6	139
4246.1	250128.3	250092.6	35.742	165.3	136
4588.9	250048.6	250012.8	35.748	266.7	148
5022.8	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
Mean			35.709± 0.092	196.4	



Results of LTT with two Rb Clocks

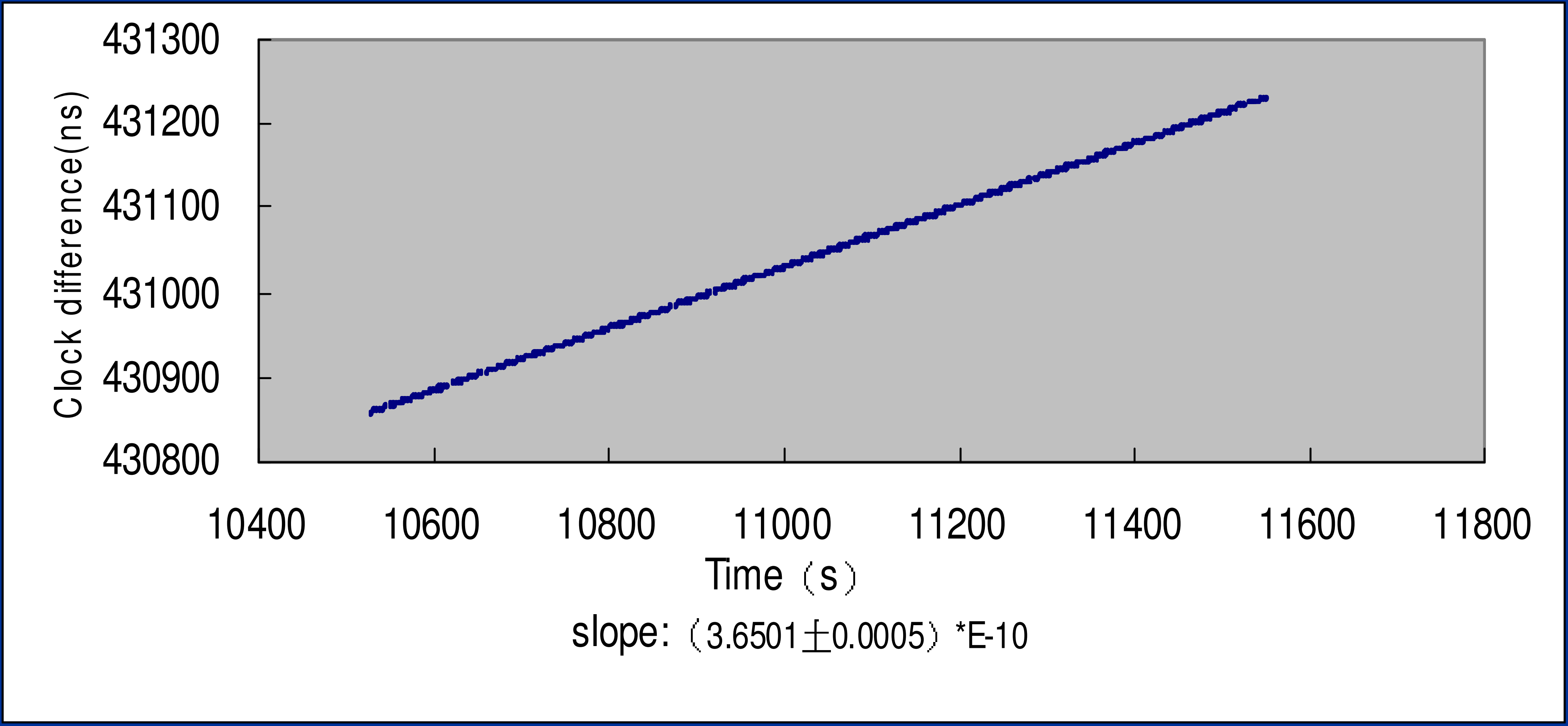
Uncertainty of measurement for the relative frequency Differences by laser link for two rubidium standards is: 1.2×10^{-13}





2 sets of LTT Results with 2 Rb Clocks

Uncertainty for measuring relative frequency difference about 4×10^{-13} in 200 seconds.



Uncertainty for measuring relative frequency difference about 5×10^{-14} in 1000 seconds

Space Environment Testing

The LTT module has passed all of the testing:

- **Vibrations**
- **Shock**
- **Acceleration**
- **Thermal circulation, -40--65 ℃**
- **Thermal vacuum, -40--65 ℃**
- **EMC**
- **Long term testing in high temperature**

Conclusion

- Flight module for Laser Time Transfer experiment has been completed, waiting for the mission 2007-2008
- With a built-in spare parts together
  - 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 is:
  - 4.0×10^{-13} in 200 seconds
  - 5×10^{-14} in 1000 seconds

Thank you !